PICES Scientific Report No. 18
2001

Proceedings of the PICES/CoML/IPRC Workshop on "Impact of Climate Variability on Observation and Prediction of Ecosystem and Biodiversity Changes in the North Pacific"

Edited by

Vera Alexander, Alexander S. Bychkov,
Patricia Livingston and Stewart (Skip) M. McKinnell

September 2001
Secretariat / Publisher
North Pacific Marine Science Organization (PICES)
c/o Institute of Ocean Sciences, P.O. Box 6000, Sidney, B.C., Canada. V8L 4B2
E-mail: secretariat@pices.int   Home Page: http://www.pices.int

Table of Contents

Section I - Presentations and Discussions at Plenary Sessions

Section II - Extended Abstracts of Individual Presentations at Breakout Group Sessions

Breakout Group 1: Physical/Chemical Oceanography and Climate

Breakout Group 2: Phytoplankton, Zooplankton, Micronekton and Benthos

Breakout Group 3: Fish, Squid, Crabs and Shrimps

Breakout Group 4: Highly Migratory Fishes, Seabirds and Marine Mammals

Section I

PRESENTATIONS AND DISCUSSIONS AT PLENARY SESSIONS

INTRODUCTION AND OVERVIEW OF WORKSHOP OBJECTIVES

Vera Alexander[1] and Patricia Livingston[2]

[1] School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 245 O'Neill Bldg., Fairbanks, AK 99775-7220, U.S.A. E-mail: vera@ims.alaska.edu

[2] Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, U.S.A. E-mail: Pat.Livingston@noaa.gov

The Census of Marine Life (CoML) is an ambitious program that seeks to answer the question of what did live, what does live, and what will live in the oceans. Although broad in overall scope, the program is moving forward through a series of focused pilot projects and international activities. Also, as one approach, CoML is forming partnerships with and supporting other organizations with compatible interests, and which can contribute to the goals. To this end, the Alfred P. Sloan Foundation, through the CoML, is co-sponsoring this workshop on the North Pacific.

The CoML goal coincides with the efforts of the North Pacific Marine Science Organization (PICES), which seeks to understand and predict changes in marine ecosystems of the North Pacific induced both by changes in environment and by human activities. PICES has developed, as its major research effort, a program called "Climate Change and Carrying Capacity". This fits well into the CoML framework, and the two organizations have much to gain from interaction.

The main focus of this workshop is to review the goals and strategies for observing North Pacific marine ecosystems and their biodiversity, and to improve our ability to predict ecosystem changes. This will be accomplished by: (i) defining existing observation and prediction system (regional and basin-scales); (ii) identifying needed improvements to the existing system for increasing our understanding of biodiversity and climate-linked changes in biodiversity; and (iii) nominating existing time-series and predictions for inclusion into a PICES Ecosystem Status Report.

Time-series are especially important for evaluating climate change impacts, and drawing conclusions on effects on biodiversity. At this workshop, the participants will examine the available information for the North Pacific Ocean with a strong emphasis on time-series of data. Prepared during the workshop will be the compilation of existing time-series on: physical and chemical oceanography and climate; phytoplankton, zooplankton, and micronekton; fish and crustaceans; and marine mammals and birds from the eastern, western, and open North Pacific. Information will be contributed on the state of knowledge and the major information gaps will be identified. Although the primary emphasis of the workshop will be on the time-series information, candidate predictive models (from purely physical to coupled biophysical models) that could be used to forecast future climate changes and their effects on biota, will also be identified.

Integrating national monitoring efforts for assessing the present state of North Pacific ecosystems has long been a focus of PICES. PICES is proposing the creation of a periodic North Pacific-wide status report, and the output of this workshop will be a critical stepping-stone in determining the feasibility and needs for such a report, as well as identifying the approach.

The workshop structure will be a combination of plenary and breakout sessions. The first plenary session will focus on the goals and objectives of the three main workshop sponsors: Census of Marine Life, International Pacific Research Center and PICES, along with an overview of the objectives of programs, which are closely related to those of this workshop. Breakout sessions will place participants into broad disciplinary groups, to review the available time-series and predictive models, and to suggest improvements in terms of sampling and modeling strategy, and the addition of new time-series observations that are not yet part of the monitoring system. The final session will consist of reports from the breakout session leaders and plenary discussion of workshop recommendations.

PLENARY SESSION PRESENTATIONS

The Census of Marine Life: An update on activities

Cynthia Decker
Consortium for Oceanographic Research and Education, Suite 800, 1755 Massachusetts Ave. NW, Washington, DC, 20036 U.S.A. E-mail: cdecker@brook.edu

Introduction

The Census of Marine Life (CoML) is an emerging international research program to assess and explain the diversity, distribution, and abundance of marine organisms throughout the world's oceans. The planning and development stage for this decadal program is expected to require 1-2 more years. Pilot field projects should take place in 2002-2004. The main field projects should occur in 2005-2007. Analysis and integration of information should culminate in 2008-2010.

Scientific Steering Committee

Leadership and guidance for the Census of Marine Life are the responsibilities of the international Scientific Steering Committee (SSC), formed in June 1999. The SSC has met six times, and will meet during the rest of 2001 in Alaska and Argentina. The present focus of the SSC is the development of the scientific strategy for the CoML. The SSC has initially chosen to remain small in order to ease the scheduling of frequent meetings, but it expects that its membership will grow as the program takes shape and becomes more global. Subcommittees will be formed to lead particular aspects and projects of the CoML. Current SSC members are J. Frederick Grassle (Chairman), Rutgers University, U.S.A.; Vera Alexander, University of Alaska Fairbanks, U.S.A.; Patricio Bernal, Chile, and Intergovernmental Oceanographic Commission, France; Donald Boesch, University of Maryland, U.S.A.; David Farmer, Institute for Ocean Sciences, British Columbia, Canada, and University of Rhode Island, U.S.A.; Olav Rune Godoe, Institute of Marine Research, Bergen, Norway; Carlo Heip, Netherlands Institute of Ecology, The Netherlands; Poul Holm, Southern Denmark University, Denmark; Yoshihisa Shirayama, Kyoto University, Japan; and Andrew Solow, Woods Hole Oceanographic Institution, U.S.A.

Secretariat and Scientific Team

The Secretariat for the CoML program is located in Washington, DC, and is hosted by the Consortium for Oceanographic Research and Education (CORE). CORE is comprised of 62 oceanographic research institutions in the United States including universities, government laboratories, and non-profit aquaria. Dr. Cynthia Decker, a benthic ecologist, directs the activities of the Secretariat. Her associates include Pamela Baker-Masson, concerned with public outreach and education; David Hilmer, ocean science specialist; and Scott Sparks, program associate and webmaster.

Alasdair McIntyre, emeritus professor of fisheries and oceanography at the University of Aberdeen, Scotland, is serving as a senior consultant to the Census of Marine Life SSC and Secretariat, helping to develop European participation in the CoML. Dr. McIntyre earlier served as editor-in chief of Fisheries Research and as chairman of the United Nations Joint Group of Experts on Scientific Aspects of Marine Pollution (GESAMP).

The SSC and Secretarariat have hired Dr. Ronald O'Dor, Professor of Biology at Dalhousie Univeristy, Halifax, Canada, to be the Senior Scientist for the Census of Marine Life. Dr. O'Dor is an expert in cephalopod taxonomy, physiology and behavior, and has done research around the world on these organisms. Dr. O'Dor will start his duties with the CoML in late March, 2001, and will work with the SSC and the Secretariat to advance the Census of Marine Life program with international governmental, non-governmental organizations, and the general public.

Scientific strategy

The scientific strategy, laying out the overall goals and plans for the CoML, is scheduled for release early in 2001, for review and comment by the scientific and relevant stakeholder communities. The document will be posted on the CoML website (http://www.coml.org) as well as actively circulated. The plan is to revise the document for publication by September 2001.

The SSC has sought to balance the writing of planning documents with the timely launching of components of the CoML that the community has indicated are already well-defined and urgently needed. Two components of the CoML, its framework for data assimilation (OBIS), and its studies to document the history of marine animal populations (HMAP) are now underway. In addition, several pilot field projects are in planning stage.

Ocean Biogeographical Information System

The Ocean Biogeographical Information System (OBIS) is envisioned as a distributed network of repositories of marine biological and environmental data for use in examining changes in diversity, distribution, and abundance of organisms in time and space. In May 2000, the CoML announced the funding of eight projects to foster the design and development of OBIS. Under the auspices of the US National Oceanographic Partnership Program (NOPP), eight OBIS projects received funding totaling US $3,700,000 over two years (see http://core.cast.msstate.edu/censpr1.html). The projects will involve the participation of researchers at 63 institutions in 15 countries.

In September 2000, the CoML sponsored an international workshop at the University of Rhode Island Graduate School of Oceanography to further plan and organize the OBIS network. Co-chaired by Fred Grassle and Mel Briscoe (US Office of Naval Research), the workshop brought together the principal investigators of the eight funded projects, as well as several experienced leaders in the design and management of oceanographic and ecological databases. Topics discussed included interoperability of databases, taxonomic and regional data priorities, and the management of OBIS. A Workshop report has been posted on the CoML website.

The SSC will consider the workshop's recommendations for the governance of OBIS and will work with other stakeholders to develop effective mechanisms for its rapid, reliable fruition. The SSC will establish a steering committee for OBIS that will guide the development of the system, particularly in the context of other data system efforts that are emerging such as the US Virtual Ocean Data Hub and the Global Biodiversity Information Facility (GBIF).

History of Marine Animal Populations

Early in the planning for the CoML, participants recommended strongly that the program include a historical component to obtain, assemble, and make accessible information on marine animal populations since fishing became important. The History of Marine Animal Populations (HMAP) will combine classic historical archival research with marine biology to examine the distribution and abundance of species in the oceans over the past 500-1,000 years. The aim of HMAP is to improve our understanding of marine ecosystem dynamics through interdisciplinary studies, specifically with regard to the ecological impact of large-scale harvesting, long-term changes in stock abundance, and the role of marine resources in the development of human society. Integral to HMAP is the design and implementation of standard databases for marine species in collaboration with OBIS, the design and implementation of innovative biological sampling techniques to explore the marine environment, and the identification and use of historical data to aid in the development of predictive environmental models.

In December 2000, the SSC announced the formal launching of HMAP, with the establishment of Centers for the Study of the History of Marine Animal Populations at Southern Denmark

University, University of Hull (UK), and the University of New Hampshire (U.S.A.). The initial phase of HMAP, supported with more than US$1,200,000 in grants, will include case studies of marine populations in seven regions involving 31 institutions in 18 countries. The overall leader of HMAP is Steering Committee member Poul Holm of Southern Denmark University. A special issue of the International Journal of Maritime History dedicated to HMAP will be published in early 2001 (http://www.cmrh.dk/hmapindx.html).

Pilot projects

The Census of Marine Life will ultimately be the sum of a set of specially designed field projects observing populations in a variety of regions and ways, and integrated with ongoing (and enhanced) survey activities conducted by fisheries and environmental agencies. The SSC has been working with several segments of the research community to design pilot projects that can demonstrate the effectiveness in diverse settings of new approaches and technologies for the observation of marine life. While the SSC can influence resources sufficient to help completion of the planning phases for pilot projects, each project must ultimately secure the finances for research activities on its own. The goal is for the pilot projects to get the financial commitments to be "in the water" soon and to be completed in 2-3 years, so they can serve as examples for the main body of fieldwork conducted under the CoML. So far, groups of scientists have initiated planning for six promising pilot projects under the auspices of the CoML.

Census of Marine Life in the Gulf of Maine

Ken Foote, Woods Hole Oceanographic Institution, U.S.A. (http://www.whoi.edu/marinecensus/)

The Gulf of Maine and Georges Bank are much-studied regions commercially important for fisheries, and they thus offer an excellent chance to calibrate and demonstrate the superiority of new technologies to describe the diversity, distribution, and abundance of marine life. Targets include finfish, zooplankton communities, and the poorly-known benthic communities. A workshop held May 2-3, 2000, led to the establishment of a steering committee for the project and laid the basis for a regional consortium of institutions to carry out the project.

Ecosystems of the northern mid-Atlantic

Odd Aksel Bergstad, Institute of Marine Research, Norway

The biology of the waters overlying the Mid-Atlantic Ridge has been little studied and offers difficult challenges for new technologies to see deep and far. The tentative project goal is to identify and model the ecological processes that cause variability in the distribution, abundance, and trophic relationships among organisms inhabiting this pelagic zone. A planning workshop held February 12-13, 2001, in Bergen, Norway, has led to the establishment of a steering committee, which will further develop the project.

Pacific Ocean salmon tagging

David W. Welch, Pacific Biological Station, Nanaimo, British Columbia, Canada

Little is known about the distribution and behavior of salmon once they leave the rivers. This project proposes to use electronic tags and innovative acoustic arrays to track and monitor salmon populations on the continental shelf of Canada and the United States and in the open waters of the North Pacific. A planning workshop held December 8-9, 2000, in Vancouver, Canada, brought together leading experts on a variety of salmon populations to consider the design of this project and how it can serve as a template for study of salmon and other anadromous fish populations in the world.

Tagging of Pacific pelagics

Barbara Block, Stanford University, U.S.A.

A much better understanding of the distribution and behavior of large pelagic animals at the top of the food chain may allow strong inferences about the distribution and abundance of many other organisms that live in the oceans. A workshop held November 13-14, 2000, explored the design of an ambitious pilot project in the North Pacific to deploy advanced electronic data-storage tags to track and monitor large vertebrates, such as whales, sea turtles, and tuna. The workshop generated great interest among the public in the CoML as evidenced by coverage in the San Francisco Chronicle and on the news websites of ABC News and National Geographic (see http://www.abcnews.go.com/sections/science/DyeHard/dyehard001129.html).

Chemosynthetic ecosystems in the Arctic and northern Atlantic Oceans

Cindy Lee Van Dover, College of William and Mary, U.S.A.

Little is known about the basin-scale diversity, distribution, and abundance of marine life in deep sea chemosynthetic ecosystems such as hydrothermal vents and seeps in the northern Atlantic and Arctic oceans. In order to study these systems, new technologies for plume-tracking from autonomous underwater vehicles (AUVs) will need to be refined and used over large spatial scales. A planning workshop to develop this pilot project was held on 16-17 March 16-17, 2001.

Coastal survey of the western Pacific

Yoshihisa Shirayama, Seto Marine Biological Laboratory, Kyoto University, Japan

A major unanswered question is how marine biodiversity varies with the latitudinal gradient. A coastal study to be conducted under the auspices of the Diversitas International in the Western Pacific Area (DIWPA) program aims to quantitatively survey marine life and examine biodiversity in near-shore areas in the western Pacific in a continuum from the northern to southern boreal regions using traditional sampling methods (i.e., scuba gear). A workshop held in April 2001 refined the plans for this project.

Other activities

SCOR Working Group

The Scientific Committee on Oceanographic Research (SCOR) of the International Council of Scientific Unions has formed a Working Group on New Technologies for Observing Marine Life, which held its first meeting on November 9-11, 2000, in Sidney, British Columbia, Canada. The Working Group, chaired by David Farmer, is considering individual technologies, their integration, and transition to practice (http://core.cast.msstate.edu/censscor1.html).

Museums and marine laboratories

Natural history museums contain precious collections and expertise on marine biodiversity, as do marine laboratories, and the participation of these institutions is key to the success of the CoML. A workshop was held November 15-17, 2000, at the Institute of Marine Biology, Crete, Greece, that was organized by Annelies Pierrot-Bults (Zoological Museum of Amsterdam), Ross Simons (Smithsonian Institution, U.S.A.) and Carlo Heip (Netherlands Institute of Ecology, The Netherlands). This workshop explored ways for museums and marine laboratories to contribute to the CoML and their interests in it. Over 30 experts from 15 countries attended the workshop, which has sparked further interest in the CoML within these communities. A report on the Crete workshop will be published shortly.

Aquariums

Aquariums house displays of marine biodiversity and are a main way that the public learns about it. The CoML was featured in a plenary presentation in November 2000, at the International Aquarium Congress hosted by Monaco's Musee Oceanographique, and was strongly endorsed as "an opportunity too good to pass up" in the concluding summary address by Jerry Schubel, director of the New England Aquarium. Follow-up activities will increase involvement of aquariums in the CoML. Jordi Sabate, director of the Barcelona Aquarium, will convene the directors of several of the world's foremost public aquariums in the spring of 2001, to explore creation of a consortium of aquariums to work with the CoML. Meanwhile, another workshop in spring 2001, at the New England Aquarium, will bring together exhibit designers, film makers, and persons involved in outreach activities to advance the education and outreach dimensions of the CoML. Specifically, this workshop will identify the most effective vehicles for bringing the plans and discoveries of the CoML to the 150 million people who visit aquariums each year.

Southeast Asia Workshop

To strengthen CoML activities in the tropical areas of Southeast Asia and the western Pacific, the SSC is teaming with the Intergovernmental Oceanographic Commission's (IOC) SubCommission for the Western Pacific (IOC/WESTPAC). A workshop in mid-2001 at the IOC/WESTPAC headquarters in Bangkok, Thailand, will bring together numerous scientists from countries in the region involved in assessing the diversity, distribution, and abundance of species in Southeast Asia and the western Pacific.

POGO

About twenty of the world's leading oceanographic research institutions are now participating in a new Partnership for Observation of the Global Oceans (POGO), with a Secretariat at the Bedford Institute of Oceanography, Nova Scotia, Canada. The POGO institutions play major roles in the development and deployment of new monitoring systems, such as the Argo floats. The leaders of POGO are eager to assure that biological observations develop in conjunction with other environmental measures and have decided to make biological observations the focus of their 2001 meeting. The CoML provided a progress report at the November 2000 POGO meeting in Sao Paulo, Brazil (http://www.oceanpartners.org/).

US government initiatives

The US Congress passed the Oceans Act in 2000. This legislation directs that a Presidential Commission on the Oceans be established to review all US government ocean activities in the next two years and provide recommendations to the President and Congress. The Census of Marine Life expects to be invited to make a presentation to the Commission soon after it is established.

The US government is considering a major new initiative on ocean exploration, as recommended by the President's Panel on Ocean Exploration, whose report was released on December 4, 2000, in Washington DC. The report recognizes the Census of Marine Life and the Ocean Biogeographical Information System. Marcia McNutt, director of the Monterey Bay Aquarium Research Institute, chaired the panel, whose members included Frederick Grassle and Jesse Ausubel (http://oceanpanel.nos.noaa.gov/panelreport/ ocean_panel_report.html).

National Committees

Several nations are now in the process of bringing together the stakeholders in the CoML within that country to determine how best to organize the program at the national level for the Program. Following a pattern successful in other major global research programs, which require organization at both the international and national (and sometimes regional) level, the formation of National Committees for the Census of Marine Life should be one of the important developments during the next couple of years. The SSC and Secretariat are eager to work with the national interests for this purpose, and small amounts of funds will be available to help convene the appropriate national stakeholders.

Decadal climate variability in the Pacific Ocean, and theories as to its cause

Julian P. McCreary, Jr.
International Pacific Research Center, University of Hawaii, Honolulu, Hawaii, U.S.A. E-mail: jay@soest.hawaii.edu

Interest in decadal variability in the Pacific region increased considerably during the 1990s, both at mid-latitudes (PDV) and in the tropics (EDV). During the first half of the decade, the tropical

Pacific remained anomalously warm and this warming appeared to have limited ENSO predictability in coupled models (Ji *et al.* 1996). This EDV also had significant economic impacts, a prime example being the severe drought in Northeast Australia. At the same time, PDV has attracted much attention (Trenberth and Hurrell 1994; Mann and Park 1996; Nakamura *et al.* 1997). See Miller and Schneider (2001) for a recent review.

Observations

PDV is present in both atmospheric and oceanic variables. In contrast to ENSO, however, it does not have a sharp spectral peak, suggesting that it does not result from a single, well-defined process and even that it may be generated stochastically.

It is also not clear if there is just one type of PDV. Nakamura *et al.* (1997) and Nakamura and Yamagata (1999) reported two modes of North Pacific decadal variability based on sea surface temperature (SST) data, which they obtained using the empirical orthogonal function (EOF) statistical technique. Figure 1 shows the first two EOFs from their analysis. The EOFs were obtained in the rectangular box indicated in Figure 1, and the fields outside the box were then found by regressing the EOF time-series on SST anomalies in the full basin. Thus, implicit in their study is the idea that the box region is the key area for the generation of PDV. The first mode is confined to the North Pacific mid-latitudes, with most of its amplitude centered on the Subarctic Front. The second EOF extends over much of the basin. In northern mid-latitudes, it has a distinctive dipole-like structure, with anomalies of opposite sign on either side of the Subtropical Front, and anomalies with significant amplitude throughout the tropics in both hemispheres. It should be stated, however, that the EOF statistical technique seeks to find separate modes of variability. It may be, then, that there is really only one mode, that the EOFs in Figure 1 really represent two different phases of the same oscillation.

Figure 2 shows a time-series of SST anomalies in the NINO3 region (after Timmermann and Jin, 2001). To emphasize the decadal variability, the thick curve plots the 10-year running mean of the standard deviation of the time series.

There is a remarkable periodicity in the curve, with a time scale of 15-20 years. Thus, one aspect of EDV is that the amplitude of El Niño varies with surprising regularity on decadal time scales.

Hypotheses

At the present time, prominent aspects of PDV and EDV have already been successfully simulated in solutions to coupled ocean-atmosphere models, but neither the nature nor location of the primary generation mechanisms have yet been clearly identified. Indeed, the studies explore several different types of hypotheses, which can roughly be divided into three categories, namely, that PDV and EDV are generated by: i) midlatitude processes only; ii) both midlatitude and tropical

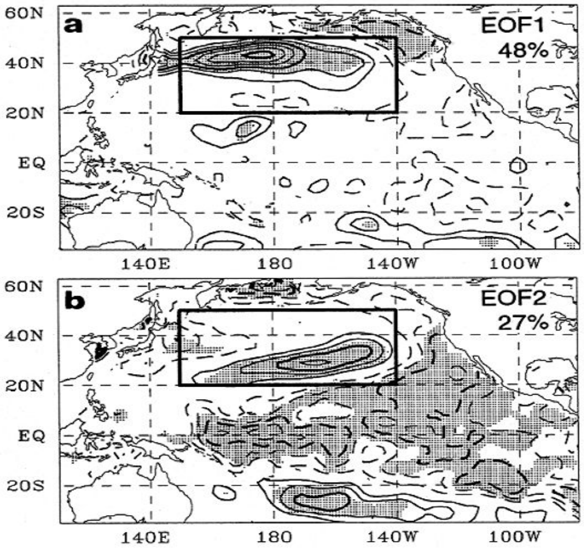


Fig. 1 First (top) and second (bottom) EOFs of decadal variability in North Pacific wintertime SST for 1968-92. The EOFs are determined within the indicated rectangular box, and linear regression coefficients are plotted between Pacific SST and the time-series (PCs) associated with the two modes. The contour interval is 0.1; it is thickened every 0.3, dashed for negative, and zero lines are omitted. Shaded areas are the regions in which correlation between SST and a given PC exceeds the 90% significance level assuming 3 degrees of freedom (after Nakamura *et al.* 1997).

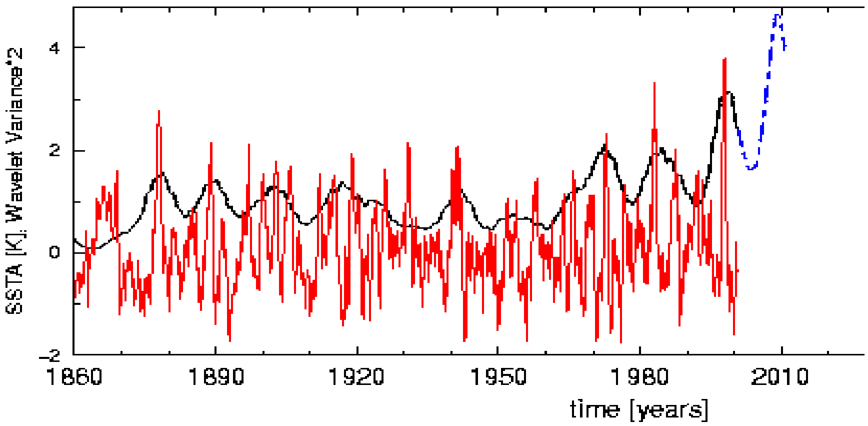


Fig. 2 Observed NINO3 SST anomaly time-series (highly variable curve), together with the 1-year running mean of its variance (smoother curve). The latter curve indicates that the amplitude of ENSO varies with a time-scale of 15-20 years (after Timmermann and Jin 2001).

processes; and iii) tropical processes only. I comment here on all these processes but focus on the first category, noting the role of the North Pacific Subtropical Cell (STC) in the generation of EDV.

Mid-latitude processes only

Latif and Barnett (1994, 1996) reported a mode of decadal oscillation in a solution to their global, coupled general circulation model (GCM). It was associated with SST anomaly patterns similar to both of the EOFs in Figure 1, with one pattern developing into the other. The oscillation existed even when tropical feedbacks were suppressed, indicating that its dynamics are distinctly different from those of ENSO. The authors concluded that positive feedbacks involving mid-latitude wind stress and heat flux anomalies were important for the mode's excitation, whereas subtropical gyre adjustment and advection (which both have decadal time scales) were likely responsible for determining its period. Other modelers, however, have not been able to produce as strong a midlatitude mode (e.g., Palmer and Sun 1985; Ferranti *et al.* 1994; Peng *et al.* 1995), likely because the other atmospheric models did not respond as effectively to mid-latitude SST anomalies as the one used by Latif and Barnett (1994, 1996).

Several pathways have been proposed to account for how mid-latitude PDV might influence the tropics. One involves atmospheric teleconnections from mid-latitudes to the tropics. Pearce *et al.* (2000) noted that in their coupled model the wind anomaly associated with PDV extended well into the tropics, and this anomaly generated the model's EDV. The other involves teleconnections from the subtropics to the tropics via the ocean's North and South Subtropical Cells (STCs).

The STCs are shallow (less than about 500 m) meridional circulation cells in which water flows out of the tropics within the surface layer, subducts in the subtropics, flows equatorward within the thermocline, and upwells in the eastern equatorial ocean (McCreary and Lu 1994; Liu *et al*. 1994; Rothstein *et al.* 1998; Lu *et al.* 1998). Figure 3 illustrates the STC pathways in the Rothstein *et al.* (1998) solution, showing streamlines at the surface (top panel) and in the thermocline layer (bottom panel).

The STC pathway has recently been proposed by Gu and Philander (1997) as a possible explanation for EDV. They hypothesized that SST anomalies in the North Pacific are subducted into the thermocline to join the North STC, and are subsequently advected to the equatorial Pacific with a time lag of the order of a decade, thereby providing a delayed negative feedback (labeled the vT′ hypothesis). This idea received observational support from Deser *et al.* (1996), who were able to follow the equatorward movement of a subsurface

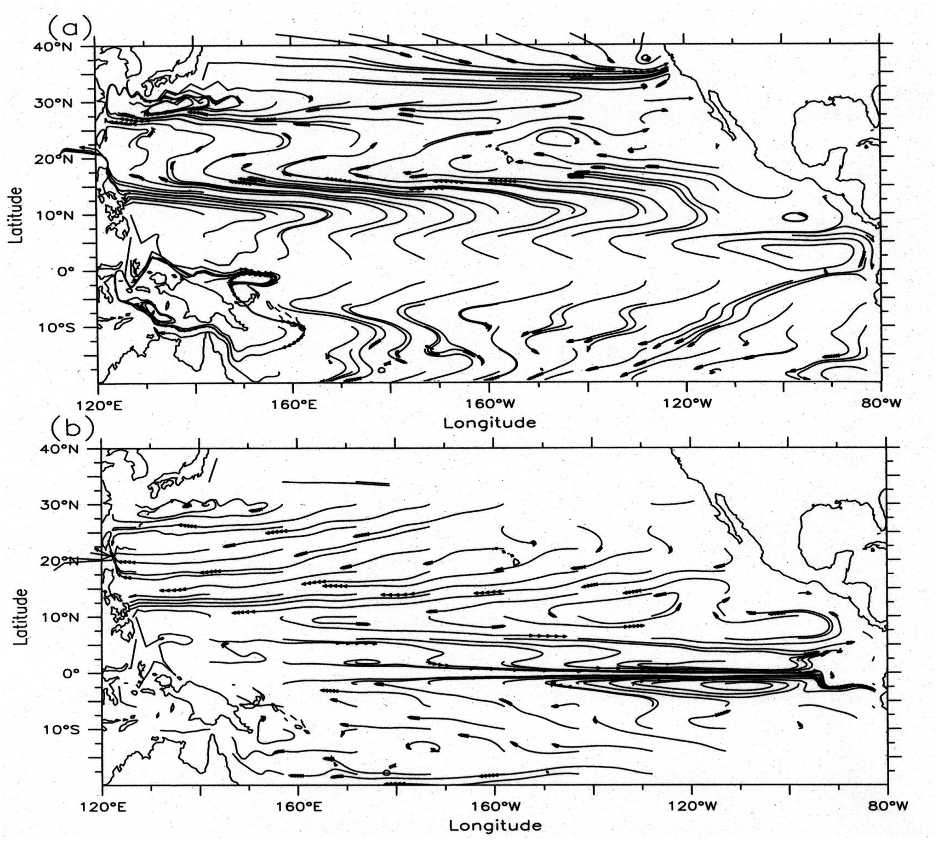


Fig. 3 Surface (top) and thermocline-level (bottom) currents from the Rothstein *et al.* (1998) solution. Areas of upwelling and subduction are labeled in the top and bottom panels, respectively. The panels illustrate the presence of closed, shallow, meridional overturning circulations, the model's North and South Subtropical Cells, which carry cool thermocline water into the tropics and return warm surface water to the subtropics.

anomaly for some distance. However, they did not follow the signal far enough to determine whether it moved into the equatorial region or simply recirculated within the Subtropical Gyre. Recent solutions to oceanic GCMs suggest that most of this signal does in fact recirculate, with little ever reaching the equator (Schneider *et al.* 1999; Nonaka *et al.* 2000). As proposed by Gu and Philander (1997), then, the STC pathway may not provide a sufficiently strong interaction to account for ENSO decadal variability.

An alternate hypothesis is that EDV is generated by variability in STC strength rather than its subsurface temperature (the v′T hypothesis). This idea has been explored by Kleeman *et al.* (1999) and Solomon *et al.* (2001) using intermediate coupled models. In the former study, solutions developed two oscillations, corresponding to PDV and to ENSO. Subtropical wind anomalies associated with the PDV mode altered the strength of the STC, thereby causing more or less cool thermocline water to flow to the equator, which led to a change in the size and strength of the equatorial cold tongue. This change in turn fed back to the atmospheric model to generate EDV. Solomon *et al.* (2001) extended and improved the Kleeman *et al.* (1999) model. They showed that the model PDV was generated by processes similar to those suggested by Latif and Barnett (1994, 1996), but that convection was important in northwest Pacific. In addition, they also reported solutions in a parameter range where the PDV mode is damped, requiring tropical air-sea interactions to maintain it. Thus, in this solution the generation of PDV is tightly linked to tropical air-sea interactions, similar to the solutions discussed next.

Tropical and mid-latitude processes

A number of studies have suggested that the generation mechanism of PDV (and EDV) may originate in the tropics, with PDV at mid-latitudes resulting from ENSO-like atmospheric teleconnections from the tropics (Yukimoto *et al.* 1996, 1998; Knutson and Manabe, 1998). In these solutions, subtropical Rossby waves provide the negative feedback that forces the solutions to shift from one extreme state to another (cold to warm state). The time scale of the decadal oscillation depends on the latitude band of the Rossby waves: the farther poleward the band is located, the longer is the period of the oscillation. The basic idea is thus analogous to the delayed-oscillator theory of ENSO, except that in the ENSO case the Rossby waves are equatorially trapped. A theoretical limitation of the idea is that there is no obvious dynamical reason why the system selects a particular latitude band for the Rossby waves, one that provides variability at decadal time scales rather than some other period. On the other hand, since observed PDV does not have an obvious preferred period, perhaps there is no preferential latitude band and this limitation is not so bad.

Tropical processes only

Finally, other studies using intermediate and simple coupled models suggest that EDV is generated entirely within the tropics by stochastic processes. This type of EDV is implicit in the solutions reported in Zebiak and Cane (1987). Recently, Timmermann and Jin (2001) have explored the nature of EDV in a simple (low number of degrees of freedom), tropical, coupled system, arguing that the decadal response results from tropical nonlinear interactions alone. They demonstrate that in their model the EDV has a character well known in applied mathematics, namely, that of “homoclinic chaos”. In addition, in their solution the amplitude of ENSO varies decadally, rather like the observations in Figure 2. The authors also note similarities between their simple solutions and those to the Case and Zebiak (1987) model. Solutions of this sort have the advantage that they do not develop a sharp decadal peak, consistent with the observations.

Conclusion

In conclusion, the current suite of hypotheses for PDV and EDV is a confusing one, pointing toward the potential importance of several, apparently conflicting mechanisms. Part of the confusion may result from the fact that there is not one simple explanation for PDV and EDV, that in fact many (or all) of the aforementioned mechanisms are at work. In this regard, it is interesting that for a particular parameter range in the Solomon *et al.* (2001) model, PDV exists only when the model also allows for ENSO. In this solution, all the mechanisms noted above are at work except stochastic forcing. This solution therefore suggests that a simpler picture of the causes of PDV and EDV will soon emerge, one that unifies many or all of the existing hypotheses.

References

Deser, C., Alexander, M.A., and Timlin, M.S. 1996. Upper-ocean thermal variations in the North Pacific during 1970-1991. J. Clim. 9: 1840-1855.

Ferranti, L., Molteni, F., and Palmer, T.N. 1994. Impact of localized tropical and extratropical SST anomalies in ensembles of seasonal GCM integrations. Quart. J. Roy. Meteor. Soc. 120: 1613-1645.

Gu, D., and Philander, S.G.H. 1997. Interdecadal climate fluctuations that depend on exchanges between the tropics and the extratropics. Science 275: 805-807.

Ji, M., Leetmaa, A., and Kousky, V.E. 1996. Coupled Model Predictions of ENSO during the 1980s and the 1990s at the National Centers for Environmental Prediction. J. Clim. 9: 3105-3120.

Kleeman, R., McCreary, J.P., and Klinger, B.A. 1999. A mechanism for generating ENSO decadal variability. Geophys. Res. Lett. 26: 1743-1746.

Knutson, T.R., and Manabe, S. 1998. Model assessment of decadal variability and trends in the tropical Pacific Ocean. J. Clim. 11, 2273-2296.

Latif M., and Barnett, T.P. 1994. Causes of decadal climate variability over the North Pacific and North America. Science 266: 634-637.

Latif M., and Barnett, T.P. 1996. Decadal climate variability over the North Pacific and North America: Dynamics and predictability. J. Clim. 9: 2407-2423.

Liu, Z.Y., Philander, S.G.H., and Pacanowski, P.C. 1994. A GCM study of tropical-subtropical upper-ocean water exchange. J. Phys. Oceanogr. 24: 2606-2623.

Lu, P., McCreary, J.P., and Klinger, B.A. 1998. Meridional circulation cells and the source waters of the Pacific equatorial undercurrent. J. Phys. Oceanogr. 28: 62-84.

Mann, M.E., and Park, J. 1996. Joint spatio-temporal modes of surface temperature and sea level pressure variability in the Northern Hemisphere during the last century. J. Clim. 9: 2137-2162.

McCreary, J.P., and Lu, P. 1994. On the interaction between the subtropical and the equatorial oceans: The Subtropical Cell. J. Phys. Oceanogr. 24: 466-497.

Miller, A.J., and Schneider, N. 2000. Interdecadal climate regimes dynamics in the North Pacific Ocean: Theories, observations and ecosystem impacts. Prog. Oceanogr. 47: 355-379.

Nakamura, H., and Yamagata, T. 1999. Recent decadal SST variability in the Northwestern Pacific associated atmospheric anomalies. *In* Beyond El Niño: Decadal and interdecadal Climate. *Edited by* A. Variability, and Navarra. Springer, Berlin, pp. 49-72.

Nakamura, H., Lin, G., and Yamagata, T. 1997. Decadal climate variability in the North Pacific during the recent decades. Bull. Amer. Meteor. Soc. 78: 2215-2225.

Nonaka, M., Xie, S.-P., and Takeuchi, K. 2000. Equatorward spreading of a passive tracer with application to North Pacific interdecadal temperature variations. J. Oceanogr. 56: 173-183.

Palmer, T.N., and Sun, Z. 1985. A modeling and observational study of the relationship between sea surface temperature in the northwest Atlantic and atmospheric general circulation. Quart. J. Roy. Meteor. Soc. 111: 947-975.

Pearce, D.W., Barnett, T.P., and Latif, M. 2000. Connection between the Pacific Ocean tropics and midlatitudes on decadal time scales. J. Clim. 13: 1173-1194.

Peng S., Mysak, L.A., Ritchie, H., Derome, J., and Dugas, B. 1995. The differences between early and midwinter atmospheric response to sea surface temperature anomalies in the northwest Atlantic. J. Clim. 8: 137-157.

Rothstein, L.M., Zhang, R.-H., Busalacchi, A.J., and Chen, D. 1998. A numerical simulation of the mean water pathways in the subtropical and tropical Pacific Ocean. J. Phys. Oceanogr. 28: 322-344.

Timmermann, A., and Jin, F.-F. 2001. Homoclinic chaos: a paradigm for decadal ENSO amplitude modulations (Submitted.).

Trenberth, K.E., and Hurrell, J.W. 1994. Decadal atmosphere-ocean variations in the Pacific. Clim. Dyn. 9: 303-319.

Yukimoto, S., Endoh, M., Kitamura, Y., Kitoh, K., Motoi, T., Noda, A., and Tokioka, T. 1996. Interannual and interdecadal variabilities in the Pacific in the MRI coupled GCM. Clim.e Dyn. 12: 667-683.

Yukimoto, S., Endoh, M., Kitamura, Y., Kitoh, A., Motoi, T., and Noda, A. 2000. ENSO-like interdecadal variability in the Pacific Ocean as simluated in a coupled general circuylation model. J. Geophys. Res. 105, 13: 945-963.

Zebiak, S., and Cane, M. 1987. A model of El Niño-Southern Oscillation. Mon. Wea. Rev. 115: 2262-2278.

Comments on LMR-GOOS recommendations

Warren S. Wooster
School of Marine Affairs, University of Washington, 3707 Brooklyn Ave. NE, Seattle, WA 98105-6715 U.S.A. E-mail: wooster@u.washington.edu

The GOOS (Global Ocean Observing System) is being developed by IOC (UNESCO), with the cooperation of ICSU, WMO, and UNEP. FAO has joined in supporting consideration of living marine resources. The system intends to monitor changes in the condition of the ocean and its ecosystems, to process and analyze the resulting data, and to make them available to users. It is in effect an extension of the weather monitoring network to the ocean and arose from realization that the ocean and atmosphere were closely linked in the development of climate change.

Initially GOOS planning was dominated by physical scientists who were accustomed to networks of routine measurements and to having the observational data made available in near real time. Until last summer, there were four planning panels – climate, coastal, health of the ocean, and living marine resources (LMR). The last three have now all been merged into a so-called Coastal Ocean Observations Panel (COOP). Of these various elements, LMR had a late start and a brief life, from its first meeting in March 1998 to its last (fourth) in May 2000.

One reason for the late start was the controversy over what should be monitored – e.g., just plankton or also fish – and who were the potential users of the findings. There were two false starts from different ends of that controversy before a new panel was formed. The beauty of stopping at the plankton level is that the data are largely apolitical. Scarcely any humans are harvesting plankton, but by the same token, there is no constituency clamoring for such data. Attempting to transform plankton data into useful predictions of distribution, abundance, and availability of wanted fish and shellfish products is not a task for the faint of heart. But as soon as fish are included, political interests are aroused. One of the most serious consequences is that data become proprietary and real-time international exchange of such data becomes unlikely. Also, the task of assessing and predicting fish stocks is a tightly-held national prerogative, not one to be shared freely with other countries.

It is possible to identify many of the users of living marine resources and of information concerning their distribution and abundance. In the most obvious case, fisheries extract and sell such resources, and information on present and future status is useful to the fishers, industrial, subsistence, or recreational, and to those who manage their activities. Those who manage other human activities that affect marine ecosystems are also potential customers. Oceanographers, fishery biologists and investigators of climate change and its impacts can also use the outputs of a comprehensive ocean observing system.

Early on in its new life, the LMR Panel decided to take an ecosystem approach, to consider monitoring changes in the state of marine ecosystems along with the forcing functions of such changes. If assessments of such observations could be routinely produced, they would be of great utility at a range of time scale, from interdecadal and decadal to the seasonal assessments and predictions needed for fishery management. Essential ecosystem components to be monitored include the gamut of trophic levels, from plankton up to fish and top predators like marine mammals and seabirds. Plankton are important not just because of their trophic role, but as potential indicators of ecosystem changes. A complete ecosystem assessment cannot leave out certain significant components, for example salmon, because they “belong” to some country or international organization.

Obviously monitoring life in the sea is vastly more complex than that of the relatively simple abiotic components like temperature or atmospheric pressure. On large, ocean basin scales only satellite observations of surface ocean color, a measure of surface phytoplankton concentration, are routinely made. Zooplankton are only routinely sampled in a few regional programs (e.g., CalCOFI) and CPR surveys. Fish and shellfish of commercial interest are sampled largely by commercial and research fisheries for them on a local scale, and the only large scale information comes from compilations of catch statistics a few years after the fact. Unlike the situation with surface weather and ocean physical information, there is at present no obvious funding in prospect for large scale monitoring of living marine resources.

Sampling strategy is affected by the distribution of biota, especially those components of commercial or other human interest. The intensity of necessary sampling in time and space increases from the open ocean toward the coastal zone as does the availability of support for an observational program. While in the open ocean, regular sampling of biota is limited by the availability of platforms of opportunity, in waters less than a few hundred miles from the coast there are often research surveys funded by the coastal state.

Some ongoing programs have been identified as elements of the so-called Initial Operating System. In the North Pacific these are the Japanese and Korean LMR observing systems, the CalCOFI observations, and those of the Canadian Ocean Station P and Line P. Another category is that of LMR pilot projects which includes ongoing or planned programs intended to develop experience with routine biological observations. These include the northeast Pacific CPR surveys and the proposed project to study Biological Action Centers (BACs). Also, several retrospective studies were commissioned with a view to learning what sorts of observations permit identifying significant environmental changes such as regime shifts. In the PICES region, these were in the southern part of the California Current (CalCOFI and Mexico) and a joint Japan-Korea project in the East Sea/Japan Sea and the East China Sea.

The LMR Panel produced a catalog of desirable observations, physical, chemical and biological, and many of these may be appropriate for the open ocean. On the regional scale, however, there are significant differences between, for example, what is appropriate in the North Sea and what off the Peruvian coast. Thus our "strategic plan" included some examples of more specific suggestions relating to upwelling ecosystems, the Scotian Shelf ecosystem of Atlantic Canada, the Yellow Sea and East China Sea, and the Gulf of Guinea. Monitoring systems in these regions are in widely different stages of development, and it is hoped that they may be enhanced and brought together through the action of organizations such as ICES and PICES.

The generalized catalog of potential observations, physical and biological, is highly schematic. Think of it as listing all of the ingredients of some elaborate dish, say a bouillabaisse. Now we need a recipe, to select the proper quantities of each of the components and to determine how best to prepare them. The recipe for optimal monitoring schemes in the PICES region has been under consideration by the MONITOR Task Team and will likely be discussed at this meeting.

If one had a comprehensive set of monitoring observations, what could be done with them? In the first place, there are largely unsolved problems of compiling, storing, and making available for retrieval biological data and information that are far more heterogeneous than the more standard physical data. Then there are the problems of bringing them together with relevant physical and other data in a holistic analysis. This will undoubtedly involve the use of appropriate models such as those being developed in GLOBEC projects.

The Panel proposed that the assessments be prepared in regional analysis centers (RACs). In the PICES region, one can visualize perhaps three RACs, one for the open ocean, located perhaps in Hawaii, one for the eastern North Pacific and Bering Sea, located perhaps in British Columbia, and one for the waters off eastern Asia, perhaps under the sponsorship of NEAR-GOOS. Analysis teams should include scientists from different disciplines, and participation in such activities should attract the interest of graduate students as well as that of established scientists. In many parts of the world, RACs are expected to serve as centers for capacity building as well as for analysis.

The analyses will require a blending of the biotic and abiotic data from all sources, national and international, within a region. They should yield descriptive products on the current state of the ecosystem and its recent and longer-term changes, and analytic products in the form of forecasts of probable future conditions of the ecosystem and its components. Levels of information detail should extend from raw data to indices, alerts, and forecasts. The products would be regularly provided, perhaps on a quarterly basis, to participating countries and organizations and would be made widely available on the web. They could, among other things, contribute to improving the observational system. RACs might be based at national centers but would include participation from other countries contributing data and ideas.

Examples of descriptive efforts along these lines for several PICES regions are regularly produced by Freeland, Stabeno, and Sugimoto, and published in PICES Press. These are primarily summaries of physical conditions, reflecting the availability of data and the interests of the authors. There are also more comprehensive, but less frequent, syntheses such as the Canadian DFO Ocean Status Reports.

The desired structure and contents of such ecosystem status reports are topics for discussion at this workshop. The collective wisdom of this group should lead to a better understanding of what is desirable and what is feasible with current or anticipated technology and organizational structures and within conceivable budgets. The discussions should help to clarify how the monitoring system can best be strengthened to provide the necessary information and what arrangements would most facilitate regular preparation of the status reports.

RAC assessments can be described as follows:

Input data: atmospheric; physical, chemical, biological oceanographic; fisheries
Sources: national and international
Descriptive products: current state of ecosystem, recent and longer-term changes therein
Analytical products: forecasts of probable future conditions of ecosystem and components
Levels of information detail: (1) raw unformatted data; (2) indices; (3) alerts, status of stocks, maps; (4) forecasts

Background and objectives of POGO

Kees Zwanenburg
Marine Fish Division, Bedford Institute of Oceanography, 1 Challenger Drive, Dartmouth, NS, Canada. B2Y 4A2 E-mail: Zwanenburgk@mar.dfo-mpo.gc.ca

The Partnership for Observation of the Global Oceans (POGO) is a forum recently created by leaders of major oceanographic institutions (presently 14 countries) to promote global oceanography, particularly the implementation of international and integrated ocean observing systems.

The long-term goals of POGO are to participate in the creation and operation of an integrated global ocean observing strategy that addresses the information needs of decision-makers, researchers, service providers, and the general public by:

- Providing an informal forum for dialogue among leaders of key oceanographic institutions;
- Development of an advocacy plan for observing systems;
- Participating in the process to secure governmental commitments to funding ocean observing systems;
- Integrating the observational needs of different ocean disciplines (circulation, *biology,* climate);
- Reducing the barriers between research and operational research;
- Making the case for extensive and sustained observations, research, and modeling;
- Encouraging developing countries to participate fully in collecting and using environmental information; and
- Promoting training education and capacity building in oceanic observation.

POGO supports global oceanographic research and operational ventures but it is not a vehicle for launching new international programs. One of POGO's goals is to act as a catalyst and facilitator to develop and enhance existing programs, and to undertake and participate in collaborative training and capacity building. POGO can act as an effective voice for the oceans. POGO membership is open to individual institutions or consortia of institutions promoting regional collaboration and co-ordination.

POGO activities to date

Planning for POGO started in March 1999, and the first formal meeting was held in December 1999. At this meeting, an initial workplan was developed that included the following items:

- development of an advocacy plan for observing systems;
- participation in the process to secure governmental commitments to funding ocean observing systems;
- a data interchange pilot project; and
- establishment of a data clearing house for POGO members and the broader community.

The second meeting was held in December 2000, in Sao Paulo, Brazil. International organizations present were: IOC (Intergovernmental Oceanographic Comission), SCOR (Scientific Committee on Ocean Research), Argo, CLIVAR (CLImate VARiability and predictability), COOP (COastal Ocean Panel of GOOS), GODAE (Global Ocean Data Assimi-lation Experiment), OOPC (Ocean Observation Panel), and CoML (Census of Marine Life – Sloan Foundation).

The meeting focussed on issues pertinent to the southern ocean. Two-thirds of the world's oceans are in the Southern Hemisphere while most oceanographic institutions are in the Northern Hemisphere. The participants adopted a declaration to promote observations in the Southern Hemisphere, to identify the gaps in these observations, and means to fill them.

There was agreement to promote education by instituting a scholarship scheme in collaboration with SCOR and IOC, and to provide training to scientists and technicians from developing countries related to global ocean observations.

POGO agreed to co-sponsor SEREAD (Scientific Educational Resources and Experience Associated with the Deployment of Argo drifting floats in the South Pacific Ocean).

Structure of POGO

Executive Committee

Dr. Charles Kennel, Founding Chairman (Director, Scripps Institute of Oceanography, U.S.A.)

Dr. Robert Gagosian (Director, Woods Hole Oceanographic Institution, U.S.A.)

Dr. Howard Roe (Director, Southampton Oceanographic Centre, UK)

Dr. Michael Sinclair (Director, Bedford Institute of Oceanography, Canada)

Dr. Rolf Weber (Director, Instituto Oceanografico, Univeristy of Sao Paulo, Brazil)

Executive Director

Dr. Shubha Sathyendranath (Bedford Institute of Oceanography, Canada)

Future Activities

The next meeting of POGO is scheduled for fall, 2001, at the Bedford Institute of Oceanography. The major themes of the meeting will be:

1. Biological observations - observations are more complex, less automated, and vary depending on the objectives of the study. The needs of programs with climate/change carbon perspective and those that target biodiversity will be examined, so that POGO can requisite observations (note LMR GOOS has a lot to offer).
2. Time-series observations to complement the Argo program.

Plans for a CoML Workshop on Canadian Marine Biodiversity: Pacific, Arctic, and Atlantic

Kees Zwanenburg
Marine Fish Division, Bedford Institute of Oceanography, 1 Challenger Drive, Dartmouth, NS, Canada. B2Y 4A2 E-mail: Zwanenburgk@mar.dfo-mpo.gc.ca

Rationale and objectives of the workshop

The world demand for food from the oceans is expected to outstrip availability within the next few decades. Increased use of the oceans for extraction of non-renewable resources and the accelerating growth of coastal population centers will put additional pressures on these systems. In Canada this is reflected by increasing pressures on wild fish and invertebrate stocks, some to the point of fishery closure, increases in offshore oil and gas exploration, and increases in non-consumptive and other ocean use activities. At the same time there is increasing demand for conservation of marine habitats and biodiversity. The latter reflects a growing recognition that the welfare of mankind is inextricably linked to the welfare of these marine systems both as sources of food and as indicators of overall biosphere health. Rational management of future harvesting and other human marine activities requires a reliable information base and theoretical framework with which to make effective decisions. This workshop proposes to develop a national perspective on marine biodiversity in Canada's ocean territories, to develop recommendations for improved monitoring of this diversity in future and to provide guidance on what key factors may control biodiversity.

By signing the International Convention on Biodiversity, Canada has agreed to: make inventories of biodiversity, monitor changes in biodiversity, and make plans to conserve biodiversity. Although Canada ranks among the world leaders in marine research and has been carrying out biophysical monitoring since at least the 1950s, knowledge of its vast ocean territories is still rudimentary for many areas, especially for many groups of organisms inhabiting them. A pre-requisite to developing effective programs to protect habitats and biodiversity is to determine the extent to which information on biodiversity is available for Canada's Pacific, Arctic and Atlantic Ocean territories. Identifying the shortcomings in this information will allow us to amend existing biophysical monitoring activities to ensure that these information gaps can be filled. In addition, the theoretical framework within which these data are interpreted and from which generalities regarding biodiversity can be drawn are not well established for marine systems. Such a framework would allow us to make predictions about what major factors control biodiversity within marine systems and therefore what mitigative procedures would be effective for its maintenance. Most ecological theory and ecological generalizations about biodiversity were developed using terrestrial systems. The second pre-requisite therefore is to examine the applicability of terrestrial ecological theory to marine systems.

The Centre for Marine Biodiversity (CMB) will convene a national workshop to examine these biodiversity issues in Canadian marine waters. The CMB is proposing this workshop in recognition of the many projects relating to biodiversity that are being carried out in all of its ocean territories (Pacific, Arctic, and Atlantic) and the need to consolidate and review this knowledge at a national scale. Canada is well positioned for this workshop given the activity and caliber of its marine science community, the long tradition of monitoring of its marine systems, and the implementation of ecosystem level research in many of its marine institutions. Specifically the workshop will achieve the following objectives:

- A comprehensive description of information on biodiversity available for all of Canada's ocean territories (Pacific, Arctic, and Atlantic). This includes information collected as a result of government-funded biophysical monitoring surveys as well as the results of research carried out by universities, NGO's, fisheries organizations, and First Nations. The key elements of these data will be time and location of collection, the method of collection (sampling gear), and the number of specimens of each species observed.

- A gap analysis of these data to determine where information on marine biodiversity is lacking (both geographically and taxonomically).
- Recommendations for the improvement / augmentation of biophysical monitoring programs in each of the Pacific, Arctic, and Atlantic oceans based on the gap analysis of existing data, and focussed by model results if these indicate key taxonomic groups for which information is presently missing.
- An evaluation of the applicability of existing ecological theory and generalizations to marine biodiversity. Such an evaluation will focus on identifying key factors that maintain or modify the biodiversity of marine systems. This will be at three distinct but inter-dependent levels, ecosystem diversity, species diversity within ecosystems, and population diversity within species.
- Development of a National Plan for producing inventories of marine biodiversity, modifying or augmenting existing biophysical monitoring programs to ensure adequate monitoring of biodiversity, and providing guidance for the development of biodiversity conservation / augmentation plans.

Summary of proposed work

The CMB was recently established at the Bedford Institute of Oceanography to provide a focal point for the range of biodiversity related research presently being conducted in government institutes, universities, and NGO's in the Atlantic region. The proposed workshop will be attended by invited experts and others from the Pacific, Arctic and Atlantic regions of Canada and by international experts. They will develop a detailed overview of current knowledge and gaps in knowledge about organismal diversity in its three oceans. The workshop will also develop an overview of current models used to explore the trophic inter-relationships and organismal dynamics within Canadian marine ecosystems. The results of the gap analysis and model overviews will be used to focus recommendations for improving / augmenting existing biophysical monitoring programs. Finally, the workshop will examine and debate the underlying ecological theory applicable to the maintenance of biodiversity at the marine ecosystem, species, and populations levels with the specific objectives of identifying key factors controlling diversity at these levels of organization. The findings of the workshop will be used to develop a National Plan for cataloguing, monitoring, and providing the theoretical principles to govern the plans for conservation of biodiversity in Canadian marine territories. This plan will provide guidance for Canada to fulfill its obligations under the International Convention on Biodiversity.

Technical description of proposal

We propose a Canada-wide approach to ensure that the workshop reflects biodiversity issues from all three of Canada's oceans, and to encourage co-ordination and co-operation among researchers working in these areas. Such collaboration is essential to the successful development of a national view of marine biodiversity. Since development of a Canadian view of marine biodiversity could provide significant insights or lessons to a global scale project, DFO and the Census of Marine Life will partner funding of the project.

The motivations for the Census of Marine Life are that it provides opportunities to make exciting discoveries about our world, that it supports and operationalizes the International Convention on Biodiversity, and that this improved knowledge will lead to an improved ability to manage marine resources. Specifically the objectives of the Census are to describe: (i) what did live in the oceans, (ii) what does live in the oceans, and (iii) what will live in the oceans.

Between 1997 and the present, the Census of Marine Life sponsored a series of expert workshops examining the justification, scope, and feasibility of such a project (Ausubel 1999). These workshops have concluded that this is one of the grand challenges of marine science whose execution has the potential to unify all its disciplines (biology, chemistry, and physics). The global objectives of the Census are not only about classifying and counting the number of organisms in the sea; they are about understanding the complexities of biological-physical-chemical coupling in dynamic marine environments. An international steering committee has been established to integrate the most valuable and feasible ideas resulting from these and future workshops into a 10-year strategy document.

The historical component of the program will involve rescuing and putting into electronic formats historical information on biodiversity. For the Canadian workshop this will be accomplished, in part, by developing a meta-database of existing information on biodiversity. Once the data sources have been identified it may be feasible to consider development of an integrated biodiversity data set for Canada. Previous projects which developed integrated data sets of biophysical monitoring information (i.e. Mahon *et al.* 1998) resulted in many new insights into biogeography and (in this case) fish assemblages at previously unexplored geographic scales. The program is also developing an Ocean Biogeographical Information System (OBIS) which could be used to develop the integrated biodiversity data set. Work being carried out through Canada's Marine Environmental Data Service (MEDS) may also provide direction on how to merge these biological data with the accompanying physical data.

The "present" component of the program will involve a number of new field programs specifically aimed at assessing the efficacy of new technologies to make synoptic and synchronous measures [of biodiversity] over large areas of ocean. These will be in the form of pilot project in a number of key locations (Georges Bank / Gulf of Maine, Mid-Atlantic ridge and overlying deep-water, vent and seep communities, Pacific large pelagic fish populations, North Pacific salmon populations, and Western Pacific near-shore fauna). For the Canadian workshop we propose that the present component consist of an analysis of the available information to determine data gaps that will provide broad direction for the modification of existing biophysical monitoring programs to ensure effective future monitoring. We also propose that detailed direction for improved monitoring would be aided by results of modeling efforts to determine key structural or trophodynamic groups within systems.

Although integration and analysis of historical data, and identifying and filling in data gaps will lead to an improved description of Canada's marine system, the ultimate objective is to be able to predict what will happen to the diversity in these systems in the future. This objective requires the ability to model the systems with the objective of identifying major forcing variables, or at least to identify the major factors controlling the key species groups. This work is pre-requisite to developing or implementing management measures to protect or enhance the diversity of these systems. Such modeling will require a theoretical framework within which to interpret the existing data. These issues have been extensively deliberated for terrestrial systems but not for marine systems. Canada is presently embarking on a program to define and establish Marine Protected Areas. Although the objectives for these areas have not been explicitly articulated, they do imply some desire to protect biodiversity at least within the boundaries of the areas. The theoretical basis for determining the size, number, and location for such areas in order to maintain or enhance biodiversity has not been clearly articulated. Although it is not necessary to delay the implementation of MPA's while this theory is developed, deliberation and refinement of these concepts may lead to generalities that improve the efficacy of these areas. Specifically, knowledge of what controls diversity within marine systems will allow for more effective management.

An appraisal of current Pacific Ocean monitoring efforts existing within PICES countries

David W. Welch
Fisheries & Oceans Canada, Ocean Sciences & Productivity Division, Pacific Biological Station, Nanaimo, British Columbia, Canada. V9R 5K6 E-mail: welchd@pac.dfo-mpo.gc.ca

During the PICES Seventh Annual Meeting in Fairbanks (October 1998), it became clear that the PICES community does not have a good sense of how well the North Pacific is monitored. As a result, following the meeting we worked to collect information on current monitoring efforts within the PICES region. For purposes of this paper, we define monitoring as regular systematic ocean sampling. For simplicity, we restricted our survey to ocean monitoring that is still on-going. If we plot all of the ocean sampling that is currently occurring, the map of the North Pacific Ocean and adjacent seas looks fairly well-covered (Fig. 4). Reasonably extensive time-series of data exist at Station P (since 1949), Line P (since 1956), the GAK-1 line (since 1970) and the CalCOFI grid (since 1949).

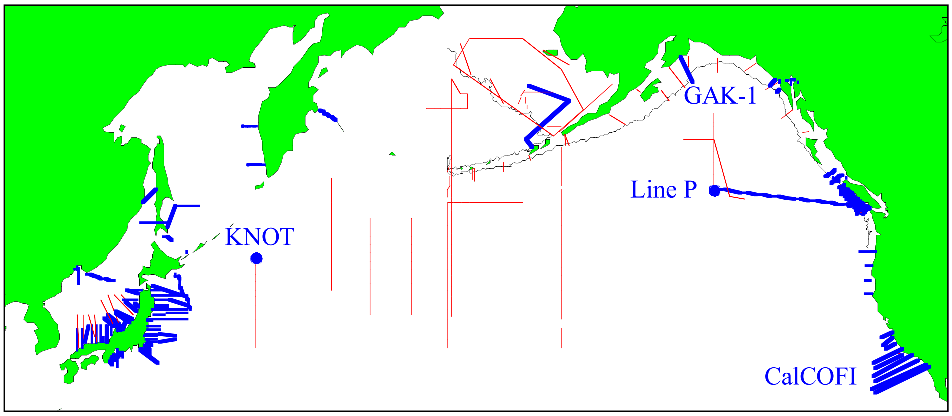


Fig. 4 Summary of on-going monitoring efforts in the PICES arena. The figure shows all locations sampled at least once per year.

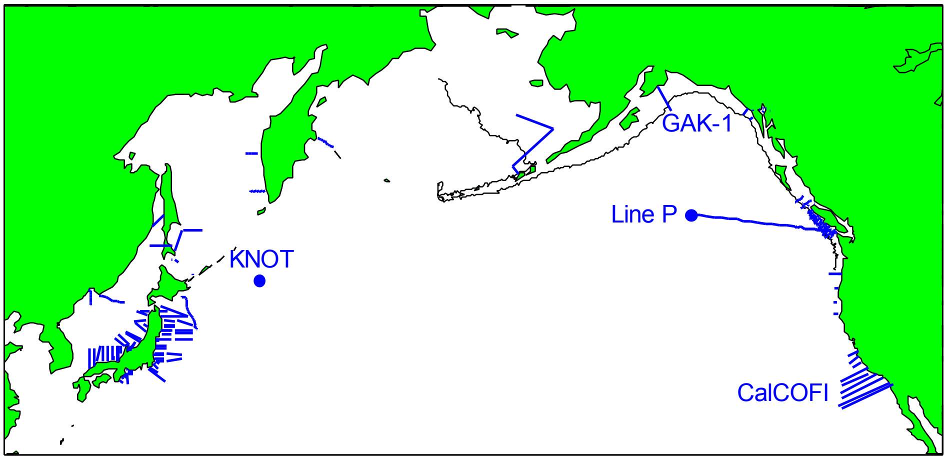


Fig. 5 The same chart as Figure 4, but restricting the definition of monitoring to sampling that occurs two or more times per year. Very little of the North Pacific is adequately monitored if seasonal variation occurs.

However, the time of peak abundance of the dominant copepod *Neocalanus plumchrus* has shifted by approximately two months in the eastern North Pacific (Mackas 1998), emphasizing the need for seasonal coverage in order to identify such changes. If we therefore restrict our definition of "monitoring" to sampling activities that re-sample the same locations two or more times per year, the picture changes dramatically (Fig. 5). The limited sampling is particularly noticeable in the open ocean, where apart from Line P and the new Japanese Station KNOT, no monitoring activities are taking place. As Steele (1998) has noted, coastal zooplankton populations appear to be forced by the offshore populations (at least in the Atlantic), so it is reasonable to expect that events happening offshore will have significant impacts in the shelf region as well. It is clear, however, that the role of offshore and shelf ecosystems under climate change will not be resolved with the existing monitoring effort.

Census of Marine Life – POST (Pacific Ocean Salmon Tagging) proposal

David W. Welch
Fisheries & Oceans Canada, Ocean Sciences & Productivity Division, Pacific Biological Station, Nanaimo, British Columbia, Canada. V9R 5K6 E-mail: welchd@pac.dfo-mpo.gc.ca

The goal of this project, which is currently under review by the CoML for funding a two-year planning phase, is to develop a project focussed (initially) on Pacific salmon. The purpose is to showcase the use of new electronic tagging technology that should allow marine scientists, for the first time, to really track and evaluate the movements of marine fish in the ocean environment. A companion program, "TOPP" (Tagging of Pacific Pelagics), may also go forwards which would focus on using Pacific bluefin tuna and elephant seals using different classes of electronic tags. This program is being co-ordinated by Barbara Block, Dan deCosta, and George Boehlert in California, U.S.A.

The biological objective of POST is to evaluate whether salmon do not merely return to their home address or spawning grounds, but also home to marine feeding grounds using population-specific migration routes. If this concept is correct, then salmon can be thought of as animals whose marine life history phase is every bit as complex and sophisticated as its freshwater phase. The main difference is that the ocean life history of salmon (and all other migratory fish) is hidden within the opaque medium of seawater.

The proposed CoML POST program has two components – an offshore component using archival tags to track the movements of Pacific salmon in the open ocean, and a nearshore component that would use an acoustic array to track the movements of salmon tagged with acoustic tags along the continental shelf (Fig. 6).

Only the second component is of direct relevance to the purpose of this meeting. Although acoustic tracking is normally considered to be of use over short distances and restricted time periods, it is likely that we can design and build an acoustic monitoring network that could stretch the length of the West Coast of North America at relatively low cost. This network is called "POTENT" (for ***P***acific ***O***cean ***T***racking ***A***nd ***E***valuation ***N***e***T***work), and would consist of about 600-700 low cost acoustic receivers that would be deployed in a series of acoustic listening lines, that would stretch across the shelf on the sea bottom from land to the shelf break.

As the continental shelf off the West Coast of North America is relatively narrow (20-30 km wide in most places), we believe that it will be possible to place a series of receivers at roughly 1-km spacings that should provide for virtually complete detection of all acoustically tagged animals that swim above it (Fig. 7). As each tag has a unique acoustic signature, and each receiver records the date and time that each tag is detected, it is possible to build up a detailed picture of the

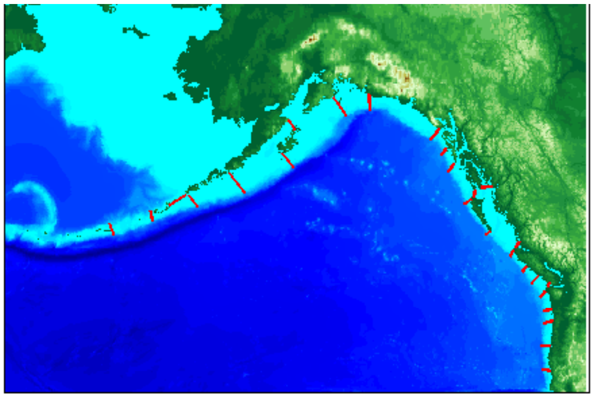


Fig. 6 Conceptual example of the monitoring network. Monitoring lines (in red) will be placed using islands and straits as bottlenecks to minimize the length of monitoring lines. For example, all tagged salmon migrating to or from the Fraser River or the East coast of Vancouver Island could be monitored with two short lines in Johnstone and Juan de Fuca Straits. Their detection north or south of the straits would demonstrate which direction specific stocks move and their rates of migration. Similar design criteria would apply to other major rivers such as the Columbia. Actual positions need to be determined as part of the planning process to minimize disruption to fisheries.

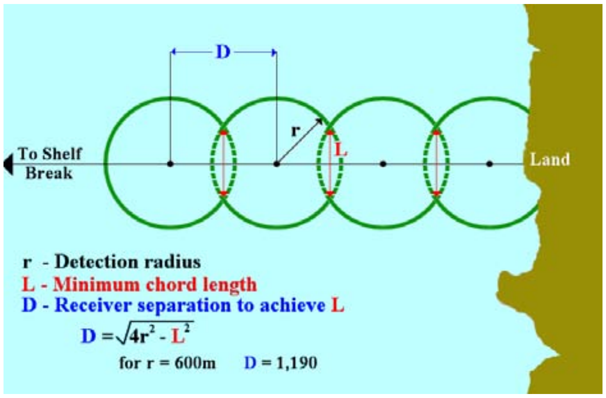


Fig. 7 Conceptual example of the cross-shelf monitoring array. The basic design goal is to determine the detection radius, r, at which an acoustically tagged animal can be identified under different oceanographic conditions. Knowing r, it is possible to determine the spatial separation, D, for the receivers to ensure that an animal crossing the array at right angles has a high probability of being detected. For a salmon smolt travelling at 20 cm/sec, assuming that the minimum chord length is L=100 m in the example given results in the animal travelling within the detection zone for a minimum of 8 minutes.

movements of individual animals during their migrations along the continental shelf over many months or years at sea. This approach should for the first time allow the study of large scale movements of shelf-resident marine fish, which are not otherwise amenable to study.

The POTENT array, if built, is thus of some interest for monitoring animals over wide regions along the continental shelf. However, a further aspect of the array is of relevance, which is its use as a framework within which a much wider range of sea-bed instruments (such as temperature or salinity probes) could sit. Assuming that the initial infrastructure can be developed, it should be possible to place a wide range of additional sensors on the seabed, and use the same infrastructure to retrieve long-term measurements of oceanographic properties as well. One could, for example, envisage such a seabed network recording the rate of movement of an El Niño at depth up the coast, since the greatest warming during the last two El Niños occurred at 200-400 m depth off British Columbia.

REPORTS OF THE BREAKOUT GROUP DISCUSSIONS

After the plenary session reports on large international programs, the workshop participants were separated into four breakout groups organized by discipline. Breakout Group 1 consisted of experts in physical/chemical oceanography and climate. Group 2 was phytoplankton, zooplankton, micronekton and benthos experts. Group 3 consisted mainly of scientists involved in fish, squid, crab, and shrimp population analyses. Group 4 was for migratory fish such as salmon and tunas, seabirds, and marine mammals. Breakout group leaders asked participants to report on national monitoring activities within each discipline and their individual reports are contained in Section II. Each group then discussed the status of the monitoring, modeling and prediction system in the North Pacific with regards to the discipline. Monitoring gaps, priority sampling and analysis activities were identified.

Breakout Group 1: Physical/Chemical Oceanography and Climate

Chairman: Richard E. Thomson
Rapporteur: James E. Overland

Participants: Steven J. Bograd, Alexander S. Bychkov, Kimio Hanawa, Makoto Kashiwai, Andrei S. Krovnin, Vyacheslav B. Lobanov, Allen Macklin, Humio Mitsudera, Yukihiro Nojiri, Fangli Qiao, Warren S. Wooster, and David Foley. Suam Kim attended part time.

Introductions and preliminary discussion

The morning session on the first day (March 7) began with each participant giving their name and affiliation, and outlining their area of research. Introduction was followed by a general discussion that attempted to define the exact goals of the breakout group in terms of the challenges presented in the workshop description. There was some uncertainty in the goals and the best approach to proceed. The initial discussion eventually centered on several main themes:

- The importance of national governments in the establishment and maintenance of time-series for observing North Pacific marine ecosystems and their biodiversity. Too often, continuation of important time-series is determined by the ability of individual scientists to secure funding and, unless the program is "institutionalized", it may end with the departure of the leading proponent of the program.
- The fundamental physical and chemical measurements needed for any long-term monitoring of the ocean. Minimum requirements are temperature and salinity from CTDs, but preferably would also include meaurements of nutrients, dissolved oxygen, beam attenuation, chlorophyll, carbonate parameters, currents, and high-frequency bioacoustics.
- Identification of "critical" time-series, such as those from coastal lighthouses and oceanic gyre sites (Station P and Station KNOT) that should be maintained to some level regardless of politics and funding constraints.
- The approaches and sensors that are needed to overcome the logistical and funding difficulties required maintaining long-term physical and chemical oceanic time-series. Newly emerging technological advanced projects, such as the proposed NEPTUNE project in the northeast Pacific, offer an opportunity for oceanographers to collect long-term, externally powered, real-time, simultaneous physical, chemical, biological and geophysical data in the open ocean.
- The degree of "value-added" information (i.e., degree of time-series interpretative) that should accompany any PICES database, and the need for a "stand-alone" document – such as a regularly updated State-of-the-Ocean Report – for managers.

Presentations on existing and proposed time-series observation programs and research

The afternoon of the first day (March 7) and the morning of the second day (March 8) were devoted to presentations by individual scientists on material they had prepared for the meeting (see Table 1 and Section II). The talks provided detailed information on existing physical/chemical databases for the North Pacific archived by American, Canadian, Chinese, Japanese, Korean, and Russian national institutions. Presentations afforded insight into past, present and future field programs for each country and associated research programs within the institutions represented by each of the participating scientists. Talks were generally informal and informative, ranging from presentations on data inventories to reports on scientific interpretation and numerical modeling. Some impressions are summarized below:

- It is clear that the major sea-going nations of the North Pacific collectively hold an impressive range of continuing (as well as recently terminated) time-series of physical and chemical data. Most participants reported on one or more oceanographic time-series (often bottle and/or CTD temperature and salinity data series) of more than 10 to 15 years duration, as well as shorter (2 to 5 year) data series from process-based studies. The latter tend to be multi-disciplinary and encompass a wide range of oceanic measurements. Much of these "untapped" data are securely stored away in the archives of various institutions. In some instances, different institutions in the same country have limited access to each other's data series.
- Most of long-term data series have been collected under the auspices of fisheries, ship navigation (e.g., ice concentrations and currents), and climate-related programs. Time-series for process-based studies are generally only a few years but encompass a broader range of physical, chemical and biological variables. Unlike the open ocean areas, there generally are sufficient data from most coastal seas to accurately define seasonal and interannual variability.
- Most of the existing datasets contain standard temperature and salinity data series from bottle/CTD casts, but many also include other oceanic parameters such as chlorophyll, beam (light) attenuation, nutrients, dissolved oxygen, carbonate parameters, current speed and direction, and zooplankton net haul time series. Sea surface temperature (SST) from satellite AVHRR imagery and SeaWIFS ocean colour are critical to examining long-term variability but are often too limited by cloud and fog for short-term process-related studies.
- Data coverage is highest within territorial seas and the continental margins of the World Ocean, and marginal at best in the offshore waters of the central Pacific, especially regions outside commercial shipping lanes.
- Data collection is now generally complemented by primitive equation biophysical modeling and box-type ecosystem productivity modeling.
- Scientists at the meeting were generally enthusiastic – albeit cautious – about sharing information on existing data sets and setting up a cooperative exchange program.

Time-series data requirements

Following the informal presentations on March 8, the group momentarily lost its direction. It was not clear how to proceed and how to address the formidable tasks set out by the convenors. The original goal of the meeting was seen by some as "analogous to climbing Mount Everest in winter without oxygen". After a brief discussion, it became clear that our goal was not to reach the peak but to set up "base camps" for future assaults on the database summit.

We decided to return to the theme of meeting which was "to review the available existing time-series and predictive models, to discuss the utility of those for assessing biodiversity and its changes, and to suggest improvements in terms of sampling and modeling strategy, and the addition of new time series observations that are not yet part of the monitoring system".

Table 1 Presenters and themes for Breakout Group 1.

Presenter	**Type of data series described**
Bograd, Steven U.S.A.	(a) CalCOFI (1949-present) physical and biological data for the coast of California; (b) PMEL/NIMPS data server. Data on NOAA & CalCOFI websites.
Hanawa, Kimio Japan	Presented a handout of material on repeat sections. JMA repeat surveys 137°E, 155°E, 165°E. Also short coastal lines 4x per year CTD/nutrients and physics. Fisheries surveys of phyto/zooplankton along 179.5°W.
Kashiwai, Makoto Japan	Repeat lines by JFA (referred to David Welch's overhead from his talk). Has a program for distributing fisheries data. Noted the problem with data exchange among Japanese agencies.
Krovnin, Andrei Russia	Discussed monthly mean data collected by Russian fisheries agencies since 1950. Time-series exist for winter months and for ice cover in the Sea of Okhotsk. T and S data for the NW Pacific. Data are in digital form; older data in paper form.
Lobanov, Vyacheslav Russia	Pacific Oceanological Institute database (http://poi.dov.ru). Sakhalin Hydrometeorological Administration and Sakhalin Institute of Fisheries and Oceanography (SakhNIRO) sections off Sakhalin Islands continuing since the 1950s. POI studying the eddy regime off the Kuril Islands from 1990 till 2000 as an indicator of climate regimes.
Macklin, Allen U.S.A.	Indices from gridded data sets. Bering Sea ice pack data. Find an earlier transition from spring to summer. Timing of the last spring storm in the Bering Sea used for pollock predictions. North Pacific bottom pressure data at 1-minute samples collected for tsunami warnings since 1986. Alaska line 8 has 16-year data set. Pollock larvae survey = 17 years data set. Alaskan Stream work began in 1987; 7 years of current moorings. North Pacific CTDs since 1932; Sitka air temp since 1829; North Pacific index since 1899; satellite-tracked drifters 1986-2000.
McLaren, Ron Canada	Canadian meteorological program in the North Pacific. Array of 6-12 deep-drogued drifters since the mid-1980s (pressure and temperature sensors), and moored met buoys (6 m NOMADs and 3 m Discuss) measuring wind speed and direction, SST, air temperature, pressure, wave height, and wave period since late 1980s.
Mitsudera, Humio Japan/U.S.A.	Share data server with PMEL and have distributed data site at University of Hawaii. Argo implementation and remote sensing data.
Nojiri, Yukihiro Japan	Discussed measurement of carbonate parameters data in the North Pacific. Also collection of pCO_2, hydrography, DIC, and nutrient data. CO_2 and nutrients from underway sampling. 1998 began KNOT time-series. Compared time-series from Station P and Station KNOT. Station P has higher productivity in winter but to his surprise, the two are the same in summer (need to verify this). Chemists need coverage in the South Pacific on a repeated track. Has a website for T/S and CO_2 data.
Overland, James U.S.A.	Discussed NCEP (National Center for Environmental Prediction). Data from 1947- present. Used fixed physics and data assimilation to produce three-daily and monthly data files and maps.

Table 1 (continued)

Presenter	**Type of data series described**
Qiao, Fangli China	Presented results for a numerical model of Jiaozhou Bay. Other areas of interest include Yellow Sea area (observations), Kuroshio (have 18 years of data).
Thomson, Richard Canada	Discussed programs and data collected by the Institute of Ocean Sciences. Omitted to discuss ongoing paleooceangraphy studies examining piston, box and freeze cores from anoxic basins in British Columbia to examine histories of pelagic fish abundance, earthquake occurrences, and climate change.
Batchelder, Hal U.S.A.	Breakout group 2. US GLOBEC program: Transects off Oregon 4x per year for 6 to 7 years. Extensive CODAR array. Long-term observation program along Seward Line 1997-2005. AVHRR imagery and SeaWIFS.
Foley, David U.S.A.	Pacific basin wide TOPEX/Poseidon, SeaWIFS and measurement of wind stress, SST, wind stress curl, and chlorophyll. Websites for real-time data access.
Kim, Suam Korea	Breakout group 3. Described the 22 transects conducted around Korean Peninsula, occupying about 75 stations, plus lighthouse coastal data dating to 1965. 6 surveys per year (every other month) for T, S, nutrients, DO, zooplankton.

The following factors were addressed:

- The need to collect and process high-quality, reliable physical and chemical data of sufficient sampling frequency to define seasonal, interannual and decadal variability, and climate-scale trends.
- The need to distribute these data on a timely basis to national and international users (through joint programs if needed).
- A requirement to analyze and interpret time-series data in terms of physical and chemical dynamics of interest to biologists and political decision-makers.
- The need to provide oceanographic data for formulation, calibration and validation of numerical models of ocean/atmosphere processes and climate change.

Regional data coverage

Given its considerable observational expertise, the breakout group decided to separate the North Pacific into nine distinct oceanographic regions and then discuss the degree of coverage in each of the primary regions. A photocopy of the North Pacific was supplied by Dr. Nojiri, and group members were asked to sketch on the maps the locations and types of surveys their institutions are providing, separating these into "terminated data series" (Fig. 8) and "continuing data series" (Fig. 9).

The general conclusion is that there are considerable physical, chemical and biological data collected within the coastal domains and continental margins of the North Pacific, but a marked paucity of data series for the central Pacific and Subarctic Gyre regions. AVHRR satellite imagery and SeaWIFS are hampered by cloud cover. However, TOPEX/POSEIDON is not hampered by clouds and has been providing critical time-series data on sea level height anomalies and their propagation in the open ocean and coastal seas.

The 9 Biophysical Domains identified for the North Pacific were identified as the:

1. California Current System (including hydrothermal venting regions)
2. Alaska Current and Gulf of Alaska System

3. Bering Sea
4. Central North Pacific
5. Sea of Okhotsk
6. Sea of Japan
7. Western Subtropical Gyre (including the Kuroshio)
8. Western Subarctic Gyre (including the Oyashio)
9. East China Sea

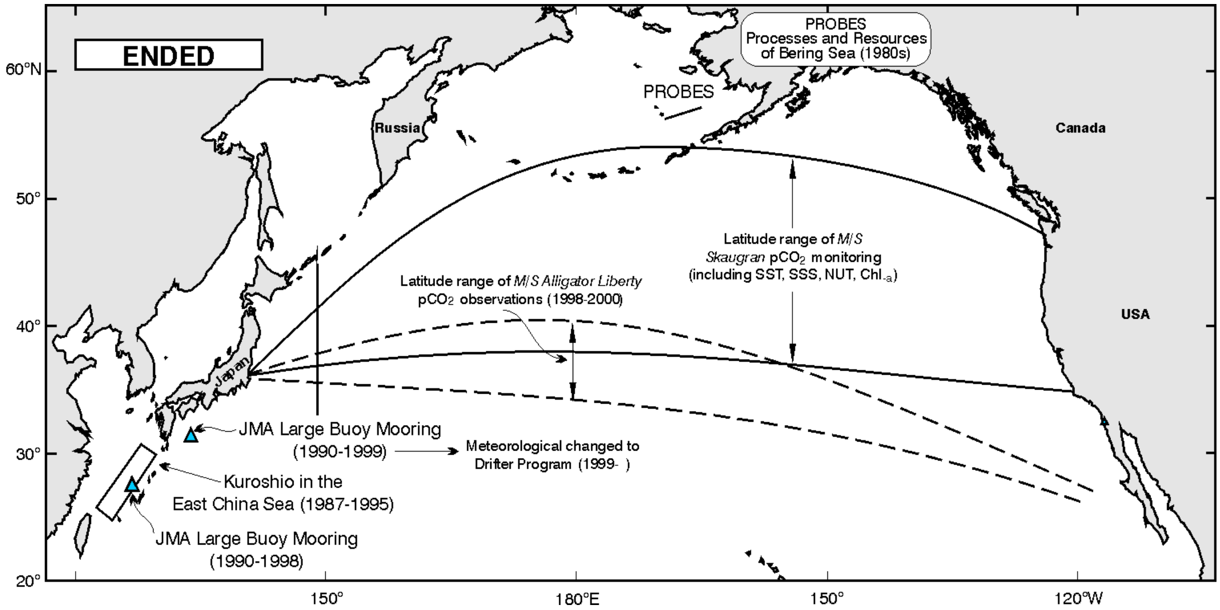


Fig. 8 Time-series observations of physical/chemical or atmospheric parameters that have been discontinued.

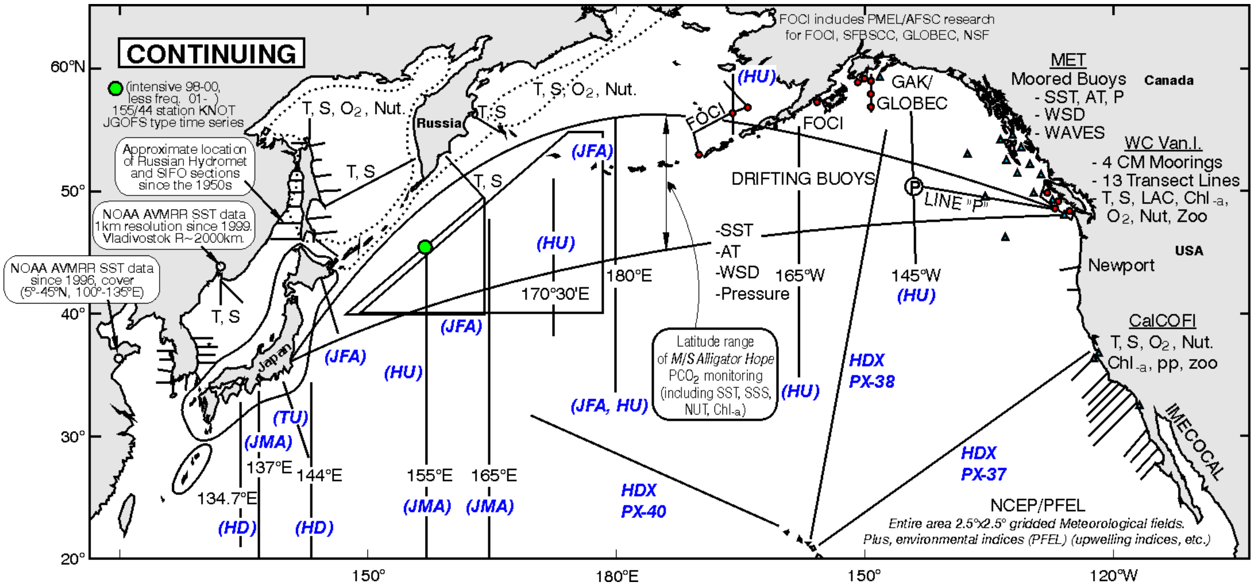


Fig. 9 Time-series observations of physical/chemical or atmospheric parameters that are continuing.

Sea of Japan

JMA (Japan) sections
NFRDI (Korea) transects
TINRO (Russia): 2 sections
SakhNIRO (Russia): semi-annual sections off Sakhalin Island
NEAR-GOOS activities

Coastal Japan

Since 1964: T, S, nutrient, chlorophyll, zooplankton

Coastal Korea

Since 1965: T, S, DO, nutrients, chlorophyll, zooplankton

Western Subarctic Gyre (and Oyashio)

HNFRI (Japan): Line A (7 years)
JMA (Japan): lines along 41.5° and 144°E; SST data composite
Station KNOT (1998-)

Western Subtropical Gyre (and Kuroshio)

JMA (Japan): lines along 137°, 155°, and 165°E
JHD (Japan): lines along 134.7° and 144°E; also G, P Lines
NIES (Japan) and IOS (Canada): Basin wide CO_2 measurements since 1995

Sea of Okhotsk

TINRO (Russia): Sakhalin and Kamchatka transects, T, S, DO, nutrient, zooplankton
VNIRO (Russia): weekly SST from satellites and ships
SakhNIRO (Russia): semi-annual sections off Sakhalin Island
JMA, JHD and VNIRO: sea-ice data

Bering Sea

TINRO and KamchatNIRO (Russia): Kamchatka Current (in 1970s and 1995-); SST, winds, T, S, DO, nutrient, zooplankton, primary productivity, currents
FOCI (U.S.A.): 2 moorings and sections; sea ice
NMFS (U.S.A.): survey data

Central Pacific

Station HOT (U.S.A.): 22°N station and transect monthly along 175.5°E since 1998
Hokkaido University, HU (Japan): survey lines along 170°E, 180° and 165°W; Line P and ships of opportunity

Gulf of Alaska

FOCI (U.S.A.): Shelikof Strait since 1985; T, S, nutrient, chlorophyll, primary productivity, zooplankton, currents
GAK (U.S.A.): line since 1971, now part of US GLOBEC; CPR lines, T, S, nutrient, chlorophyll, zooplankton
IOS (Canada): La Perouse/GLOBEC lines off Vancouver Island and northern Washington State
IOS (Canada): Line P and Station P (1956-)
HU (Japan): line along 145°W
NMFS (U.S.A.): Gulf of Alaska groundfish surveys
NMFS (U.S.A.)/DFO (Canada): west coast of North America hake surveys (every 3 years)
Meteorological buoys report near real-time hourly data on wind speed and direction, wind maximum, SST, air temperature, atmospheric pressure, significant wave height, and wave period
Drifting buoys provide information on atmospheric pressure, SST, air temperature, and wind speed and direction (some buoys only)

California Current System

IOS (Canada): Station P/Line P; La Perouse/ Canadian GLOBEC programs; T, S, nutrient, chlorophyll, zooplankton
US GLOBEC: Newport Oregon line (originally in the 1960s; restarted 1996-); T, S, nutrient, chlorophyll, zooplankton
CalCOFI (U.S.A.): ongoing since 1949; T, S, nutrient, chlorophyll, primary productivity, zooplankton
Canada/U.S.A. Vents programs (focus on Juan de Fuca Ridge). T, S, currents, nutrients, zooplankton

MBARI moorings and Scripps (U.S.A.) pier time-series

IMECOCAL line off Baja (U.S.A./Mexico)

Santa Barbara Basin (U.S.A./Mexico)

Meteorological buoys report near real-time hourly data on wind speed and direction, wind maximum, SST, air temperature, atmospheric pressure, significant wave height, and wave period

East China Sea

SOA (China): five standard sections since 1960

JMA (Japan): PN line

Strait of Georgia

IOS (Canada): CTD, DO and nutrient data time-series begun in 1999

Except for the Sea of Japan

NIES (Japan): VOS CO_2 program

PICES "State-of-the-Ocean Reports" and establishment of a meta-database

The general consensus of the breakout group was that:

- PICES could provide a "virtual" site for communication of data inventory (i.e., provide information on geographical/time/type of data and data source) but should not attempt to store the data. NOAA scientists attending the meeting had considerable expertise on setting-up and maintaining a meta-database site. They should be consulted prior to and during formulation of any database site.
- PICES could provide a site for regional large-scale climate indices such as the Southern Oscillation Index, Pacific Decadal Oscillation, and Length of Day Index, and other indices.
- PICES should oversee an annual (or semiannual) report detailing the "State-of-the-Ocean" for the North Pacific which summarizes the temperature, salinity, currents, winds, primary/secondary production, fisheries productivity, carbonate parameters, and other oceanographic factors (including results of numerical modeling and theoretical studies). Several nations presently issue such status reports for their areas of interest.
- The reporting frequency should be at least annual but would prefer monthly so that seasonal cycle can be defined.
- The information should be widely distributed through as many organizations as possible. PICES should help establish a meta-database by supporting (or finding support for) existing facilities set up by NOAA on the west coast of the United States.

Breakout Group 2: Phytoplankton, Zooplankton, Micronekton, and Benthos

Chairmen: David L. Mackas and Young-Shil Kang

Participants: Vera Alexander, Harold Batchelder, Sonia D. Batten, Richard D. Brodeur, David M. Checkley Jr., Sanae Chiba, Cynthia Decker, Rita Horner, Takahito Iida, Shin-ichi Ito, Michio J. Kishi, Toru Kobari, Kosei Komatsu, Allen Macklin, Phillip R. Mundy, William T. Peterson, Sei-Ichi Saitoh, S. Lan Smith, Takashige Sugimoto, Kazuaki Tadokoro

Preliminary discussions

We began with a general discussion of the need for improved ocean observation and prediction systems. Briefly, sustained and enhanced ocean time-series are necessary because:

- The oceans are not constant (there are large changes at interannual and longer time scales);
- Some of these changes cannot yet be predicted (the ocean generates "surprises"); and
- Present time-series are insufficient for diagnosis and prediction (inadequate density

and integration among all variables and regions).

We next reviewed the specific objectives for this workshop/breakout group. These were:

- To describe what we are now doing (coverage, methodology, data management),
- To document successes and problem areas (lessons from past and present activities), and
- To develop plans for the future.

Individual presentations on existing observation and modeling programs

Most of the Breakout Group agenda (afternoon of March 7, all of March 8) was filled by a series of presentations on existing observation and modeling programs (Table 2). Extended abstracts of individual presentations can be found in Section II. The presentations provided a good overview of the lower trophic level time-series observations now being made in many parts of the North Pacific. However, there may be some important omissions. For example, our Breakout Group lacked representation from China or Russia, and also from the international community of intertidal/subtidal benthic ecologists.

Table 2 Presenters and themes for Breakout Group 2.

Presenters	**Topics**
V. Alexander	Oral presentation
H. Batchelder	U.S. GLOBEC Northeast Pacific Program observations, retrospective studies and model products
S. Batten	Continuous Plankton Recorder pilot study in the North Pacific
R. Brodeur	Micronekton data dets in North Pacific
D. Checkley	Plankton in the California Cooperative Fisheries Investigations
S. Chiba	Japan Sea time-series - qualitative study on lower trophic level ecosystem may reveal the process on climate-ecosystem interaction
R. Horner	Phytoplankton data from the Gulf of Alaska, British Columbia, and the Pacific coast of the U.S., with emphasis on harmful algal bloom species
S.-I. Ito	Time-series of the Tohoku National Laboratory
Y.-S. Kang	Monitoring system and long-term trend of zooplankton in the Korean waters
T. Kobari	180º time-series information
C. Lange (presented by R. Horner)	Scripps Pier phytoplankton time-series
D. Mackas	Canadian activities and plans for zooplankton, phytoplankton, micronekton, and benthos monitoring in the Pacific Ocean
A. Macklin	Physical and biophysical time-series originating from or used by Fisheries Oceanography Coordinated Investigations (FOCI) in the North Pacific Ocean and Bering Sea
W. Peterson	Zooplankton time-series - Oregon, Washington and N. California
S.-I. Saitoh	East-west variability of primary production in the subarctic North Pacific derived from Multi-Sensor Remote Sensing during 1996-2000
N. Shiga	Oral presentation
K. Tadokoro	Long-term variations of plankton biomass in the North Pacific

Group discussion of shared themes (characteristics, strengths and weaknesses of North Pacific time-series observation programs)

Spatial coverage and sampling frequency

For the margins of the North Pacific (inland seas, continental shelf and slope regions, boundary currents), time-series coverage ranges from poor to fair (in most high latitude and subtropical regions), and to very good (waters off Japan and Korea, the continental US and southern Canadian coasts, and some parts of Alaska).

In contrast, *open ocean regions are consistently undersampled*, except for a few variables and regions that can be sampled from satellites (e.g. ocean color in locations with low or moderate cloud cover). Seasonality of biological production and upper ocean physics is very strong in the North Pacific, but very few open-ocean programs have a sampling frequency sufficient to resolve seasonal phasing and amplitude.

Biological coverage

For mesozooplankton and phytoplankton, most North Pacific time-series provide indices of biomass (typically either wet weight, dry weight, or displacement volume for mesozooplankton; chlorophyll-*a* concentration for phytoplankton). Some time-series include additional information on taxonomic (and sometimes age/stage) composition within these categories. There was a strong consensus that *this information on biological composition has been very useful* where and when it has been available.

Unfortunately, there are fewer (and in some cases no) time-series observations for two key groups of "lower trophic level" pelagic organisms that play very important roles in oceanic food webs and geochemical cycles. Some of the conspicuous gaps:

- Very small "microbial loop" taxa such as bacteria, picoplankton and microzooplankton (some exceptions: HOTS, Station P, US GLOBEC and some Japan coastal lines);
- "Micronekton" - this category includes taxa for which quantitative sampling is very difficult: small mesopelagic fishes, shrimps, squids, and (to a lesser but significant extent) euphausiids. They are too large and agile to be well-sampled by standard zooplankton nets, but are (to date) not targeted by commercial fishing gear.

For benthic taxa, availability of time-series data drops off steeply with distance from shore. Many intertidal benthic time-series exist, but collection and use of these data is for the most part by individuals and organizations outside the PICES scientific community. This could (and should) be changed by more collaboration between biological oceanographers and intertidal ecologists.

There is much less time-series information on North Pacific sub-tidal and deep-sea benthos. One-time baseline studies have been done for a few regions (e.g., Bering Sea, southern BC continental shelf). Time-series data for large benthic epifauna are sometimes available from fisheries assessment trawl surveys (e.g., Anderson and Piatt 1999). For infauna and small benthic epifauna, breakout group members were unaware of sustained benthic time-series, except for site-specific studies of environmental perturbations in near-shore regions, and some recent repeat observations of hydrothermal vent environments.

Paleoceanography is based primarily on "benthic" sampling of chronologically stratified sediments. Comparison/intercalibration with water-column time-series from nearby regions is essential if we wish to interpret the longer time scales of ocean variability.

Duration and life expectancy of observation programs

There is a worrisome mismatch between time scales of North Pacific variability, and the typical duration of observation programs. Although this meeting has documented an increasing number of North Pacific time-series, nearly all sampling programs are either fixed duration (typically ≤ 5 years) or continue on an uncertain 'year by year' basis. Lack of long-term continuity appears to be more attributable to lack of funding agency commitment than to lack of interest and commitment by individual researchers.

Given the importance of decadal and longer time scales of climate variability, are 5-10 year fragments sufficient ingredients for a "long-term observation program"? If not, how and to whom do we convey this message? What can we offer as remedies? Can we use technology to reduce the cost per data point? From preliminary knowledge of spatial and temporal scales of variability, can we now design less detailed, but more permanent, sampling designs? What is the optimal mix of spatial lines and grids with single-point Eulerian time series?

Sensors and platforms

Existing biological oceanographic sampling programs in the North Pacific make broad use of dedicated survey cruises and satellite remote sensing. The ship-based methods used for time-series *in situ* sampling (nets, water bottles, auxiliary electronic sensors on CTDs) are generally effective, although taxonomically selective and perhaps a bit dated (see *Biological coverage* section above).

There is effective spot use of commercial ships-of-opportunity and dedicated moorings carrying sediment traps and/or optical and acoustic sensors. Promising opportunities for the future include: high frequency acoustics (we are behind fisheries scientists in standardized measurement of acoustic backscatter); supplemental "add-on" sampling that uses research vessels as ships-of-opportunity, "moorings of opportunity", "drifters of opportunity", "ocean observatories", autonomous nutrient analyzers; use of optical plankton counters (OPCs) for quick analysis of size spectrum of net samples, broader routine use of quick and simple indicators like Secchi depth.

Integration with operational and diagnostic simulation models

Efforts to couple time-series observations with marine ecosystem models are expanding rapidly in the United States and Japan, somewhat less rapidly in other PICES nations. Breakout group members agreed that this is an important activity, beneficial to both data collectors and modellers. Some issues that were identified in our brief discussion:

- Most modellers of lower trophic levels use a quantification based on (pooled) biomass rather than numeric abundance. This is effective for biogeochemical applications, but may be less effective for applications involving population dynamics (survival, recruitment) of individual target species or changes in community composition.
- Neither models nor sampling can be completely detailed in every respect. Model development always involves tradeoff choices in model complexity (e.g., space and time resolution vs. community structure and diversity). There is a good discussion of this issue in the recent GLOBEC International "Report of the GLOBEC Focus 3 Working Group on Modelling and Predictive Capabilities".
- Data assimilation (the constraint of model output by ongoing observations) is proving extremely useful in meteorology and physical oceanography, but is not yet common in biological models.

Community data archival and availability

There has been ongoing, but slow, progress toward "data sharing" in biological oceanography. Compared to physical oceanographic and meteorological data (for which there is a large amount of accessible "shared" data), obstacles include the high diversity of type and quality among measured biological variables, occasional long time lags for sample workup, scientific culture, and (in a few cases) political sensitivity. More complete participation can be enforced by research funding policies. However, it is also important that data originators "buy-in" voluntarily to data sharing. This will occur if and because "community" data banks are set up in a way that the data originators find accessible and useful. Specific suggestions and problems mentioned in our group discussion:

- Metadata clearing house (A PICES node of OBIS?);
- Problem of no fixed internet address for web-access data and derived-index time-series ("URL mutation"); and

- Regional Analysis Centers (products, tools to aid formatting and analysis, site and funding vehicle for comparative analysis projects, politically neutral).

Additional gaps, problems and opportunities

Taxonomic capacity is declining, at the same time as we are learning (or re-learning) the value of species-level identification for understanding ecosystem structure and change. There is a critical need to maintain and restore access to this expertise. CoML has a clear interest and could play an important role. Suggested initiatives included:

- development of a Pacific identification clearing house;
- funding of graduate-level "taxonomic apprenticeship" programs; and
- alternative computer-based formats for identification guides.

Standardization/intercomparison of sampling methods is needed. Simplicity and constancy have merit. However, methods will differ and evolve. In cases where methods change within a time-series, there should be an adequate overlap and intercomparison period. There should also be careful choice/calibration of methods on any startup of new time-series.

Between-nation coordination and intercomparison of results (both in regions with overlapping sampling, and between separated regions) could be improved. Because of the importance of long-time scale and large spatial scale variability of marine ecosystems, there is great benefit in ensemble comparisons/contrasts among time-series from both adjoining and widely-separated ocean regions. PICES has been very effective in establishing a forum for this exchange, and a willingness of individuals and nations to participate. However, data-handling tools to facilitate collaborative analysis are not yet in place (this could be a valuable role for proposed PICES Regional Analysis Centres).

Value-added biological sampling could be conducted. Pacific monitoring programs that are now primarily focussed on physical oceanography and air-sea interaction (e.g., NEAR-GOOS, Argo) could be expanded at modest incremental cost to include biological measurements.

"State of the North Pacific" report

In the opinion of the breakout group leaders, there was general endorsement of the value of such a report, but some apprehension about capacity and infrastructure to ensure consistent and timely delivery of the proposed contents.

We concluded with a brief discussion of issues such as:

- Optimal ratio of fact to interpretation/opinion (the breakout group consensus was that some interpretation is desirable and necessary);
- Editorial/vetting structure;
- Frequency of publication/release: breakout group consensus is that there should be an annual report, possibly supplemented by less detailed releases at more frequent (quarterly) intervals;
- What contents? Suggestions follow:
  For a quarterly issue/update:
  - SeaWiFS composites
  - Real-time *in situ* data (where available)
  - CalCOFI plankton volumes, egg surveys
  - Preliminary (anecdotal) notifications of faunistic/floristic changes

  For a more extensive annual compilation and summary:
  - Pigment samples
  - Carbon chemistry
  - Plankton (phyto, microzoop, mesozoop) biomass and/or community composition (about 12-month time lag, may be possible for only a subset of samples, species)
  - Rate measurements and derived properties (e.g. productivity maps)
  - Fish larval surveys?
  - Results from recent retrospective & model analyses

Breakout Group 3: Fish, Squid, Crabs and Shrimps

Chairmen: Anne B. Hollowed and Suam Kim

Participants: Richard D. Brodeur, Cynthia Decker, Steven R. Hare, Patricia Livingston, Gordon A. (Sandy) McFarlane, Bernard A. Megrey, H. Geoffrey Moser, Yasunori Sakurai, Hiroyuki Sakano, Robert Spies, Qisheng Tang, Daniel M. Ware, AkihikoYatsu, Kees Zwanenburg

Introduction

The Fish, Squid, Crabs and Shrimps (FSCS) breakout group focused their discussion on three primary questions: What information should be examined? What is the availability of information? What is the most expeditious way to develop a PICES indices database to examine this information?

Presentations from workshop participants provided an overview of the availability of information from each of the PICES regions (see Section II for extended abstracts of individual presentations). These presentations provided strong evidence of the role of ocean variability in shifts in marine fish and shellfish community structure.

Candidate biological indicators

Collectively breakout group members supported the development of leading indicators of climate change based on four types of biological measures: shifts in production, shifts in growth or condition, shifts in distribution, and shifts in community structure.

Production

- Annual production
    - Recruitment
    - Egg and larval surveys
    - Juvenile surveys
    - Diet composition of key predators: available for most regions
- Estimates of biomass or abundance
    - Fishery independent surveys targeting species
    - Catch statistics for target species
    - Anecdotal information
        - Bycatch in fishery independent survey
        - Bycatch in commercial fishery for other species
    - Changes in predation mortality
    - Hatch-date distributions

Growth and condition

- Annual or semi-annual measures of growth
    - Size or weight at age
    - Daily and annual growth increments
- Annual or semi-annual measures of reproductive potential
    - Fecundity
    - Maturity at age
- Annual or semi-annual measures of larval condition
    - RNA/DNA ratios
    - Stable isotopes
    - Lipid content
    - Free fatty acids
- Food habits information
    - Shifts in diet composition
    - Shifts in percent fullness

Distribution

- Distribution by life history stage
    - Range-wide by species
    - Range-wide by species by age or size
    - Index regions
        - spawning habitat
        - foraging habitat
    - Patchiness
    - Average area required to include the majority of the population (e.g. 75%)
    - Number of non-zero sets
- Migration pathways

Change in community

- Stock structure
  - Genetics
  - Parasites
  - Trace elements of otoliths
  - Morphology
- Species assemblages
- Food habits
  - Seasonal diet composition
  - Annual diet composition
- Diversity indices
  - Functional diversity
  - Species diversity
  - Average trophic level of the population

Candidate species

Upon review of the variety of biological indicators, breakout group participants realized that it would be unreasonable to suggest that each member nation should collect indices for all major species within each region. However, it might be reasonable to suggest that a smaller group of indicator species or indicator regions (in the case of community studies) would be comprehensively monitored on a regular basis (annually or semi-annually). Breakout group participants identified several candidate species for consideration in the PICES report:

- *Gadids*: walleye pollock, Pacific cod, Pacific hake
- *Small pelagics*: anchovy, Pacific sardine, chub mackerel, Pacific herring, Pacific saury, osmerids
- *Pacific salmon*
- *Sablefish*
- *Invertebrates*: common squid, selected crustaceans (e.g. king crab)
- *Rockfish* including thornyheads
- *Flatfish:* Pacific halibut, small mouthed flounders
- *Small yellow croaker*
- *Lightly exploited or non-commercial species:* sharks, myctophids
- *Commercially exploited sharks*

North Pacific Ecosystem Bio-Physical Meta-database and "State of the North Pacific" report

A major impediment to the development of the PICES "State of the Ocean" report is that it would require an infrastructure to access information from each member nation. One possible solution to this problem would be for PICES to suggest a rapid method for identifying and updating annual information from each member nation.

Dr. Megrey presented an overview of the Bering Sea Ecosystem Biophysical Metadatabase (http://www.pmel.noaa.gov/bering/mdb/). It was developed for the Bering Sea, however, it could be expanded to encompass other PICES regions. The BSEBM allows researchers to search for information by region using key words. Once a data set is identified, the user can access the data if the contributor volunteers a web-accessible link to information. In theory, the BSEBM platform could operate as a distributed database for rapid access to summarized information from each member nation. This platform would provide a possible mechanism for expediting the development of a summary of biological indicators on an annual basis. Based on this possibility the group made the following recommendations.

Recommendations

1. Workshop participants should encourage member nations to submit information on observational time series and analytical products to the North Pacific Ecosystem Bio-Physical Meta-database by the next PICES Annual Meeting.
2. A sub-group should be formed to establish protocols to facilitate searches for specific data types and indices (e.g., key word dictionary).
3. Each member nation will collect a suite of leading indicators of ecosystem patterns and trends. Time series of this sub-set of indicators will be provided to PICES.
4. PICES will require an individual to summarize this information into an annual report on the status of the North Pacific.

Remaining Questions

What are the gaps in information?

- For some transboundary species in the western Pacific, fisheries statistics are spatially limited and information is missing for some regions;
- Data is limited for non-commercially exploited species, particularly small pelagic species (e.g., myctophids, osmerids and squid) that are not well sampled by standard surveys;
- A variety of different gears and mesh sizes are needed to measure the diversity of species in the system;
- Seasonal coverage is limited which impacts our ability to evaluate the ontogenetic movements of fish.

What time-series are particularly informative for understanding or evaluating climate changes in biodiversity?

- Research survey CPUE by species;
- Bycatch data from fisheries observers - caution should be used when interpreting these data because a variety of factors influence the catch rates;
- Spatial distribution of total effort by fisheries (see caution above);
- Time-series of fish prices and associated landings;
- Species composition and catch rate from ichthyoplankton surveys.

What types of analyses or models are useful for best understanding climate related changes in biodiversity?

- Analysis of the spatial distribution of fish relative to environmental characteristics;
- Retrospective studies based on trends in stock production;
- Examine a variety of species diversity indices (e.g., slope of the size spectrum, Shannon-Wiener index, species richness) relative to a suite of environmental indices;
- Nested statistical models relating biological time series with environmental co-variates (recruitment, growth etc.);
- Changes in functional groups.

How can PICES facilitate and coordinate the collection and analysis of information for producing a North Pacific-wide ecosystem status report based on our time series and analytical products?

- Improve intra-national cooperation and coordination through symposia and workshops;
- Can TCODE members be charged with this responsibility?
- Recommend the formation of a cooperative group to enhance the exchange of information on transboundary stocks and oceanic species (e.g., Pacific pomfret and flying squid).

Breakout Group 4: Highly Migratory Fishes, Seabirds and Marine Mammals

Chairmen: Hidehiro Kato and Jeffrey J. Polovina
Rapporteur: Stewart (Skip) M. McKinnell

Participants: Richard J. Beamish, Douglas F. Bertram, Phillip R. Mundy, Robert Olson, Hiroshi Ueda, Yutaka Watanuki, David W. Welch

Time-series and their recent trends presented by species groups

Salmon

The North Pacific Anadromous Fisheries Commission (NPAFC) has agreed to provide salmon abundance information to the PICES Ecosystem Status Report. Their first contribution to the report will be prepared at the NPAFC research planning and coordinating meeting in Seattle, in March 2001. Historical catches of salmon in Canada, Japan and the United States, were reported annually to the INPFC from 1952-1992. With the creation of NPAFC in 1993, Russia became a member nation, and Russian catch statistics have been reported annually, as have hatchery release statistics. In the absence of NPAFC data, salmon experts in our breakout group noted the following:

- Coho, chinook and steelhead catches declined somewhat synchronously in the coastal northeastern Pacific during the 1990s.
- Coho and chinook abundance in the past several years show evidence of increasing in Washington/Oregon.
- High sockeye returns to the Fraser River in 2001 have been forecast.
- Alaska salmon in central/southeast have generally increased in abundance and variance in the 1990s.
- Chum/chinook survival in the Yukon River in recent years is low and certain populations have been extirpated.
- PSMFC coded wire tagging database exists from 1974 to present.
- Salmon catches in western Alaska have gone from consistently high abundance to exhibiting much higher variance.
- The Japanese salmon catch peaked in 1997 and a sharp decline occurred thereafter. Masu salmon have persisted at very low levels since the 1960s.
- National Salmon Resources Center has been established to replace the National Research Institute of the Hokkaido Salmon Hatchery.

Seabirds

- Pacific Seabird Group and USGS have established a database of seabird time-series for the entire North Pacific and that will be accessible on the web.
- Cassin's auklet population, monitored at Triangle Island (central British Columbia) since the 1970s, has exhibited a long-term decline. However, in 1999/2000 the reproductive rate sharply increased.
- No indication of changes at Frederick Island (northern British Columbia) for the same species.
- In Japan, time-series of Black-tailed gull and slaty-back gull abundance are available since 1980, and for rhinoceros auklet and Japanese cormorant since about 1984. The data show interannual variability but no evidence of trends.
- Reproductive success of black-footed and Laysan albatrosses, measured at French Frigate Shoals since 1980, remained generally stable for both species since the early 1980s, but sharp declines have been observed in the last few years.

Marine mammals

- Whaling statistics (operational time budget, length, sex, stomach contents, blubber thickness) are available from the 1950s to 1987 through the International Whaling Commission (IWC), and since 1996, data from Japan research whaling is collected by the Japan Far Seas Laboratory in Shimizu. Systematic sighting surveys are available since 1982 from dedicated surveys, largely in the western Pacific, conducted by the National Research Institute of Far Seas Fisheries (NRIFSF), Shimizu. Also, platform-of-opportunity (POP) sighting surveys were conducted largely by U.S. researchers since the mid-1970s in the eastern Pacific. Shore-based censuses are available in specific locations (e.g., North American gray whales). Orca abundance and distribution is assessed in North American coastal waters.
- Grey whales are fully recovered after approaching near extinction. Bowhead whale monitoring has detected an increase in abundance.
- Sperm whale abundance along the coast of Japan is estimated at 170,000 animals and has been increasing 6-11% per year. Sperm whale stomach samples have the potential to sample deep water squid status.
- Minke whale population is estimated at 23,000 animals and increasing in northwestern North Pacific. Prior to 1975, their diet was mainly mackerel or some similar schooling fishes in waters off the Pacific coast of Japan. By the late 1970s, it changed to Japanese pilchard and this status continued until 1987. From 1996 onward, their diet contained an abundance of Pacific saury or anchovy.
- For pinnipeds, rookery counts are typically used to gauge abundance, but in some areas

index of thickness of blubber is available. Steller sea lion have been declining in abundance in Alaska and the south Kuril Islands. There is no abundance information prior to the 1970s.

- Hawaiian monk seals in the northwestern Hawaiian Island chain have been monitored since the early 1980s. Monk seal pup girth decreased from the mid-1980s to the mid-1990s and increased after 1998.

Tunas

- Stock assessments on tuna species in the eastern tropical Pacific are available from the mid-1970s for yellowfin, skipjack, and bigeye. Model estimates of yellowfin tuna recruitment incorporate sea surface temperature (SST). There seems to be a relationship with tropical SST anomalies leading recruitment by 6 months. Large increases of yellowfin tuna followed the recent El Niño. Data on the average weight of the catch are available since 1975.
- Bluefin tuna spawn in the western Pacific and some migrate to the eastern Pacific. Catch data are available from 1960-1998 for purse seiners in the eastern Pacific and Japanese longline fishery largely in the western Pacific, from 1952-97. Japan's Far Seas Fisheries Lab is conducting a major archival tagging study of bluefin tuna.
- North Pacific albacore catch rate time-series from US troll vessels is maintained by NMFS/SWFSC and extends from 1960 to the present. The data show a drop in the catch rates in the mid-1970s to the mid-1990s, with an increase in the late-1990s.

Models

In the North Pacific, in recent years there have been numerous ECOPATH/ECOSIM models developed covering regional as well as gyre scales. Some are used to explore both bottom-up and top down forcing. The supporting documentation for these models contains a wealth of information on marine ecosystems across the North Pacific. In the breakout group, ECOPATH/ECOSIM models were presented for the Western Pacific Transition Zone and subarctic, Prince William Sound, Northwest Hawaiian Islands, and Eastern Tropical Pacific.

Dynamic ecosystem models such as ECOSIM can be useful in understanding mechanisms or hypotheses to explain observed time-series trends as well as in identifying species to monitor.

Habitats

In addition to monitoring trends in organism abundance, it may be useful to monitor the dynamics of oceanic habitats that are important to apex species foraging, reproduction or migration. This may include location, spatial scale, and intensity of specific fronts, eddies, and upwelling regions which have been identified as critical oceanic habitat.

Discussion points

Regarding what species are well monitored, commercially exploited species have the longest time-series. Formerly commercial cetacean species have rather good time-series of absolute abundance, especially minke whale. Some seabird series are also good (30 years at Farallon Is.).

Regarding what species would be best for comparative analysis of ecosystems, Rhinoceros auklets and salmon are found all around the Pacific Rim. However, if a monitoring program is to be set up, it may be best to establish a sampling project in a region that takes all trophic levels into consideration, rather than try to use the same species throughout the region.

Regarding parameters to monitor, characteristics such as birth/death rates, fecundity, school size, age at maturity, blubber thickness, and lipid contents may be more timely indicators of climate impacts than population size, since the latter integrates many years.

PICES can facilitate the writing of an ecosystem status report and include electronic version of the data; perhaps every year. For the first report, each country might nominate people to write the report.

CLOSING PLENARY DISCUSSION AND RECOMMENDATIONS

Participants discussed the common themes and gaps identified in the breakout group reports and made recommendations for PICES action on several items.

North Pacific Ecosystem Meta-database

The most common recommendation of the breakout groups dealt with ensuring that the time-series information and scientific contacts identified at the workshop be recorded and updated in the North Pacific Ecosystem Meta-database in which TCODE has already placed the PICES long-term time-series `information. This meta-database, originally titled the "Bering Sea Ecosystem Meta-database", was initiated by two US researchers to provide a means of promoting scientific collaboration and research on the Bering Sea. Direct links to data are only available if the researcher wishes to make it assessable. Otherwise, the meta-database provides information on who to contact about the data.

Participants endorsed the proposal that the existing meta-database be considered as the PICES North Pacific Ecosystem Meta-database. Presently, the database is maintained and updated by U.S. researchers through various funding sources that will be exhausted by the end of 2001. If it is to be considered as a PICES meta-database, then it was recommended that it be shown as a link on the PICES web site, even if it physically resides on a U.S. server at present.

Further discussion about the database involved details on how to ensure that keyword indices for the database are sufficiently detailed to obtain good quality data searches. It was recommended that TCODE examine the existing keyword indices of this database and suggest revisions. It was also recommended that TCODE explore the OBIS database system, which is being developed under funding by the Sloan Foundation's Census of Marine Life. TCODE should then determine whether the North Pacific Ecosystem Meta-database could be considered a contribution to the OBIS system or whether the Meta-database would require revision to be compatible with OBIS. Funds for future enhancements and maintenance of the meta-database might be obtained through written proposals to the Sloan, Packard, or W. Alton Jones Foundations, which might support this activity. The CoML funding announcement will be coming out in early fall 2001, but it was not clear whether the announcement would include this type of work.

Another issue surrounding the database was how to ensure information on all data (meta-data) presented at this workshop could be entered into the database. Sending database forms for participants to fill out and return might get very low response rates. Participants agreed that the optimal solution would be for the meta-data lists compiled at the meeting to be given to the present North Pacific Ecosystem Meta-database administrators. These people would then do follow-ups with individual researchers to ensure that all meta-data sources are entered into the Meta-database, using the keyword list agreed upon by TCODE.

Data gaps and exchange

It was clear from the breakout group presentations that there were data gaps for many groups, particularly for lower trophic level species. As found in data gathering efforts for other world oceans, there was a noticeable lack of long time-series information in both coastal and open ocean areas for benthic invertebrates, primary production, secondary production, micronekton and small pelagic fish biomass and dynamics. It was also obvious that data collection in the margins (continental shelves) was much denser than in the open ocean. Most sampling methodology used in the long time-series tend to be more traditional, low technology approaches such as continuous plankton recorders and net sampling.

As noted before in many PICES gatherings, participants recognized that no individual country could provide a complete sampling coverage of the open ocean. Nations need to pool observational resources in order to provide a complete program in these areas. One possibility would be to enhance or begin sampling temperature, salinity, chlorophyll-*a*, fluorometry, and plankton (through continuous plankton recorders and/or optical plankton counters) on ships-of-opportunity. It was recommended that MONITOR Task Team examine pilot projects of this nature and also consider projects for putting biological sensors on Argo floats and buoys, and using commercial fishing vessels for data gathering. Some of the technological and practical problems of adding biological sensors to buoys were mentioned. The Marine Mammal and Bird Advisory Panel (MBM) might also want to consider proposals or projects that relate to video monitoring of birds and mammals along CPR cruises and solving species identification and density estimation problems associated with such a program. Coordinated proposals or discussion between MBM and CPR panels and MONITOR Task Team for these projects should be planned. Technological advancements in various fields will also be the theme of the PICES Eleventh Annual Meeting in 2002, so some of these issues could be examined further at that meeting.

It was recommended that PICES make formal connections with programs that are planning coordinated, technologically-advanced observation and communication systems. The NEPTUNE underwater observatory for the northeast Pacific is a program initiated by the University of Washington that will be a contribution to the "Dynamics of Earth and Ocean Systems" planning effort of the US National Science Foundation. There also exists a separately funded Canadian NEPTUNE program led by several Canadian universities. Other nations, such as France, Germany and Japan, have expressed a strong interest in providing contributions to a global NEPTUNE program. The US Consortium of Oceanographic Research and Education (CORE) Task Team on Ocean Observations has prepared a report on an integrated ocean observation system that should be considered by PICES, and by MONITOR Task Team in particular.

It was also suggested that PICES further exploit scientific platforms-of-opportunity for filling data gaps. This would require more communication among PICES scientists about national cruise plans, particularly in international and transboundary waters, in order to provide more scientific exchange.

To address the technological difficulties in assessing small pelagic fish, it was recommended that FIS Committee consider a new working group to examine this problem and make recommendations on how to improve sampling of these important links in marine food chains.

There was mention of the idea that physical models could be used to fill historical gaps in the data record. Some examples were given of how this is being done by US researchers. Simulation models that include biology could be used to identify important ecosystem components that would warrant increased sampling effort. Other data gaps might be clearer once PICES completes one or two Ecosystem Status Reports and more recommendations might be made at that time with regard to filling identified gaps.

Data exchange was discussed as an issue to bring forward to Governing Council. MONITOR and TCODE, in particular, should consider specific data exchange issues and develop recommendations for Science Board and Governing Council to consider. There was also data exchange issues discussed in relation to the WMO Data Buoy Cooperation Panel. Presently, there are separate web sites and access for buoy data from various PICES nations. It would be of great value to those making ocean predictions to have these data sources joined and linked, through the work of a North Pacific Data Buoy Cooperation Panel, and then linked to the PICES web site.

North Pacific Ecosystem Status Report and Regional Analysis Centers

There was general recognition that the initial North Pacific Ecosystem Status Report would take the form of a "quick" report that might omit substantial interpretation of the observed trends. Some components of the report, such as physical oceanography and atmospheric information, might be updated more frequently (e.g., quarterly) than other components such as fish stock assessments that might be carried out on an annual time frame. Thus, one possibility would be that the report might be updated quarterly on the PICES web site for some components but less frequently for other components. There would also need to be further work on future reports to decide how to provide objective interpretation and expert opinion of the trends to decision-makers. This is an area that is actively being worked on in some PICES countries and by ICES. We may need to have future workshops to refine a set of quantitative ecosystem change indicators and methods for synthesizing and interpreting results of these change indicators for a target audience that might consist of the interested public and policy- and decision-makers in PICES countries.

Details regarding actual production of the report were discussed. One suggestion was that the analyses should be done and the report prepared by PICES. Another idea was that report sections would be prepared by co-lead authors, one from each side of the North Pacific. Some thought that what we would be doing was similar to what the Intergovernmental Panel on Climate Change (IPCC) is doing. This group bases its assessment mainly on published and peer-reviewed scientific technical literature and individuals contribute ideas. IPCC working group group reports are prepared by co-leaders, with many experts that represent a balance of geographic areas. There is an effort to achieve consensus in the reports and then a set of procedures is followed to accept and approve the report, first by the working group and then by the IPCC. Reports are reviewed by experts and by governments before a final draft is prepared for approval by the IPCC. A summary for policymakers is also prepared and approved. A recommendation was made to contact ICES to look at their structure and procedures for stock and environmental assessments and also how they are proceeding with providing ecosystem advice.

There was a suggestion that the procedure should be to get PICES and other international organizations and their experts together to agree on an assessment. The assessment would then adopt the practice used in stock assessment reviews, where a draft document is provided about 6 months before the meeting for review. A final, revised draft would then be prepared for approval at the annual meeting. The PICES-GLOBEC Climate Change and Carrying Capacity (CCCC) Program was mentioned as the primary PICES group that should be performing these assessments, though it should also be recognized that PICES Working Groups and Advisory Panels would also provide important scientific input to these reports.

The concept of Regional Analysis Centers (RACs) was discussed as a way for PICES to have a central focus for supporting the work involved in producing an Ecosystem Status Report. Participants mentioned two different ways of viewing these centers. One type of RAC would be an actual geographic location and building with staff assigned to it. The other view was that it could be thought of as a virtual entity, such as the Human Genome Project, where a variety of organizations and individuals contribute to the work even though they may not be housed in a common center. (It should be noted that post-workshop review of this revealed that this Project is actually operated in the U.S. through a research institute whose function is to coordinate the research, which may be performed either internally or by other institutions.)

Similarly, the Space Environment Database and Analysis Tools project was mentioned as another model. This project is carried out by the Central Laboratory of the Research Councils of the United Kingdom, which provides the building space for outside researchers, plus its own technical experts to work on joining and interpreting data. Funding for this Central Laboratory is provided mainly by the other Research Councils of the U.K.

Finally, participants thought that although the RAC concept would draw heavily upon a distributed network of scientists to contribute to the work, some central support would still be required to accomplish the work. Initially, one person in the PICES Secretariat might be sufficient to organize and coordinate the work involved in producing an Ecosystem Status Report.

Section II

EXTENDED ABSTRACTS OF INDIVIDUAL PRESENTATIONS AT BREAKOUT GROUP SESSIONS

GROUP 1: PHYSICAL /CHEMICAL OCEANOGRAPHY AND CLIMATE

CalCOFI hydrographic climatology

Steven J. Bograd
NOAA/NMFS, Pacific Fisheries Environmental Laboratory, 1352 Lighthouse Avenue, Pacific Grove, CA 93950, U.S.A. E-mail: sbograd@pfeg.noaa.gov

Introduction

Routine oceanographic sampling within the California Current System has occurred under the auspices of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) since 1949, providing one of the longest existing time-series of the physics, chemistry and biology of a dynamic oceanic regime. All data are now available on a CalCOFI CD-ROM, obtainable from the Scripps Institution of Oceanography (for details see http://www.calcofi.org). The principle objective in preparing the CD-ROM was to make these data easily accessible to the general oceanographic community, as well as to provide a baseline data set from which water property anomalies can be computed and compared between regions along the West Coast. Thus, in addition to providing the 50-year dataset, we also include a climatology of the CalCOFI hydrographic data, as well as a program for computing the mean values of various physical variables at any given location within the CalCOFI domain and for any day of the year. (Data and software are also available directly from the website noted above.)

Data

The historical CalCOFI sampling grid extends from the southern reaches of Baja California northward to the California-Oregon border, and out to several hundred kilometers offshore, with 36 nominal lines oriented approximately perpendicular to the coastline. Stations are designated by a line and station number (e.g., 77.60 is station 60 on line 77). Nominal station spacing is approximately 70 km offshore (e.g., distance between 77.60 and 77.70), but is considerably less inshore of station 60. The greatest spatial and temporal coverage occurred during the early years of the program (1950-1960), when multi-vessel cruises occupied significant portions of the grid at monthly intervals (Moser *et al.* 1988). Quarterly surveys were conducted annually from 1961 to 1965, with target months of January, April, July and October. Monthly coverage was resumed, but only triennially, between 1966 and 1984. Measurements were made on over 23,000 stations on this grid over the 35-year period from 1949 to 1984. Through 1964, standard station sampling consisted of 12- to 18-Nansen bottle casts mostly to 500-m depth (and occasionally to 1,200 m or 2,000 m). STD or CTD casts were taken subsequently, often in conjunction with a Nansen cast or with several water-bottle samples for calibration (Lynn *et al.* 1982). Values of oceanographic parameters were interpolated to standard depths. All data from observed and standard depths are published in Scripps Institution of Oceanography data reports.

The present CalCOFI grid, a subset of the historical grid which has been occupied quarterly since 1984, comprises nearly 7,500 station occupations (through January 2001) from six nominal lines between San Diego and Point Conception. Routine station activities include CTD/rosette casts to 500-m depth, bottom depth permitting, with continuous measurements of pressure, temperature, conductivity, dissolved oxygen and chlorophyll fluorescence. Water samples are collected at 20 depths, with variable spacing depending on depth of the chlorophyll, oxygen and salinity extrema and the thermocline depth (Hayward and Venrick 1998). Salinity, oxygen and nutrients are determined for all sampled depths, while chlorophyll-*a* and phaeopigments are determined within the top 200 m, bottom depth permitting. Details of the standard sampling and analysis procedures can be found in any of the recent CalCOFI data reports, e.g., SIO (1999).

Methods

The CalCOFI CD-ROM and website include climatologies of the hydrographic data. We describe the mean seasonal variability of 7 hydrographic variables (temperature, salinity, density, oxygen concentration, oxygen saturation, dynamic height anomaly and spiciness) at 14 standard levels (0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500 m) for all stations within the CalCOFI dataset for which sufficient data exist. Spiciness, as defined by Flament (1986), is a state variable (units of σ_t) that is most sensitive to isopycnal thermohaline variations and least correlated with the density field. It is conserved in isentropic motions, and is defined to be largest for warm and salty water.

Our approach follows that of Lynn (1967) and Lynn *et al.* (1982), in which the mean seasonal variation is obtained by a least squares regression of the data to annually periodic sinusoids. Since the time intervals between measurements are irregular, and typically consist of 3-4 month gaps, we restrict our harmonic analysis to include only the annual and semiannual harmonics. The general form of the regression curve is:

$$Y = A_1\cos\Phi + B_1\sin\Phi + A_2\cos2\Phi + B_2\sin2\Phi + C,$$

where Φ is the angular equivalent of the day of the year in radians, and C is the annual mean value. In the least squares regression, the sum of the squares of the data anomalies from the regression curve is minimized with respect to each of the five coefficients, with the resulting set of equations solved simultaneously for the coefficients (Lynn 1967). In order to maintain sufficient data for performing the regression, the criterion of at least 5 occupations (for a given variable, at a particular station and standard depth) were required within each 60-day period of the time series.

The files containing the derived harmonic coefficients for each station, standard depth and variable for which sufficient data exist are included on the CD-ROM. These files are used to compute the mean values for a selected variable, station, standard depth and day of year, or to compute anomalies for a particular set of measurements.

Climatological base periods

Not all stations within the CalCOFI region have been regularly occupied since 1949. As mentioned above, there have been several fundamental changes in the areal extent of the nominal sampling grid, with the latest change occurring in 1984. It was therefore necessary to construct several climatologies that represent different portions of the region over different baseline periods. For the period 1950-1984, harmonic coefficients were computed for all stations on the entire historical grid, from Baja California to northern California, which had sufficient data. The harmonic analysis was performed on only those data from the present grid for two additional baseline periods: 1950-1999 and 1984-1999. The latter base period was chosen because it represents the period in which various changes in sampling methods and strategies were employed.

Tables of monthly mean values of each of the physical variables for the periods 1950-1984 (historical grid) and 1950-1999 (present grid), for all stations and standard depths for which sufficient data exist, are included on the CD-ROM. We also included coefficient files for the base periods 1950-1976 and 1977-1999 for all stations within the present grid, as these represent both sides of an observed “regime shift” in Pacific climate (e.g., Trenberth and Hurrell 1994; Francis and Hare 1994), and may be of use in diagnosing decadal variability in the region.

We encourage caution when using these climatologies to determine anomalies from independent observations made along the West Coast. The choice of baseline period has a significant effect on the derived mean values (Figs. 1 and 2), due primarily to an upper-level warming and freshening trend in the Southern California Bight over the past 20 years.

References

Flament, P. 1986. Subduction and finestructure associated with upwelling filaments. Ph.D. dissertation, University of California, San Diego 123p.

Francis, R.C., and Hare, S.R. 1994. Decadal-scale regime shifts in the large marine ecosystems of the northeast Pacific: A case for historical science. Fish. Oceanogr. 3: 279-291.

Hayward, T.L. and Venrick, E.L. 1998. Nearsurface pattern in the California Current: Coupling between physical and biological structure. Deep-Sea Res. II 45: 1617-1638.

Lynn, R.J. 1967. Seasonal variations of temperature and salinity at 10 meters in the California Current. CalCOFI Rep. 11: 157-174.

Lynn, R.J., Bliss, K.A. and Eber, L.E. 1982. Vertical and horizontal distributions of seasonal mean temperature, salinity, sigma-t, stability, dynamic height, oxygen, and oxygen saturation in the California Current. 1950-1978 CalCOFI Atlas No. 30.

Moser, H.G., Charter, R.L., Smith, P.E., Ambrose, D.A., Charter, S.R., Meyer, C.A., Sandknop, E.M. and Watson, W. 1988. Distributional atlas of fish larvae and eggs in the California Current region: Taxa with 1000 or more total larvae. 1951 through 1984, CalCOFI Atlas No. 31.

Scripps Institution of Oceanography, University of California. 1999. Physical, Chemical and Biological Data, CalCOFI Cruises 9802, 9803, 9804, 9805 and 9806, SIO Ref. 99-9 160p.

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

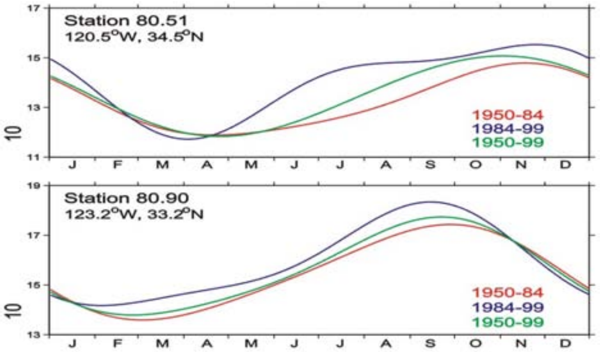


Fig. 1 Harmonic means of 10-m temperature at CalCOFI stations 80.51 (inshore) and 80.90 (offshore) for different base climatologies.

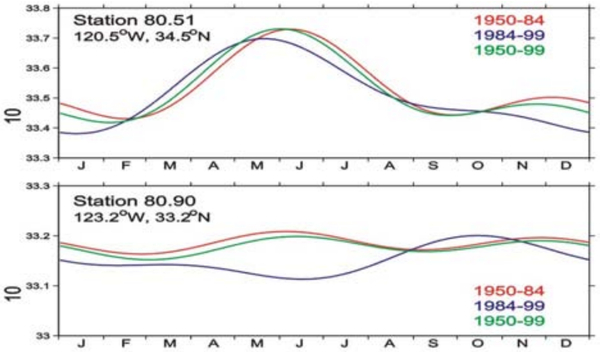


Fig. 2 Harmonic means of 10-m salinity at CalCOFI stations 80.51 (inshore) and 80.90 (offshore) for different base climatologies.

Improving access to environmental datasets: Data holdings at Pacific Fisheries Environmental Laboratory

Lynn deWitt and Roy Mendelssohn

Pacific Fisheries Environmental Laboratory, NOAA/NMFS, 1352 Lighthouse Avenue, Pacific Grove, CA 93950, U.S.A. E-mail: ldewitt@pfeg.noaa.gov; rmendels@pfeg.noaa.gov

Introduction

Research in oceanography and other environmental sciences often involves obtaining data from many sources. Unfortunately, these data are usually in multiple formats, causing investigators to spend a discouraging amount of their research time reducing data to a form useful for analysis. In addition, it is rarely possible to obtain only the small subsets of data that are pertinent to their research. This problem is often particularly acute in fisheries research, where investigators may not have familiarity with oceanographic datasets and appropriate means of subsetting them (Boehlert and Schumacher 1997). At the Pacific Fisheries Environmental Laboratory

(PFEL), we are working to provide environmental data to investigators in a more usable form.

PFEL, a component of the National Marine Fisheries Service (Southwest Fisheries Science Center), specializes in analyzing the effects of environmental variability on fisheries. Due to its cooperation with the Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC) and other data centers, PFEL has a wide variety of oceanographic and atmospheric datasets that are relevant to many areas of fisheries science, marine resource management, and climate change in the ocean. For many years, PFEL has supplied extracts from these datasets to users around the world, and has also developed a number of derived products from these datasets. These have been used in many areas of research. Currently PFEL is increasing the number of datasets available and improving access to these datasets by converting them to common formats and making them readily available over the Internet.

PFEL receives both observational data and gridded model output in near-real time (Table 1). These data include: Global Telecommunications System (GTS) surface observational data; Global Temperature-Salinity Profile Program (GTSPP, Hamilton 1994) subsurface data; and FNMOC operational forecasts of the state of the atmosphere and ocean. PFEL also maintains the World Ocean Database (WOD98, Levitus *et al.* 1998) and Comprehensive Ocean-Atmosphere Data Set (COADS, Slutz *et al.* 1985). Each data set arrives at PFEL in its own native format, each requires a different set of extraction software, and each presents its own unique problems in attempting to organize, extract, subset and distribute the data. Detailed descriptions of each currently held data set and the methods employed to place them in common formats are available in the unabridged version of this data summary (deWitt and Mendelssohn 2001), available from PFEL.

Data products

PFEL makes available a variety of products derived from the observational products and Fleet Numerical Meteorology and Oceanography Center (FNMOC) model output. Most of these products can be obtained on the Live Access Server (described below).

Table 1 PFEL Data Holdings. G or O refers to (G) Gridded derived (model output) data or (O) non-gridded observational data. Dimensions are (L)Latitude by (L)Longitude by (D)Depth by (T)Time. All data generally have global coverage, except for FNMOC SLP, which, for the years 1967 - 1981, is only available for the Northern Hemisphere. Observational (O) data, although available globally, is often locally sparse.

Data Set	Native Format	Frequency of Arrival at PFEL	Monthly Storage Required	G or O	Availability Dates	Dimensions
GTS Surface	BUFR	hourly	500Mb[1]	O	Jan 1997 - present	LxLxT
GTSPP Subsurface	MEDS	monthly	8Mb	O	Jan 1990 - present	LxLxDxT
FNMOC						
Sea Level Pressure	GRIB	6 hrs	10Mb	G	Jan 1967 - present	LxLxT
Surface Winds (20 m)	GRIB	12 hrs	18Mb	G	Jul 1998 - present	LxLxT
Surface Winds (10 m)	GRIB	bimonthly	9Mb	G	Nov 1999 - present	LxLxT
Geopotential Height	GRIB	6 hrs	14Mb	G	Jul 1998 - present	LxLxT
World Ocean Database 1998 Standard Level Data	NODC/ OCL	Archived	1541Mb Total[2]	O	Jan 1950 - Dec 1994	LxLxDxT

[1] Uncompressed, compressed size is 50 megabytes (Mb)

[2] Total uncompressed size for all probe types for standard level data for entire period of availability (from Conkright *et. al*. 1998, appendix 12A).

Historical products

On a monthly basis, PFEL generates indices of the intensity of large-scale, wind-induced coastal upwelling at 15 standard locations along the west coast of North America (3-degree intervals, 21°N to 60°N). The indices are based on estimates of offshore Ekman transport driven by geostrophic wind stress (Bakun 1973; Schwing *et al.* 1996). Geostrophic winds are derived from monthly averages of six-hourly FNMOC surface atmospheric pressure fields. The following monthly products are available for subsetting and downloading (upwelling index and along-shore transports are also available as 6-hourly and daily averaged values) for 1967 to the present:

- Surface Atmospheric Pressure
- North-South component of surface wind
- East-West component of surface wind
- North-South component of wind stress
- East-West component of wind stress
- Curl of surface wind stress
- Cube of wind speed
- North-South component of Ekman Transport
- East-West component of Ekman Transport
- Offshore Ekman transport (Upwelling index)
- Vertical Velocity into Ekman Layer
- Sverdrup Wind Stress Curl Transport

In recent years, PFEL has re-calculated upwelling indices and transports, updating the procedure to include averaging the 6-hourly transport fields rather than computing the fields from the averaged pressure, and eliminating the earlier 3°-grid limitation. In order to offer a consistent time-series to those who have been using PFEL products for a number of years, both the historical and new products remain available and are updated monthly.

Near real-time six-hourly products

Six-hourly products from the current and previous month (sea level pressure, geostrophic wind, wind stress and upwelling index) are available for viewing and download on PFEL's web page ("www.pfeg.noaa.gov", click on the "Upwelling/ Environmental Indices" button, then "Current Month's Six-hourly Products") and Live Access Server (see below). These products are automatically updated daily and include the current day's 0600Z pressure field.

Global upwelling index

From the new monthly pressure-derived products, Live Access Server users can calculate a time series of upwelling index (off-shore component of Ekman transport) for any coastal location in the Northern Hemisphere (1967-1980) and globally (1981-present). The user must provide latitude, longitude and the angle the coastline makes with a vector pointing north. A Ferret script rotates the Ekman transport in the desired direction and returns a time series at the desired location which can be viewed or downloaded.

*Extratropical Northern Oscillation Index (*NOIx*)*

Monthly values of the NOIx (extratropical Northern Oscillation Index) and its analog, the SOIx (extratropical Southern Oscillation Index), along with the traditional Southern Oscillation Index (SOI) are available for viewing and downloading on PFEL's web page ("www.pfeg.noaa.gov", click on the "Upwelling/Environmental Indices" button, and scroll down to "Other Environmental Indices") for 1948 to the present. The NOIx and SOIx are new indices (Schwing *et al.* 2001) of mid-latitude climate fluctuations that are useful for monitoring and predicting climate fluctuations and their physical and biological consequences in the Northeast Pacific.

Mixed layer depth

Monthly mixed layer depth and mixed layer depth climatology computed from the WOD98 (Levitus *et al.* 1998) standard level data are available on the Live Access Server. Mixed layer depth is computed using two different criteria (Monterey and Levitus, 1997; Monterey and deWitt, 2000) from individual WOD98 profiles, then averaged on a 1-degree latitude/longitude grid. The two criteria are: (i) a temperature criterion: mixed layer depth is determined as the depth at which the temperature falls to 0.5°C below the surface temperature, and (ii) a density criterion: mixed layer depth is determined as the depth at which the density difference from the sea surface is 0.125 σ_t units.

Table 2 Products currently available on the PMEL's Live Access Server.

Name of Dataset	Dates available	Types of Measurements/Depths
GTS Sea Surface Observations	Jan 1997 – present	Sea Surface Temperature SST Anomaly Number observations in the means
GTSPP Subsurface Temperature		Temperature at 18 standard depths (10 - 1000 m)
Real Time	Aug 1996 – present	Depths of 14 and 10-degree isotherms
Best Copy (Delayed Mode)	Jan 1990 - Dec 1998	
FNMOC Sea Level Pressure		Pressure reduced to mean sea level
1-degree model output	Nov 1996 - present	
Interpolated from larger mesh	Jan 1967 - Oct 1996	
FNMOC Surface Winds		Wind components and magnitude
10 m	Nov 1999 - present	Wind Stress components and magnitude
20 m	Jul 1998 - present	Wind Stress curl
FNMOC Geopotential Height	Jul 1998 - present	Geopotential Height at 500 mb
World Ocean Database 1998	Jan 1950 - Dec 1990	
Observational means		Temperature at 33 standard depths (0 - 5500 m)
	Jan 1945 - Dec 1994	Temperature and salinity climatology (0 - 5500 m)
Mixed Layer Depth		Mixed layer depth and mixed layer depth Climatology using two criterion
PFEL Derived Products		
PFEL "Historical" Products		
Upwelling index (N. America)		Upwelling index and along shore transport at 15 Locations along the E. North Pacific coast
Monthly	Jan 1946 - present	
Daily and 6-hourly	Jan 1967 - present	
Monthly Wind products	Jan 1967 - present	Winds, speed cubed, wind stress, wind stress curl, Ekman Transport at 15 locations along the E. North Pacific coast computed from monthly sea level pressure
Environmental Indices	Jan 1948 - present	Monthly NOIx, SOIx, SOI
Global Upwelling Index		
SLP and wind products	Jan 1967 – present	Winds, wind stress, wind stress curl, and Ekman Transport computed from 6-hourly sea level pressure
Upwelling index	Jan 1967 - present	Upwelling index (calculated using user-supplied Coastline geometry)
Near Real-time Six-hourly		
SLP and wind products	Current month	Winds, wind stress, wind stress curl, and Ekman Transport computed from 6-hourly sea level pressure
Upwelling index	Current month	Upwelling index at 15 North American and 11 South American coastal locations

Live access server

PFEL has implemented a version of PMEL's Live Access Server (LAS) (Hankin *et al*. 1999, and ferret.wrc.noaa.gov/Ferret/LAS/) which allows users to visualize, subset, and extract PFEL's data products over the Internet (deWitt and Mendelssohn, 1999 and "www.pfeg.noaa.gov"). The LAS is designed to handle gridded fields, preferably in netCDF format. As part of our routine monthly processing most PFEL standard and derived products are converted to netCDF by appending a month's worth of data onto pre-existing netCDF files. Products currently available on the LAS are listed in Table 2. Unless specified otherwise, all products are available as monthly summaries on a 1-degree grid.

In order to make observational data available on the LAS, we calculate 1-degree monthly means at standard depths. For the monthly GTS data we have so far only made temperature means available on the LAS, but these include number of observations, monthly anomalies and an attempt at some quality control. The GTSPP netCDF files include number of observations and depths of the 10- and 14-degree isotherms.

Although all the standard level WOD98 data has been converted to HDF-EOS format, we are presently only serving part of it to our users. The amount of data below 1,000 m does not justify the storage required in gridded format. For these reasons, and since we have GTSPP subsurface data available starting in 1990, our WOD98 products include monthly 1-degree summaries of temperature for the upper 1,000 m (19 depths) for the years 1950-1990. The size of the WOD98 makes it prohibitive to save the gridded product in a single netCDF file. We store the data in 51 yearly files (118.2 Mb each for a total of 6 gigabytes), and use the multi-netCDF feature of Ferret to visualize and subset the files with the LAS. In addition to the monthly temperature summaries, monthly climatologies of temperature and salinity are also available on the LAS, and we hope to make other variables available in the future.

Since gathering the supporting data can be the most time-consuming part of a research project, improvements in the time and effort necessary to access and subset environmental data products can be a great benefit to research in fisheries, oceanography, meteorology and other fields. At PFEL, by carefully choosing the formats in which we store our data, we are striving to make data products available to users in ways that are multi-platform, inexpensive and user friendly.

References

Bakun, A. 1973. Coastal upwelling indices, west coast of North America, 1946-71. U.S. Dept. of Commerce, NOAA Tech. Rep., NMFS SSRF-671, 103p.

Boehlert, G.W., and Schumacher, J.D. 1997. Changing Oceans and Changing Fisheries: Environmental Data for Fisheries Research and Management. NOAA Tech. Memo. NOAA TM-NMFS-SWFSC-239, 146p.

Conkright, M.E., Levitus, S., O'Brien, T., Boyer, T.P., Stephens, C., Johnson, D., Stathoplos, L., Baranova, O., Antonov, J., Gelfeld, R., Burney, J., Rochester, J., and Forgy, C. 1998. World Ocean Database 1998. NODC Internal Report 14, 113p.

deWitt, L., and Mendelssohn, R. 1999. Live Access Server visualizes, subsets and extracts oceanographic data. Earth System Monitor Vol. 10, No. 1.

deWitt, L., and Mendelssohn, R. 2001. Improving access to environmental datasets: Data holdings at Pacific Fisheries Environmental Laboratory. Ocean and Atmosphere Data Management submitted.

Hamilton, D. 1994. GTSPP builds an ocean temperature-salinity database: Technology and international cooperation improve access to global ocean data. Earth System Monitor Vol. 4, No. 4.

Hankin, S., Harrison, D.E., Sirott, J., Manke, A., Callahan, J., Davison, J. and O'Brien. K. 1999. Ferret and the Live Access Server. Earth System Monitor Vol. 9, No. 3.

Levitus, S., Boyer, T.P., Conkright, M.E., O'Brien, T., Antonov, J., Stephens, C., Stathoplos, L., Johnson, D., and Gelfeld, R. 1998. NOAA Atlas NESDIS 18, World Ocean Database 1998: Vol. 1: Introduction, U.S. Gov. Printing Office, Wash., D.C. 346p.

Monterey, G., and Levitus, S. 1997. Seasonal variability of mixed layer depth for the World Ocean. NOAA Atlas, NESDIS 14, 100p.

Monterey, G., and deWitt, L.M. 2000. Seasonal variability of global mixed layer depth from WOD98 temperature and salinity profiles. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-296.

Schwing, F.B., O'Farrell, M.O., Steger, J., and Baltz, K. 1996. Coastal Upwelling Indices, West Coast of North America 1946 – 1995. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-231, 207p.

Schwing, F.B., Murphree, T., and Green, P.M. 2001. A climate index for the northeast Pacific. Progress in Oceanography (in press).

Slutz, R. J., Lubker, S.J., Hiscox, J.D., Woodruff, S.D., Jenne, R.L., Joseph, D.H., Stuerer, P.M., and Elms, J.D. 1985. Comprehensive Ocean-Atmosphere Data Set; Release 1, NOAA Environmental Research Laboratories. Boulder, CO, NTIS PB86-105723, 268p.

Japanese repeat hydrographic lines in the North Pacific

Kimio Hanawa

Department of Geophysics, Graduate School of Science, Tohoku University, Aoba, Sendai 980-8578, Japan. E-mail. hanawa@pol.geophys.tohoku.ac.jp

Introduction

In this report, we introduce the present (2001 fiscal year) status of repeat hydrographic lines in the North Pacific conducted by the Japan Meteorological Agency (JMA), Hydrographic Department/Japan Coast Guard (HD/JCG), Japan Fisheries Agency (JFA) and Faculty of Fisheries, Hokkaido University (HU). The information is provided by Koichi Ishikawa (JMA), Hiroyuki Yoritaka (HD/JCG), Shin-ichi Ito (JFA) and Yutaka Isoda (HU).

Repeat lines by JMA

Long lines

JMA currently maintains two long repeat sections (Fig. 3):

1. 137°E line by the R/V *Ryofu Maru* and the R/V *Keifu Maru*
   - 1.1. every winter since 1967, every spring since 1989, every summer since 1972, and every autumn since 1992;
   - 1.2. interval of 1 degree in latitude from 34°N to 3°N;
   - 1.3. from surface to 2,000 m or bottom (every 5 degrees); temperature (T), salinity (S), oxygen (O_2), total carbonate, nutrients and others.
2. 165°E line by the R/V *Ryofu Maru* and the R/V *Keifu Maru*
   - 2.1. once a year since 1996, and twice a year since 2001;
   - 2.2. interval of 1 degree in latitude from 50°N to 3°S;
   - 2.3. from surface to 2,000 m or bottom; T, S, O_2, total carbonate, nutrients and others.

Short lines

JMA currently supports the following short repeat lines (Fig. 3):

1. PH line, along 41.5°N, south of Hokkaido, by the R/V *Kofu Maru*
2. 144°E line, along 144°E, east of Honshu, by the R/V *Kofu Maru*
3. PM line, northwest of Echizenmisaki, Japan sea, by the R/V *Seifu Maru*
4. "G" line, northwest of Sado, Japan sea, by the R/V *Seifu Maru*
5. PN line, northwest of Okinawa, East China Sea, by the R/V *Chofu Maru*
6. TK line, Tokara Straits, south of Kyushu, by the R/V *Chofu Maru*
7. "OK" line, southeast of Okinawa, south of Okinawa, by the *R/V Chofu Maru*
8. "ASUKA" line, southeast of Ashizurimisaki, south of Shikoku, by the R/V *Ryoufu Maru* and the R/V *Keifu Maru*

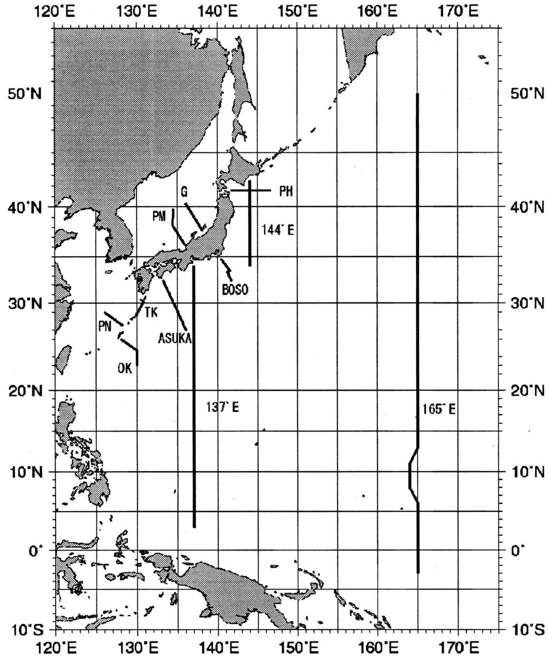


Fig. 3 Repeat lines currently conducted by JMA.

9. "BOSO" line, southeast of Boso Peninsula, east of Honshu, by the R/V *Ryofu Maru* and the R/V *Keifu Maru*

These lines are sampled at an interval of 3 months, *i.e.*, four times a year, with almost the same set of observations as at the long repeat sections.

Repeat lines by HD/JCG

Long lines

The following two long repeat sections have been maintained by HD/JCG (Fig. 4). Unfortunately, the 134°40'E line has not been supported since 1999.

1. 144°E line by the S/V *Takuyo* or the S/V *Shoyo*
    1.1. every winter since 1984;
    1.2. interval of 1 degree in latitude from 34°N to 1°S;
    1.3. from surface to 4,500 m or bottom; T, S, O_2, surface current, nutrients and others.

2. 134°40'E line by the S/V *Shoyo*
    2.1. every summer and winter since 1994 to 1999;
    2.2. interval of 1 degree in latitude from 34°N to 5°N;
    2.3. from surface to 4,000 m or bottom; T, S, O_2, surface current and others.

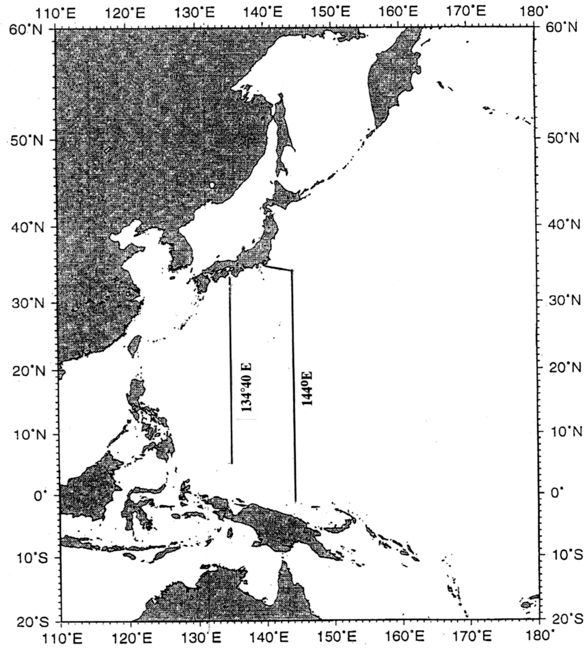


Fig. 4 Long repeat lines currently conducted by HD/JCG.

Repeat lines by JFA

Long lines

The following two long repeat sections are conducted by JFA (Fig. 5):

1. 179.5°W line by the T/V *Wakatake Maru*
    1.1. every summer since 1991;
    1.2. interval of 1 degree in latitude from 38.5°N to 58.5°N;
    1.3. from surface to 600 or 800 m; T, S, plankton and others.

2. 165°E line by the R/V *Hokko Maru*
    2.1. every summer since 1992;
    2.2. interval of 1 degree in latitude from 40°N to 50°N;
    2.3. from surface to 1,500 m; T, S, plankton and others.

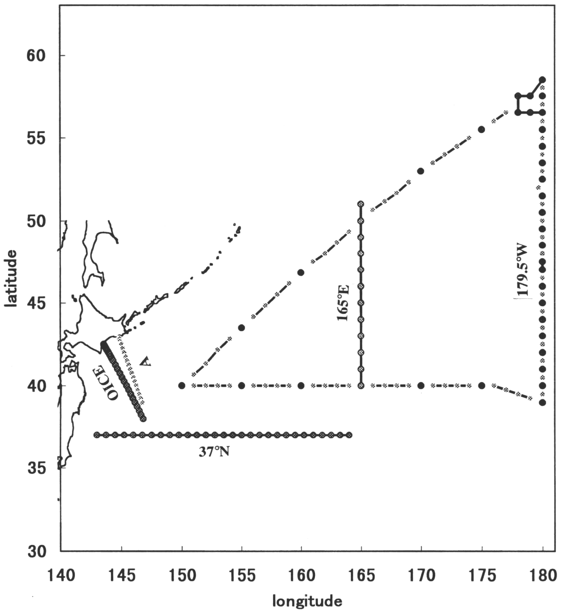


Fig. 5 Long repeat lines currently conducted by JFA.

3. A (Akkeshi)-line by the Hokkaido National Fisheries Research Institute
    - 3.1. 7 times a year since 1988;
    - 3.2. from surface to 3,100 m; T, S, plankton and others.
4. OICE (Oyashio Intensive Observation line off Cape Erimo) by the Tohoku National Fisheries Research Institute
    - 4.1. 4 times a year since 1997;
    - 4.2. from surface to 3,000 m; T, S, plankton and others.
5. 37ºN line by the Tohoku National Fisheries Research Institute
    - 5.1. every spring since 1983;
    - 5.2. interval is 45' in longitude from 143ºE to 165ºE;
    - 5.3. from surface to 1,000 m; T, S, plankton and others.

Short lines

Ocean monitoring of JFA is carried out by 7 National Fisheries Research Institutions and fisheries laboratories of 39 prefectures. Observational lines are classified into two categories. One is repeat-lines in coastal waters and the other is repeat-lines extending to offshore waters. T, S, surface current and other variables are measured at intervals of 1 month (coastal line) and 3 months (offshore line).

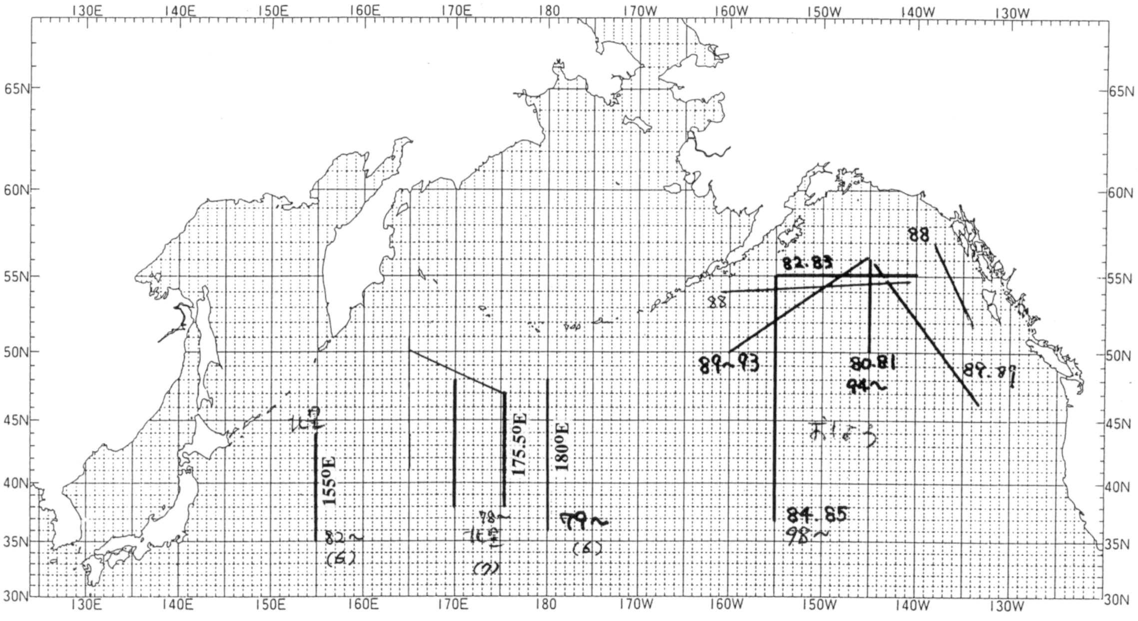


Fig. 6 Long repeat lines currently conducted by Hokkaido University.

Repeat lines by Hokkaido University

Long lines

The Faculty of Fisheries currently supports two long repeat lines (Fig. 6):

1. 155°E line by the T/V *Hokusei-Maru* to 2001, by the R/V *Oshoro Maru* from 2002
   - 1.1. every summer since 1979;
   - 1.2. interval of 1 degree in latitude from 36°N to 48°N;
   - 1.3. from surface to 3,000 m; T, S, O_2, nutrients and others.

2. 165°W line by the T/V *Oshoro Maru*
   - 2.1. every summer since 1998;
   - 2.2. interval of 1 degree in latitude from 35°N to 48°N;
   - 2.3. from surface to 3,000 m; T, S, O_2, nutrients and others.

Although HU had maintained the following two meridional lines since 1970s, they were unfortunately ended recently (Fig. 6):

1. 180° line by the T/V *Oshoro Maru*
   - 1.1. every summer since 1979 to 2000
   - 1.2. interval of 1 degree in latitude from 36°N to 48°N;
   - 1.3. surface to 3,000 m; T, S, O_2, nutrients and others.

2. 175.5°E line by the T/V *Hokusei Maru*
   - 2.1. every summer since 1979 to 1999;
   - 2.2. interval of 1 degree in latitude from 36°N to 48°N;
   - 2.3. from surface to 3,000 m; T, S, O_2, nutrients and others.

Monitoring of climatic variations in Far Eastern Seas

Andrei S. Krovnin[1], Gennady V. Khen[2], Elena Ustinova[2] and Marat Bogdanov[1]

[1] Russian Federal Research Institute of Fisheries and Oceanography (VNIRO), 17 V. Krasnoselskaya, Moscow, Russia. 107140 E-mail: akrovnin@vniro.ru

[2] Pacific Research Fisheries Centre (TINRO-Centre), Shevchenko Alley, Vladivostok, Russia. 690600

The Far Eastern Seas and the adjacent Pacific waters are the main interest for Russia in the PICES area. One of our scientific goals in this area is to understand how climate affects the ecosystem structure and the productivity of key fish species in the Russian EEZ. The research is based on several types of climatic and oceanographic data used for detecting and describing climatic variations in the northwest Pacific, and searching for empirical relationships between physical and biological parameters.

The first group of data includes time-series of monthly means of different atmospheric indices (e.g. WP index, PNA index, etc.) and basic atmospheric characteristics (pressure, geopotential heights, air temperature at different levels). These data for the period from 1950 to the present are provided by the NOAA-CIRES Climate Diagnostic Center, Boulder, Colorado, from their web site at http://www.cdc.noaa.gov. Similar time-series are available from the Russian Hydrometeorological Center. All these data are used to give a general characteristic of climatic situation in the northwest Pacific and in the whole northern hemisphere in different seasons of the given year, or to detect tendencies in variations of large-scale atmospheric circulation with the emphasis on identifying the climatic regimes.

Sea surface temperature anomalies (SSTA), especially in winter season, are a very good indicator of climatic changes in the ocean. It is important to have SSTA time-series that are representative for vast oceanic areas. Such time-series may be obtained by partitioning the North Pacific into several sub-domains with coherent anomaly fluctuations in each sub-domain. For this purpose, mean winter (January-April) values of SST in the North Pacific (from 20°N to 55°N) at grid points of 5°-longitude by 5°-latitude were used for the 1957-2000 period. These data are available from the Russian Hydrometeorological Center. For each grid point, winter SSTA were calculated as deviations from the 1961-1990 mean. To divide the North Pacific into several sub-domains, one of the hierarchical clustering methods, known as the Ward's method (1963), was used. This method is distinct from all other hierarchical clustering methods because it uses an analysis of variance approach to evaluate the distances between clusters. In short, this method attempts to minimize the sum of squares of any two (hypothetical) clusters that can be formed at each step. In general, this method is regarded as most efficient. A detailed description of the algorithm for the Ward's method used in our research can be found in Krovnin (1995). Based on results of the cluster analysis, the North Pacific was divided into five major regions: the eastern part, the central part, the northwestern part, the southwestern part, and the southern part (Fig. 7). Further analysis showed that changes in SSTA in the eastern and central North Pacific, and those in the northwestern and southwestern North Pacific, are out of phase. For each region, time-series of area-averaged SST anomalies were calculated as the spatial average of the non-normalized detrended local time-series over the region specified by the corresponding cluster (Fig. 8). The use of these calculated time-series allowed us to obtain some information about the mechanisms governing large-scale SST fluctuations. In particular, it was shown that variations in mean winter SSTA in two western regions are closely related to Western Pacific teleconnection pattern.

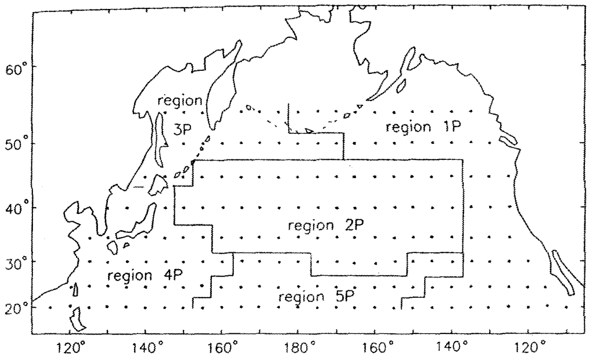


Fig. 7 Results of cluster analysis for the SST anomaly field in the North Pacific. Dots show the position of the 5°-latitude by 5°-longitude grid for the SST data.

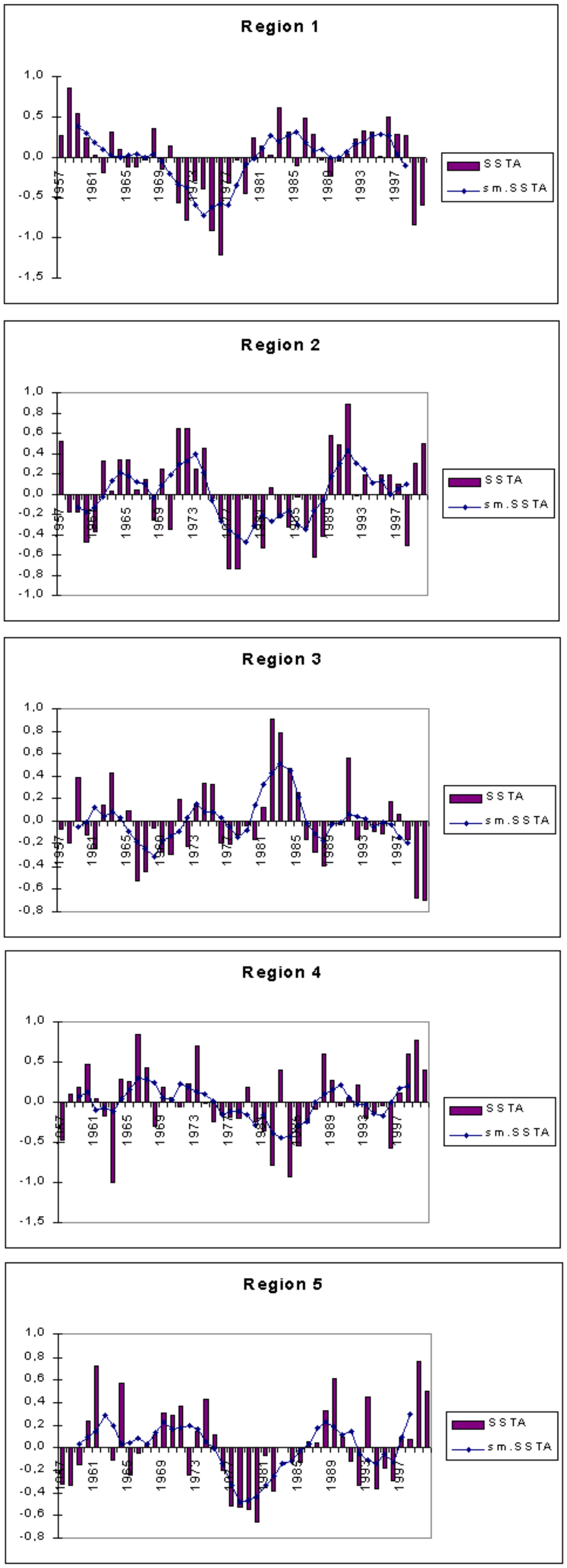


Fig. 8 Time-series of the detrended area-averaged SSTA in Regions 1-2 in the North Pacific.

In our research we used the area-averaged SSTA time-series not only to identify tendencies of changes and climatic regimes but mainly to search for teleconnections with physical characteristics in other regions of the Northern Hemisphere, e.g., in the North Atlantic, for a better understanding and explanation of the causes of climatic changes in the northwest Pacific.

The second group of data contains information on ice cover area (in % from the total area of the sea). These data are available from 1929 onwards for the Sea of Okhotsk, from 1960 for the Bering Sea, and from 1951 for the Sea of Japan. The old data are obtained with air reconnaissance. Recent data are based on information from NOAA satellites and Japanese Meteorological Agency. With the use of these data, a long-term forecast of thermal conditions in Far East Seas till 2020 was made. According to the forecast, the cold period that started there in 1998 will continue for about 20 years.

The third group of data includes a set of weekly and monthly maps of SST in the Okhotsk and Bering Seas and adjacent Pacific waters constructed at VNIRO, as a part of the program on the use of satellite and ship data to monitor the dynamics of SST in various fishing areas of the world ocean. These data are available for May-July of 1992-1993, April-November of 1994, and for the whole year from 1995 onwards. On the basis of these maps, some non-traditional characteristics of thermal conditions, such as ice-free areas, position of ice margins at different latitudes, duration of ice staying north or south of the given latitude, rates of spring warming and autumn cooling, etc., were calculated. Some examples of these characteristics are given in Figure 9. Though now these time-series are considered short, they are rather informative for describing and understanding changes in the development of seasonal processes from year to year. For example, from 1995 to 2000, ice conditions in the Sea of Okhotsk became more and more severe, but the rates of spring-summer warming increased during this period.

The fourth group of data consist of temperature and salinity time-series at several standard sections in the Far East Seas and Pacific waters (Fig. 10). Coordinates of stations and the period and frequency of observations at each section are presented in Tables 3 and 4 respectively. All these sections (except for Avachinsky conducted by KamchatNIRO) are carried out by TINRO-Centre vessels with depth resolution of 1 m during the last 10 years. The Kamchatsky section is conducted jointly by TINRO-Centre and KamchatNIRO. Until 2000, CTD Mark II and later ICTD developed by Falmouth Scientific Inc. were used for sampling. Only in recent years were the dates of cruises stabilized and sections were carried out at approximately the same time of year: Sangarsky and Trans-Okhotsk sections – in winter and summer; Kamchatsky section and section along 132°E - in summer and autumn; Avachinsky – mainly in June. All temperature and salinity measurements are controlled by deepwater thermometers and salinometer at each station.

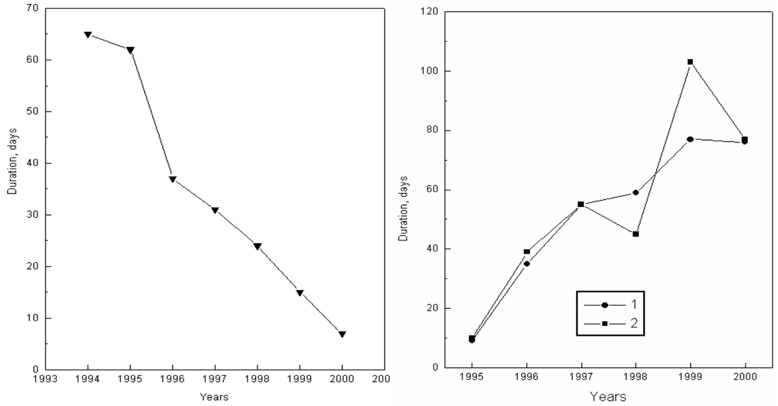


Fig. 9 Rate of spring-summer warming from 5°C to 8°C (in days) at point 49°N, 155°E (left panel), and duration of the ice period east of 148°E at 50°N (1) and south of 53°N off West Kamchatka (2) (right panel).

Table 3 Coordinates of stations at standard sections.

Sta. No.	NW Pacific Trans-Okhotsk Section[1]		Kamchatka Strait Section [2]		Sangarsky Section[3]		Section along 149°E [1] (Japanese)	Section along 132°E [3]	Section from Cape Mayachny[3] (Avachinsky)	
1	49°30'N	144°30'E	55°28'N	165°30'E	42°30'N	133°00'E	33° 00'N	43°00'N	52°30'N	159°36'E
2	49°37'N	144°56'E	55°37'N	165°12'E	42°25'N	133°30'E	33° 30'N	42°55'N	52°20'N	160°00'E
3	49°45'N	145°29'E	55°43'N	164°56'E	42°18'N	134°00'E	34° 00'N	42°50'N	52°06'N	160°40'E
4	49°52'N	146°01'E	55°46'N	164°43'E	42°12'N	134°30'E	34° 30'N	42°40'N	52°48'N	161°20'E
5	50°00'N	146°31'E	55°52'N	164°30'E	42°07'N	135°00'E	35° 00'N	42°30'N	51°30'N	161°66'E
6	50°08'N	147°01'E	55°56'N	164°13'E	42°00'N	135°30'E	35° 30'N	42°25'N	51°04'N	163°56'E
7	50°15'N	147°31'E	56°00'N	164°03'E	41°55'N	136°00'E	36° 00'N	42°20'N	50°37'N	163°53'E
8	50°22'N	148°00'E	56°05'N	163°52'E	41°50'N	136°30'E	36° 30'N	42°10'N	50°10'N	164°50'E
9	50°30'N	148°30'E	56°07'N	163°42'E			37° 00'N	42°00'N		
10	50°38'N	149°00'E	56°09'N	163°32'E			37° 30'N	41°50'N		
11	50°46'N	149°30'E					38° 00'N	41°40'N		
12	50°52'N	150°00'E					38° 30'N	41°30'N		
13	51°00'N	150°30'E					39° 00'N			
14	51°09'N	151°00'E					39° 30'N			
15	51°17'N	151°31'E					40° 00'N			
16	51°25'N	152°01'E					40° 30'N			
17	51°32'N	152°34'E					41° 00'N			
18	51°40'N	153°05'E					41° 30'N			
19	51°48'N	153°35'E					42° 00'N			
20	51°55'N	154°05'E					42° 30'N			
21	52°04'N	154°37'E					43° 00'N			
22	52°11'N	155°12'E								
23	52°19'N	155°44'E								

[1] sampling interval 0-1000 m; [2] sampling interval 0-1500 m; [3] sampling interval 0-500 m

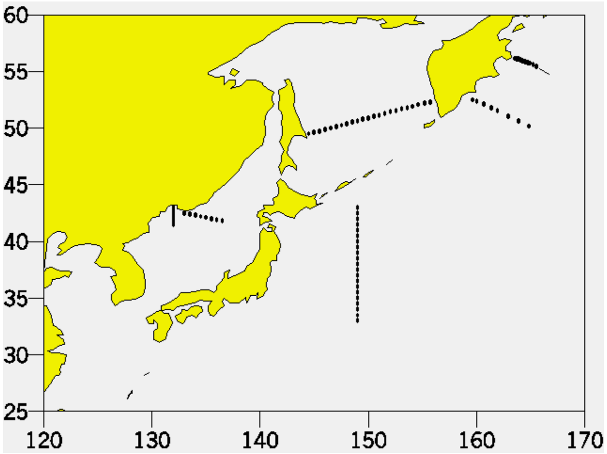


Fig. 10 Scheme of standard sections in the northwest Pacific.

The combined analysis of all described data allowed us to make the following conclusion about the present situation in Far East Seas:

1. Following the shift to a cold regime in the Sea of Okhotsk (since 1998), the cyclonic circulation in the sea strengthened. The volume transport of its main currents increased by a factor of 3 compared with the mid-1990s (warm regime). As a result, in contrast to the surface layer the warm regime was established in the intermediate layer of 500-1,000 m. It seems that the heat loss in upper layer is compensated by its increase at intermediate depths. This possibly allows a range of interannual variations in total heat budget of the sea to be smoothed, which is favorable for ecosystem stability.

Table 4 Frequency of observations at standard sections in the NW Pacific.

Years	Vladivostok Section (along 132°E)	Sangarsky Section	Trans-Okhotsk Section (Kamchatka-Sakhalin)	Kamchatsky Strait	Avachinsky Section	Section along 149°E
1953	5					1
1954	5			1		
1955	1					
1956	2					
1957	5				1	
1958	6				1	
1959	1				1	
1960	5				1	
1961	3			1	1	
1962	4				1	
1963	7			1	1	
1964	6			2	1	
1965	5	1			1	
1966	4			2	1	7
1967	6	1			1	5
1968	7	1			1	7
1969	2	1			1	10
1970	2				1	8
1971	10	1			1	6
1972	7	1			1	7
1973	6	1			1	8
1974	3				1	4
1975	5			2	1	9
1976	10	2				3
1977	4	2				1
1978	2	1		1	1	
1979	6	1			1	2
1980	13			1	1	1
1981	16	1			1	
1982	11	3			1	
1983	19	5			1	4
1984	28	15				
1985	25	18			1	7
1986	10	25			1	2
1987	7	18			1	
1988	33	38		1		
1989	22	30				
1990	10	21		2	1	
1991	10	11		1	1	
1992	7	11		1	1	
1993	5	4		1	1	
1994	7	1		1	1	
1995	3	5	1	1	1	
1996	5	1		2	1	
1997	2	2	1		1	
1998	3	2	1	2	1	
1999	2	1	1	1		
2000	2	2	2	3		
	369	227	6	27		

2. In the Bering Sea the period of weak water exchange with the North Pacific still continues. The transport of the Kamchatka Current in the layer of 0-1,500 m during summer is at a low level of about 2 Sv, while during the period of intensive water exchange it might be 10-15 Sv. But the autumn survey gave some hope on strengthening of water exchange in the near future.

References

Krovnin, A.S. 1995. A comparative study of climatic changes in the North Pacific and North Atlantic and their relation to the abundance of fish stocks. *In* Climate change and northern fish populations. *Edited by* R. J. Beamish. Can. Spec. Publ. Fish. Aquat. Sci. 121, pp.181-198.

Ward, J.H.Jr. 1963. Hierarchical grouping to optimize an objective function. J. Am. Stat. Assoc. 58: 236-244.

On time-series observation programs in the northwestern Pacific in Russia

Vyacheslav B. Lobanov
V.I.Il'ichev Pacific Oceanological Institute, 43 Baltiyskaya Street, Vladivostok, Russia. 690041 E-mail: lobanov@poi.dvo.ru

Existing and interrupted programs

Hydrographic monitoring in Russia/USSR had a peak in the 1950-70s when "weather ships" and "centennial sections" programs were rapidly developed by the State Hydrometeorological Committee, State Committee on Fisheries, and Academy of Sciences. Since the 1950s, a system of standard ("centennial") sections with biannual or seasonal hydrographic observations was designed for the Japan and Okhotsk Seas. A serious decline in observations began at the end of the 1980s, due to economical problems, but some remnants of the system survived. These include two sections in the Japan Sea and two sections in the Okhtosk Sea (see A. Krovnin in this report). Additionally, some information on Russian long-term series is presented below.

Perhaps the most impressive time-series was a system of sections around Sakhalin Island that have been maintained by the local Hydrometeorological Administration and Sakhalin Fisheries Research Institute (SakhNIRO). Luckily SakhNIRO is still managing to continue these observations (contact – Dr. Gennadiy Kantakov – okhotsk@sakhniro.ru). The principal area of monitoring covers waters in a 100-mile zone around Sakhalin Island in the Okhotsk Sea and Tatar Strait (Fig. 11). Hydrographic parameters and plankton are observed twice yearly along the standard sections, down to 500-1,500 m depth. Results of historical observations since the 1950s were published as printed and electronic versions of an atlas by Dr. Vladimir Pishchalnik *et al*. 2000 (vpishchalnik@mail.ru).

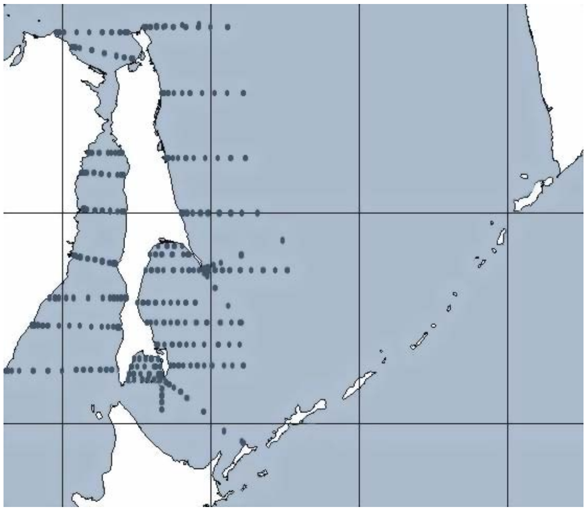


Fig. 11 Scheme of continuing survey around Sakhalin Island (source: G. Kantakov).

Another time-series is a repeated CTD survey of the Kuroshio area from 27 - 43°N and 132 - 149°E under the Russian *Razrezi* (*Sections*) program. The sections were repeated seasonally (4 times a year) in the period 1980-1990, by the Far Eastern

Regional Hydrometeorological Research Institute (FERHRI) (contact - Dr. Yuriy Volkov, director - hydromet@online.ru).

In 1989, the Pacific Oceanological Institute started regular surveys of the Kuril Islands area on an annual or semiannual bases. This included surveys implemented under the International North Pacific Ocean Climate Experiment (INROC) and observations that allow an examination of interannual variability in the Western Subarctic Gyre (see below).

Operational satellite data are available for the northwestern Pacific, Japan, Okhotsk and western Bering Sea from the Far Eastern Regional Receiving Center in Khabarovsk (FERRC), which holds historical data from Russian *Meteor, Kosmos, Ocean* and *Resurs* and *NOAA* satellites series since the 1970s, and receives operational information. The Inter-Institute Center for Satellite Monitoring of the Environment has been established in Vladivostok (contact - Dr. Emil Herbeck – ftp://herbeck.satellite.dvo.ru). This Center has maintained time-series from NOAA AVHRR since January 1999.

Monitoring of the Kuril area under INPOC and other programs

One of the findings of the INPOC project is the important role of mesoscale eddies in water exchange and modification in the Kuril area. A chain of anticyclonic eddies of 60-120 miles in diameter is regularly observed along the Kurils (e.g. Bulatov and Lobanov 1983; Yasuda *et al.* 2000), as it is evident from satellite images (Fig. 12). Intensity and location of the eddies influence the Kuril-Kamchatka Current and Oyashio branches' development and volume transport, as well as water exchange between the Okhotsk Sea and the Pacific. Correct sampling of the eddies and current branches is important for reliable estimation of mass and heat transport and their interannual variations in the area. That is why detailed hydrographic observations based on operational satellite information on eddy locations were implemented during the INPOC surveys. These observations and the following occasional surveys allowed the tracing of characteristics of

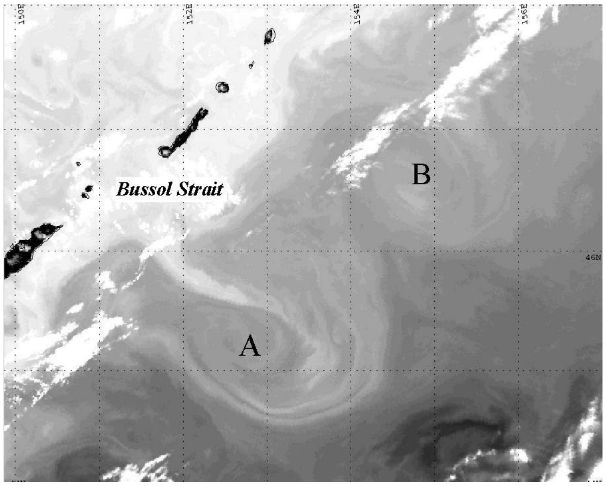


Fig. 12 Kuril eddies (A and B) on the NOAA satellite AVHRR image of May 29, 2001. Light shades correspond to cold water, white are clouds.

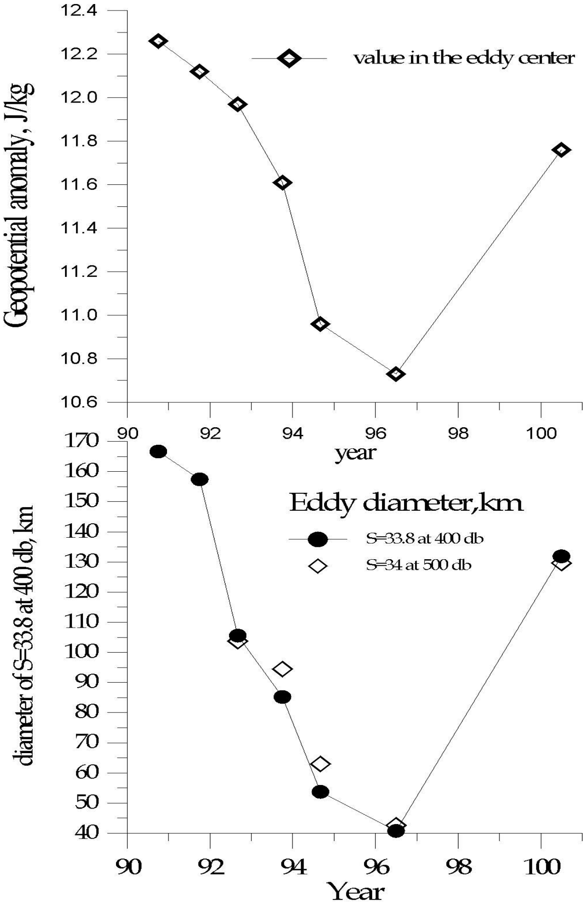


Fig. 13 Change of geopotential anomaly (upper panel) and diameter (lower panel) of the Kuril eddies off Bussol Strait during the recent decade.

the eddies and determining the Oyashio volume transport over the decadal period of 1990-2000 (Rogachev 2000). The decrease in the size and intensity of the eddies located off Bussol Strait from 1990 by the mid-1990s, and subsequent increase again by 2000 (Fig. 13), corresponds well with variations in the volume transport of the off-shore branch of the Oyashio and opposite changes in the coastal Oyashio. It was also found that eddies might be a good indicator of interannual variability in the Western Subarctic Gyre. Thus the monitoring of eddy characteristics could indicate changes of the whole large area. This program would be recommended for continuation. However, at the present, it seems hardly possible to carry out these observations on a regular basis because of a funding deficit in Russia.

Data holdings at POI

Most Russian time-series data are archived at the National Oceanographic Data Center and also in local institutional databases. Currently under a new federal program on development of the *Integrated Information System on the World Ocean*, all data storage should be combined. The main oceanographic institutes in the Russian Far East, POI, FERHRI and TINRO, have prepared an inventory and electronic catalogues of the available oceanographic data. At present, this information is being posted on web sites of these institutes:

POI: “www.pacific.marine.su” and “poi.dvo.ru”
FERHRI: “www.hydromet.com”
TINRO: “www.marine.su/TINRO”
Other sites: “www.meteo.ru”; and
“www.fegi.ru/primorye”

The POI database includes more than 750 cruises with around 360,000 stations taken from 1990 till now, from which around 125 cruises with 18,600 stations were implemented by POI expeditions.

References

Bulatov N.V., and Lobanov, V.B. 1983. Investigation of mesoscale eddies east of Kuril Islands on the base of meteorological satellite data. Soviet J. Remote Sens. 3: 40-47.

Pischalnik V.M., and Bobkov, A.O. 2000. Oceanographic atlas of Sakhalin shelf. Part 1 and 2. SakhGU: Yuzhno-Sakhalinsk.

Rogachev K. A. 2000. Recent variability in the Pacific western subarctic boundary currents and Sea of Okhotsk. Progress in Oceanogr. 47: 299-336.

Yasuda I., S.Ito, Y., Shimizu, K., Ichikawa, K., Ueda, Honma, T., Uchiyama, M., Watanabe, K., Sunou, N., Tanaka K., and Koizumi, K. 2000. Cold-core anticyclonic eddies south of the Bussol Strait in the Northwestern Subarctic Pacific. J. Phys. Oceanogr. 30: 1137-1157.

Physical and biophysical time-series originating from or used by Fisheries Oceanography Coordinated Investigations (FOCI) in the North Pacific Ocean and Bering Sea

S. Allen Macklin
Pacific Marine Environmental Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115-6349, U.S.A.
E-mail: allen.macklin@noaa.gov

North Pacific region

Recent indicators suggest that the climate of the North Pacific region is changing. Scientists think this may have started as early as 1989, when the Arctic Oscillation (AO) changed phase. However, the most significant change is the cooling of coastal waters of the Pacific Northwest and Alaska since 1997-1998, when the Pacific Decadal Oscillation (PDO, see below) probably switched phase. With coastal cooling came shifts in marine abundance, e.g., West Coast salmon that were suffering declines in abundance early in the 1990s appear to be recovering, while

Alaska salmon abundance is waning. The following sections discuss some of FOCI's climate and pollock abundance indicators in light of climate change.

Interannual variability of atmospheric forcing

The winter magnitude and position of the Aleutian Low explain much of the interannual variability of atmospheric forcing and physical oceanographic response of the North Pacific Ocean and Bering Sea. The Aleutian Low is a statistical feature formed by averaging North Pacific sea level pressure for long periods. Because this is a region of frequent storms, the averaged pressure pattern describes a closed-cell, low-pressure area over the North Pacific, much like an individual storm on a weather map. The amplitude and location of the Aleutian Low have a strong bearing on weather and ocean conditions in the region and are correlated with other climate indices such as ENSO (El Niño Southern Oscillation), AO, and PDO. A strong Aleutian Low (low pressure) is accompanied by strong winds that drive warm water from the central Pacific into the coastal regions of Alaska and the Pacific Northwest. Conversely, when the Aleutian Low is weak (higher pressure), winds are weak and coastal sea surface temperatures cool.

A measure of the strength of the Aleutian Low is the North Pacific Index (NPI, Fig. 14). It is the sea level pressure over the North Pacific averaged for January through February. The index contains strong decadal variability. For example, there is a shift from high to low values of the index in 1925, a return to high values in 1946, and a shift back to low in 1977. If the data are smoothed, secondary shifts appear (one and a half secondary shifts for each major shift) such as in 1958 and 1989. In the past two years, NPI values have been higher, indicating a weaker Aleutian Low. Consequently, wind-driven advection of warm water from the central North Pacific into the coastal regions of Alaska and the U.S. Pacific Northwest has diminished, and local processes play a larger role in determining ocean temperature near the coast.

Figure 15 shows the averaged monthly anomaly of sea surface temperature for the North Pacific during May 2000. Note the relative cooling of the coastal waters. This signature is indicative of a recent change in the PDO (see next section). The cooling began in 1998 and has associated with the La Niña, but has persisted in the northeast Pacific, which is taken as an indicator of a change in the PDO. Ocean temperatures throughout the North Pacific continued to cool during June relative to long-term climatology.

Pacific decadal oscillation

The Pacific Decadal Oscillation (PDO) Index (Fig. 16) is defined as the leading principal component of North Pacific monthly sea surface temperature variability. The PDO is a long-lived, El Niño-like pattern of North Pacific Ocean climate variability. Two main characteristics distinguish PDO from ENSO. Firstly, 20th century PDO “events” persisted for 20 to 30 years, while typical ENSO events persisted for 6 to 18 months. Secondly, the climatic fingerprints of the PDO are most visible in the North Pacific/North American sector, while secondary signatures exist in the tropics - the opposite is true for ENSO. Several independent studies find evidence for just two full PDO cycles in the past century: “cool” PDO regimes prevailed from 1890-1924 and again from 1947-1976, while “warm” PDO regimes dominated from 1925-1946 and from 1977 through (at least) the mid-1990s. Some researchers have identified a cold phase starting in 1989, others point to 1997. Beginning in early 2000, it became apparent that a shift had occurred from changes in ocean temperature (Fig. 15) and distribution of salmon and other marine species. A weaker Aleutian Low (Fig. 14) is certainly associated with this change. Major changes in northeast Pacific marine ecosystems have been correlated with phase changes in the PDO. Warm eras bring enhanced coastal ocean biological productivity in Alaska and inhibited productivity off the west coast of the contiguous United States, while cold PDO eras produce the opposite north-south pattern of marine ecosystem productivity. Causes for the PDO are not currently known. Even in the absence of a theoretical understanding, PDO climate information improves season-to-season and year-to-year climate forecasts for North America because of its strong

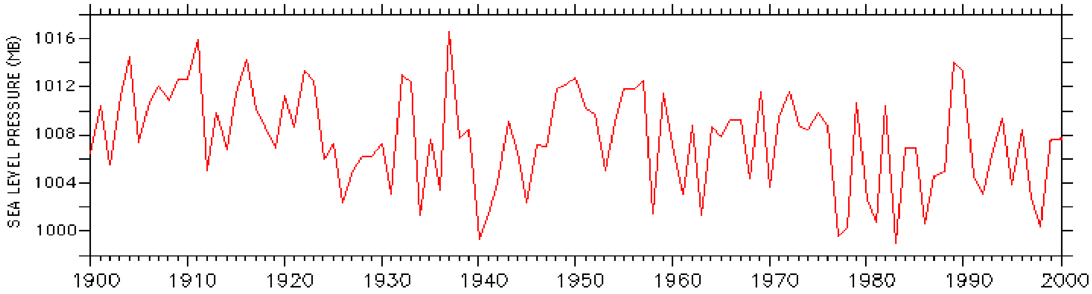


Fig. 14 The North Pacific Index (NPI) from 1900 through 2000 is the sea-level pressure averaged for January through February.

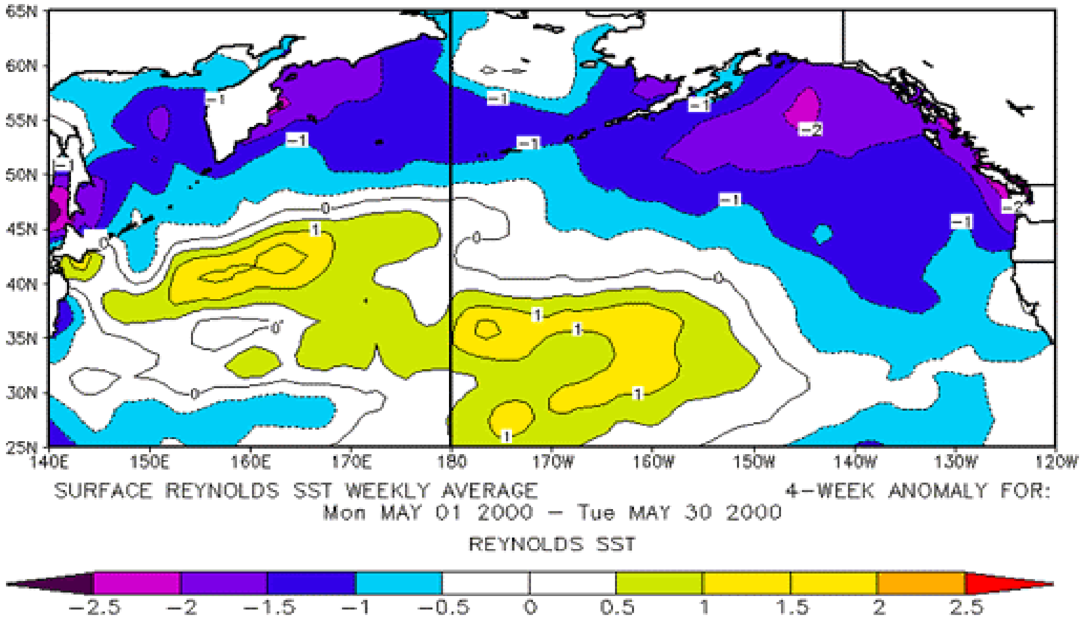


Fig. 15 The pattern of sea surface temperature anomalies for May 2000 shows a return to cool coastal waters with warmer central Pacific waters.

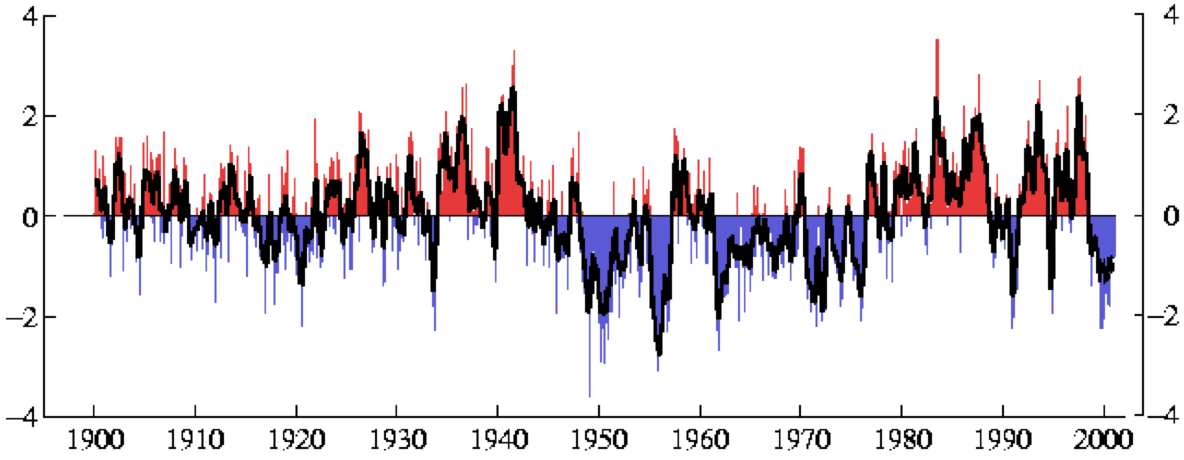


Fig. 16 Monthly and smoothed (black line) values of the Pacific Decadal Oscillation (PDO) index, 1900-2000 (updated from Mantua *et al.* 1997)

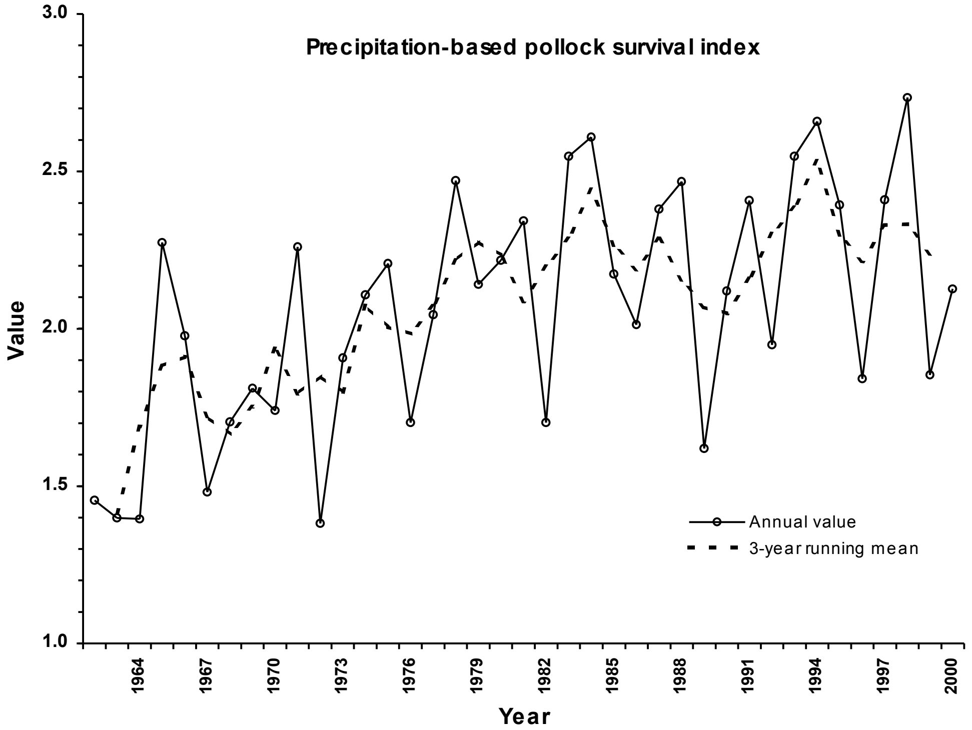


Fig. 17 Index of pollock survival potential based on measured precipitation at Kodiak from 1962 through 2000. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

tendency for multi-season and multi-year persistence. From a societal perspective, recognition of PDO is important because it shows that "normal" climate conditions can vary over time periods comparable to a human's lifetime.

Western Gulf of Alaska

Seasonal rainfall at Kodiak

Patches of larval walleye pollock have been located within mesoscale eddies. For early larvae, presence within an eddy may be conducive to survival. Eddies in Shelikof Strait are caused by baroclinic instabilities in the Alaska Coastal Current (ACC). The baroclinity of this current fluctuates with the amount of fresh water discharged along the coast. A time-series of Kodiak rainfall (inches) is a proxy for baroclinity, and thus an index for survival success of species such as walleye pollock that benefit from spending their earliest stages in eddies. Greater than average late winter (January, February, March) precipitation produces a greater snow pack for spring and summer freshwater discharge into the ACC. Similarly, greater than average spring and early summer rainfall also favor increased baroclinity after spawning. Conversely, decreased rainfall is likely detrimental to pollock survival. A pollock survival index based on precipitation is shown in Figure 17. Although there is large interannual variability, a trend toward increased survival potential is apparent from 1962 (the start of the time-series) until the mid-1980s. Over the last 15 years, the survival potential has been more level. Are the lower values of the last two years commensurate with a phase change of the PDO?

Wind mixing south of Shelikof Strait

Another survival index relates to first-feeding pollock larvae, a key survival stage when baby fish have exhausted their yolk sacs and need to capture food. Possibly because increased turbulence interferes with larvae's ability to feed, strong wind mixing events during the first-feeding period are detrimental to survival of pollock larvae. A time-series of wind mixing energy (W m^{-2}) near the southern end of Shelikof Strait (at 57°N, 156°W) is the basis for a survival index (Fig. 18), wherein stronger than average mixing before spawning and weaker than average mixing after spawning favor survival of pollock. As with precipitation at Kodiak, there is wide interannual variability with a less noticeable and shorter trend to increasing survival potential from 1962 to the late 1970s. Recent survival potential has been high. Monthly averaged wind mixing in Shelikof Strait has been below the 30-year (1962-1991) mean for the last three January through June periods (1998-2000). This may be further evidence that the North Pacific climate regime has shifted in the past few years.

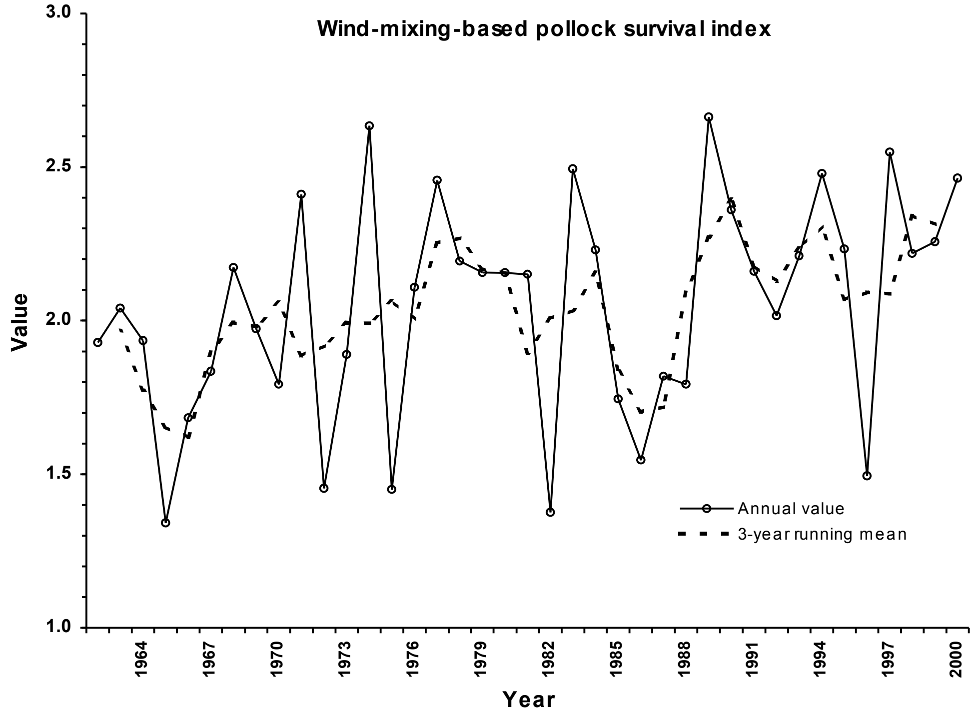


Fig. 18 Index of pollock survival potential based on estimated wind mixing energy at a location south of Shelikof Strait from 1962 through 2000. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

Eastern Bering Sea

Sea ice extent and timing

The extent and timing of seasonal sea ice over the Bering Sea shelf plays an important role, if not the determining role, in the timing of the spring bloom and modifies the temperature and salinity of the water column. Sea ice is formed in polynyas and advected southward across the shelf. The leading edge continues to melt as it encounters above freezing waters. The ice pack acts as a conveyor belt with more saline waters occurring as a result of brine rejection in the polynyas and freshening occurring at the leading edge as the ice melts. Over the southern shelf, the timing of the spring bloom is directly related to the presence of ice. If ice is present in mid-March or later, a phytoplankton bloom will be triggered that consumes the available nutrients. If ice is not present during this time, the bloom occurs later, typically during May, after the water column has stratified.

The presence of ice will cool the water column to 1.7°C. Usually spring heating results in a warm upper mixed layer that caps the water column. This insulates the bottom water, and the cold water (<2°C) will persist through the summer as the "cold pool". Fish, particularly pollock, appear to avoid the very cold temperatures of the cold pool. In addition, the cold temperatures delay the maturing of fish eggs and hence affect their survival.

Figure 19 shows the presence of ice over the southeastern shelf between 57°N and 58°N during the last 28 years. Figure 19 is divided into three panels, each representative of a climate regime: 1972-1976 ice conditions occurred during a cold PDO phase, 1977-1989 during a warm PDO and AO phase, and the years hence which seem to be in an intermediate regime reflecting a warm PDO and a cold AO. The possible change in the PDO that may have occurred about 1997 is reflected in the extreme ice conditions observed in 2000. During the first regime ice was common over this part of the shelf. In the warm period thereafter, ice was less prevalent. Since then, ice has been more persistent but not as extensive as it was prior to 1977. Recently, 2000 had the most extensive seasonal sea ice pack since 1976. There appears to be a slight reduction in ice cover during El Niño years, but the relationship is weak.

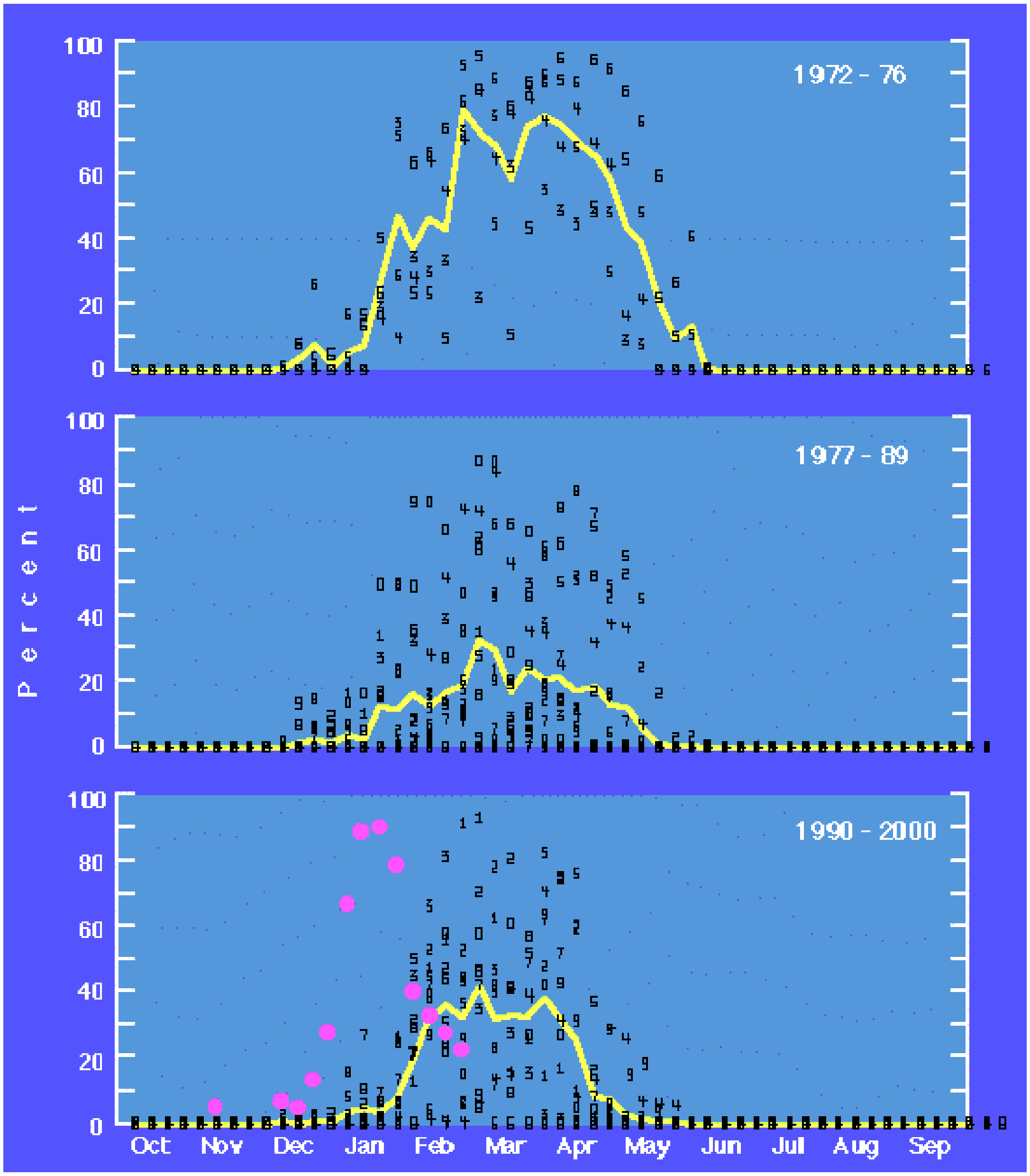


Fig. 19 Percent ice concentration over the southeastern Bering Sea shelf between 57°N and 58°N from 1972 through 2000. The pink dots in the lowest panel are for 2000.

Mooring 2: The cycle in the middle shelf

The cycle in water column temperatures is similar each year. In January, the water column is well mixed. This condition persists until buoyancy is introduced to the water column either through ice melt or solar heating. The very cold temperatures (shown in black in Figure 20) that occurred in 1995, 1997, 1998 and 1999, resulted from the arrival and melting of ice. Shelf temperature during 1999 was the coldest, well below 1995 and 1996, and approaching the cold temperatures of the negative PDO phase of the early 1970s. During 1996, ice was present for only a short time in February, however no mooring was in place. A phytoplankton bloom occurs with the arrival of the ice pack in March and April. If ice is not present during this period, the spring bloom does not occur until May or June, as in 1996 and 1998. Generally, stratification develops during April. The water column exhibits a well-defined two-layer structure throughout the summer consisting of a 15 to 25 m wind-mixed layer and a 35 to 40 m tidally mixed bottom layer (the cold pool if temperatures are sufficiently low). Deepening of the mixed layer by strong winds and heat loss begins in August, and by early November the water column is again well mixed.

The depth of the upper mixed layer and the strength of the thermocline contribute to the amount of nutrients available for primary production. A deeper upper mixed layer makes available a greater amount of nutrients. In addition, a weak thermocline (more common with a deeper upper mixed layer) permits more nutrients to be "leaked" into the upper layer photic zone and thus permits prolonged production. The temperature of the upper layer influences the type of phytoplankton that will flourish. For instance, warmer sea surface temperatures (>11°C) during 1997 and 1998 may have supported the coccolithophorid bloom.

Timing of the last spring storm

One of the striking features of the atmosphere during 1997 and 1998 was a change in the timing of the last storm and strength of summer mixing over the eastern Bering Sea. This ecosystem is particularly sensitive to storms during May. The spring bloom strips nutrients from the upper layer, and the stability of the water column isolates nutrients in the lower layer. Thus mixing and deepening of the upper mixed layer by storms in mid-to late May provide important nutrients for continuation of blooms into summer. June and July storms are less effective mixers because they are weaker and the thermocline has strengthened. May storms also lessen the density difference between the two layers (entraining denser water into the upper layer), thus permitting subsequent minor mixing events to supply nutrients into the photic zone. From 1986 to 1996, the weather during May was particularly calm; during May 1999, winds were again light. By contrast, May of 1997 and 1998 were characterized by strong individual wind events (Fig. 21). These storms presented a pathway for greater nutrient supply, more prolonged primary production, and weaker stability of the water column than observed between 1986 and 1996, and in 1999. In addition to stronger

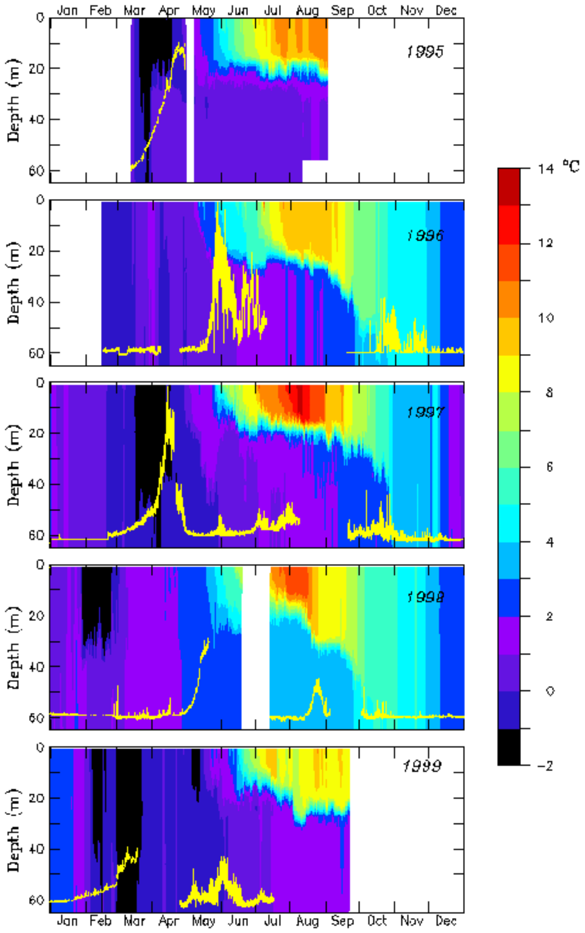


Fig. 20 Ocean temperature (°C) as a function of depth (m) and time (month of year) and fluorescence as a function of time measured at mooring site 2 during 1995 through 1999.

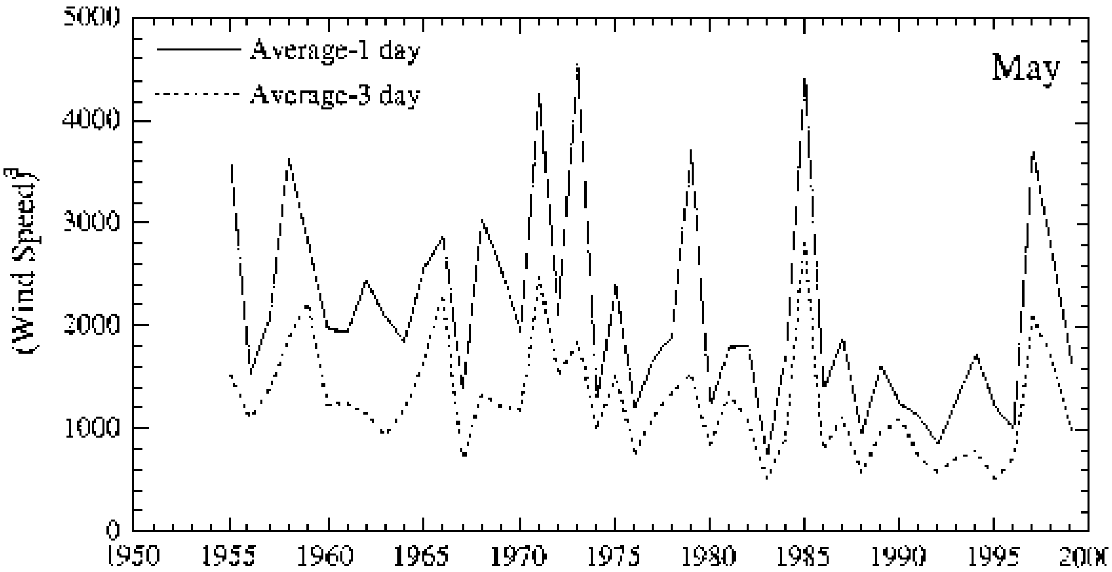


Fig. 21 Cube of wind speed (proportional to wind mixing energy) measured at St. Paul, Alaska. The solid line is the daily average; the dashed line is the 3-day average.

winds in May, the summers of 1997 and 1998 had the weakest mean wind speed cubed (a measure of mixing energy) since at least 1955. This allowed for a shallow mixed layer and thus higher sea surface temperatures. A pattern of late spring storms and weak summer winds could change the phytoplankton community. If production is prolonged into summer, the total productivity of the shelf could be enhanced, thereby affecting higher trophic levels.

Cross-shelf advection

Each spring and summer over the Bering Sea shelf, approximately half the nutrients are consumed. These nutrients apparently are replenished during winter and early spring. Cross shelf advection moves nutrient-rich basin water onto the shelf. A reduction of onshelf flow will reduce the available nutrients and thus productivity of the shelf. Understanding and monitoring the mechanisms that induce cross shelf flow are critical to management of the Bering Sea's living resources.

During the last ten years, FOCI released more than 100 satellite-tracked drift buoys in the Bering Sea. Prior to 1996, drifters deployed in the southeastern corner of the Bering Sea typically revealed persistent northwestward flow along the 100-m isobath, with cross-shelf flow occurring intermittently. In 1997, 1999 and 2000, flow along the 100-m isobath was weak or nonexistent, and there were no occurrences of onshelf flow. Flow patterns in 1998 are less well known as no drifters were deployed that year. Indices of onshelf flow and strength of the 100-m-isobath flow are derived from trajectories of the satellite-tracked drifters. Such indices are important in determining changes in flow patterns, particularly if there has been a climate regime shift as some scientists believe occurred in 1998.

FOCI time-series

FOCI has six long-term monitoring operations in the Gulf of Alaska, seven in the Bering Sea, and 21 years of hydrodynamic model results from Shelikof Strait. These are summarized in Table 5. The first is Line 8, a series of seven stations across the southwestern end of Shelikof Strait. This line has been occupied at least once each year since 1985. Measurements taken there include CTD, fine-mesh net (bongo) tows, and water samples for nutrients, chlorophyll and macrozooplankton. In some years, FOCI also deployed moorings along line 8. The second long-term measurement is a survey of abundance and distribution of late-stage pollock larvae. This survey takes place during late May and early June and has been conducted continuously since 1987, with surveys also in 1982 and 1985. Besides pollock larvae, all other contents of bongo tows are also preserved and identified. Additional measurements include water temperature and salinity. Shelikof Strait transport is measured from moorings and satellite-tracked drifters, and also inferred from a biophysical circulation and individual-based (IBM) model. Finally, FOCI has measured flow in the Alaska Stream at locations ranging from Kodiak Island to the Aleutian Islands using ship-mounted acoustic Doppler current profiles. There are also seven years when moorings were placed in the Alaska Stream. Time-series from long-term monitoring have been invaluable to FOCI in meeting its scientific and operational goals.

Beginning in about 1992, FOCI began systematic monitoring in the southeastern Bering Sea. Some measurements are available from earlier periods. The primary observations that are taken from three moorings (two on the shelf and one in the basin) and from three CTD survey locations (one across the shelf, one along the 70-m isobath, and one in Unimak Pass). In addition, transport estimates are available from satellite-tracked drifters and moorings deployed in the region since 1992.

In order to bring its science to the public table, FOCI synthesizes results from long-term measurements, process studies, and models. One result of this synthesis is a conceptual model of pollock recruitment for Shelikof Strait. The model emphasizes the environmental factors that affect the survival of pollock as they pass through their early developmental stages. Examples of these factors are climate, circulation, wind mixing, and potential for eddies. It is these elements that contribute to FOCI's pollock recruitment forecast. The annual prediction is used by the National Marine Fisheries Service (NMFS) to establish recruitment scenarios for their stock projection model. Results from that model and other information produce a quota recommendation that NMFS delivers to the NPFMC. The forecast procedure is refined as FOCI learns more about the processes that determine recruitment. FOCI presently is working with NMFS to incorporate the forecast mechanism directly into the stock projection model. FOCI's Bering Sea program is about to establish a similar forecast for that region.

FOCI has developed a spatially explicit, individual-based (probabilistic) model of egg and larval development for the purpose of hindcasting the early life history of a population of walleye pollock near Shelikof Strait. Such comparative hindcasts are used to suggest possible physical mechanisms contributing to interannual variability in recruitment success. The behaviorally modified float-tracking algorithm for each individual uses daily velocity, salinity and temperature fields generated by a wind- and buoyancy-forced, 3-D hydrodynamic model. The individual-based biological model includes processes such as consumption, energetics and growth, which differ by life stage (e.g., eggs, yolk-sac larvae, feeding larvae, and juveniles). Representative years for hindcasts are chosen to span the observed range of interannual variability in meteorological conditions and recruitment success. Interannual differences in wind and freshwater runoff lead to interannual differences in the modeled spatial paths of individuals (e.g., their retention in mesoscale eddies), and the distribution of weights and lengths among the survivors. Model output from the circulation model is available for the years 1978 through 1999 and will be updated annually.

Other time-series

FOCI and PMEL have other data series that could be useful for examining climate change in the North Pacific Ocean (Table 6). For example, a data rescue project is currently in progress to archive more than 5,000 historical CTD and X-BT casts from the Northeast Pacific Ocean dating back to 1932. Climate studies at PMEL use the long-term Sitka air temperature time series. This series is of 5-month, winter-averaged (November-March) air temperature measured at Sitka, Alaska, since 1829. The North Pacific Index (NPI) is the average sea-level pressure over the North Pacific during January and February. This index dates back to 1899. Terry Whitledge at the University of Alaska Fairbanks has estimates for Bering Sea productivity (nutrients, chlorophyll, plankton) from the PROBES and modern eras. PMEL's tsunami group maintains a series of bottom-pressure recorders at various sites in the North Pacific. Records begin in 1986 and the sensors

Table 5 FOCI data series and other products.

Series Name	Location	Variables Measured	Times of Observation
Line 8	Seven stations across the SW end of Shelikof Strait	Ocean temperature, salinity, currents, nutrients, chlorophyll, zooplankton including pollock larvae	1985 to present; most measurements in spring
Late larval survey	Western Gulf of Alaska shelf from Shelikof Strait to the Shumagin Islands	Abundance and distribution of pollock larvae and additional species, water temperature profiles, other water properties	1982, 1985, 1987 to present in late May and early June; 1986 in early May
Shelikof Strait ocean transport	Alaska Coastal Current in western Gulf of Alaska	Drifter trajectories, currents from some moorings	1985 to present, winter, spring, summer
Shelikof Strait wind mixing	Southwest end of Shelikof Strait	Wind mixing energy estimates determined from synthetic winds	Monthly since 1962
Kodiak precipitation	Kodiak, Alaska	Monthly averaged measured rainfall	Monthly since 1962
Alaska Stream	Kodiak Island to the Aleutians	Current profiles from vessel-mounted ADCP and moorings	1987 to present, usually in May
Mooring 2	Bering Sea middle shelf	Winds and currents, temperatures, salinity, chlorophyll, nitrates	Near continuous since 1995
Mooring 3	Bering Sea middle shelf	Winds, currents, temperatures, salinity, chlorophyll, nitrates	1995-1999 spring and summer
Mooring 6	Bering Sea basin north of Umnak Is.	Currents, temperatures, salinity, chlorophyll, nitrates	Near continuous since 1996
Cross-shelf survey	Southeastern Bering Sea	CTD, nutrient, phytoplankton and zooplankton samples	Winter, spring, fall since 1996
Along-shelf survey	Southeastern Bering Sea (70-m isobath)	CTD, nutrient, phytoplankton and zooplankton samples	Winter, spring, fall since 1997
Unimak Pass survey	Unimak Pass, Aleutian Islands	CTD, some nutrients, phyto- and zooplankton	At least annually since 1995
Bering Sea ocean transport	Bering Sea	Drifter trajectories, currents from some moorings	1992 to present, mostly during spring
Shelikof Strait hydrodynamic model	Shelikof Strait region, Gulf of Alaska	Modeled currents, salinity at 40 m	1978-1999

sample at least once per minute. Low-frequency instrument drift could interfere with detection of climate-scale signals. PMEL was part of a collective effort under the National Ocean Parthership Program (NOPP) to observe ocean characteristics at Ocean Station Papa (50°N, 145°W) during 1998 and 1999, and at station Mama (35°N, 165°W) during 1999. Measurements included atmospheric pressure, winds, temperature, radiation, rainfall, humidity, oceanic currents, temperatute and salinity. At Station P, chemical and biological instruments also sampled the water column. PMEL's VENTS programs has monitored ocean character in the vicinity of the Juan de Fuca and Gorda submarine ridges off the coast of Oregon since 1989. This list is not exhaustive. Other data series are available that are not mentioned here.

Table 6 Other time-series and observations.

Series Name	Location	Variables Measured	Times of Observation
North Pacific CTDs	Northeast Pacific	Temperature, (salinity), depth	1932 to present
Sitka air temperature	Sitka, Alaska	Air temperature	1829-present
North Pacific Index (NPI)	North Pacific	Average sea-level pressure during January and February	1899-present
Bering Sea productivity	Southeastern Bering Sea	Nutrients, chlorophyll, plankton	1977-1981 1997-2001
Bottom Pressure	Various stations in the North Pacific	Ocean bottom pressure	1986 to present
Ocean Stations Papa and Mama	(50°N, 145°W) and (35°N, 165°W)	Meteorological and oceanic parameters	1998 & 1999; 1999
VENTS Hydrogaphy	Juan de Fuca and Gorda Ridges	Temperature, salinity, depth	Various times since 1989

Gridded atmospheric re-analysis fields

James E. Overland
Pacific Marine Environmental Laboratory, Oceanic and Atmospheric Research, NOAA, 7600 Sand Point Way NE, Seattle, WA, 98115-0070, U.S.A. E-mail: James.E.Overland@noaa.gov

A major resource for the study of climate variability of the North Pacific is the re-analyses fields for 1948 to present, generated by the National Centers for Environmental Prediction (NCEP). In a re-analysis, an atmospheric forecasting model is run for an extended period with no changes to the physical parameterizations. Observational data from satellites, radiosondes, pilot reports and ground stations are assimilated into the model. For basic atmospheric data such as temperatures and pressures, one can think of the re-analysis as a dynamic interpolation method where the model is used to extrapolate information into data sparse regions and to make sure that the analysis are internally consistent. The model output goes beyond dynamic interpolation to provide secondary derived fields of quantities such as radiation and sensible heat flux fields and diagnostic terms such as vorticity, stream functions and various correlations. 23 variables and 9 anomaly fields are available on 17 pressure levels from 1000 to 10 mb. These include geopotential heights, temperatures, humidity and winds. 48 variable fields and 15 anomaly fields are provided at one level. These include: net and upward long wave and short wave flux at the surface and top of the atmosphere, surface sensible and latent heat flux, and precipitation rate. Secondary variables may not be as accurate as the primary variables, but because the model physics has not changed over the length of the run, they provide a major source of information for comparing spatial patterns of fluxes over decadal time scales. Data are available four times a day, as daily means and as monthly means. Data are available at the NCEP web site "wesley.wwb.noaa.gov/ncep_data/index.html". This site also provides graphics capability and various smoothing formats for displaying fields. FERRET and other programs are designed to work with the data set. Figure 22 was produced at the website showing the 1000 mb geopotential height anomaly field for February 2001. Low heights (low sea level pressure) over the western Bering Sea and high heights (high pressure) in the Gulf of Alaska gave strong southwest winds and warm temperatures over the eastern Bering Sea and Alaska.

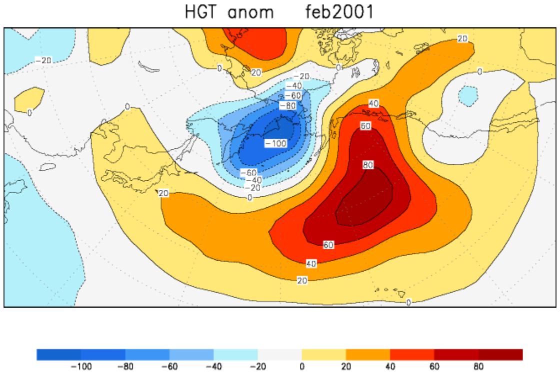


Fig. 22 The geopotential height anomaly field for February 2001 in the Pacific region.

Research on the physical-biological-chemical coupled numerical model in China

Fangli Qiao
First Institute of Oceanography, State Oceanic Administration, Xian-Xia-Ling Road, Qingdao, Shangdong, People's Republic of China. 266061 E-mail: lagfd@public.qd.sd.cn

This report introduces research on physical-biological-chemical coupled numerical model and the 3-D baroclinic current model in China, and the Yellow Sea database.

3-D marine ecosystem numerical model

Based on the China-Japan cooperation from 1997-2000, a 7-component physical-biological-chemical coupled numerical model was developed in two steps. First, following two marine mesocosm experiments in the Yangtse River estuary area in October 1997 and May 1998, a 1-D biological-chemical model, which includes nitrogen, phosphate, silicon, flagellate, diatom and detritus, was created, and the model results were compared with *in situ* data (Fig. 23). Second, zooplankton was added to the above model, and the model was combined with a 3-D physical model of Jiaozhou Bay. Located 400 km from Qingdao, this bay is one of two marine ecosystem stations in China. With this 3-D 7-component coupled model, we simulated 4 years of observations and compared them with observations at 10 stations in the bay (Fig. 24).

3-D baroclinic current model of the coastal seas of China and adjacent North Pacific

Currents play an important role in transport of marine ecosystem elements and water temperature directly influences the ecosystem. A 3-D baroclinic current model, mainly focused on the coastal seas of China and adjacent North Pacific, was developed based on the Princeton Ocean Model (POM). The comparison of model results with observations shows our ability to predict physical elements in the North Pacific region (Fig. 25).

Yellow Sea data set

Six comprehensive cruises covering the whole Yellow Sea were carried out from the spring of 1996 to the fall of 1997. Collected data cannot be released until December 2002. A list of cruises is given below (location of sampling stations is shown in Figure 26):

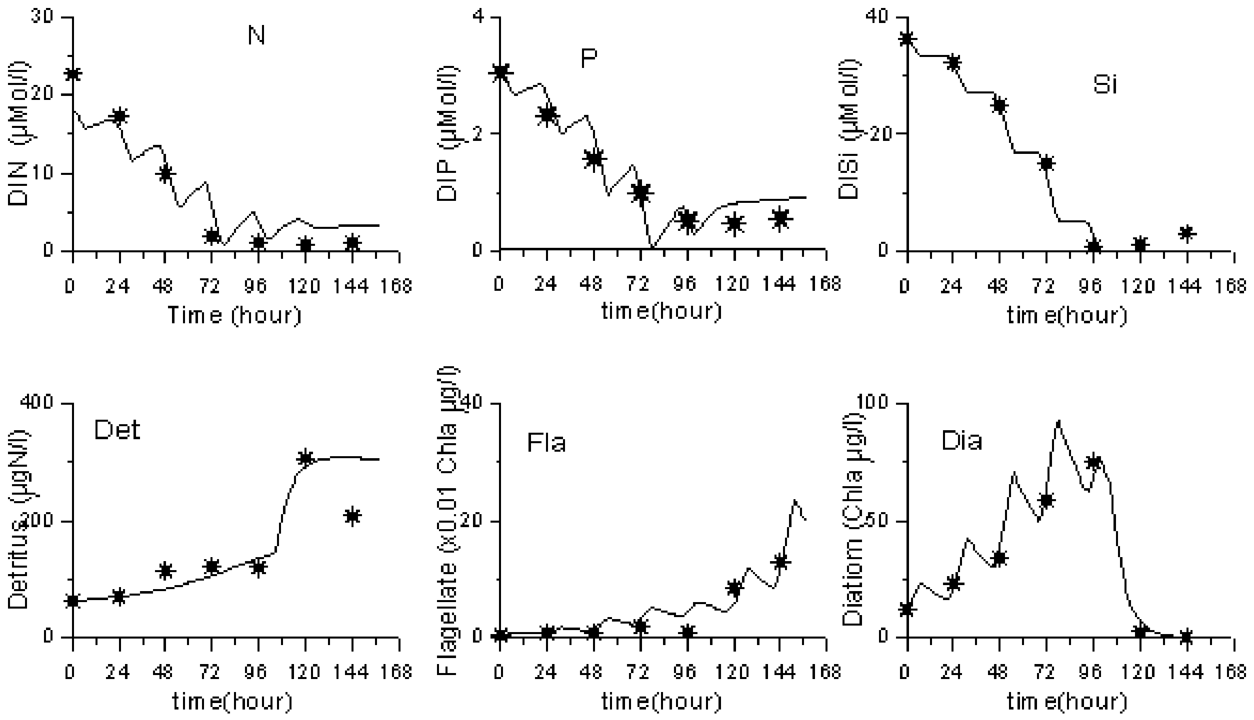


Fig. 23 Comparison of *in situ* observations in Jiaozhou Bay and results from a 1-D 6-component coupled ecosystem model (time from 09:00 (GMY08) on October 11, 1997).

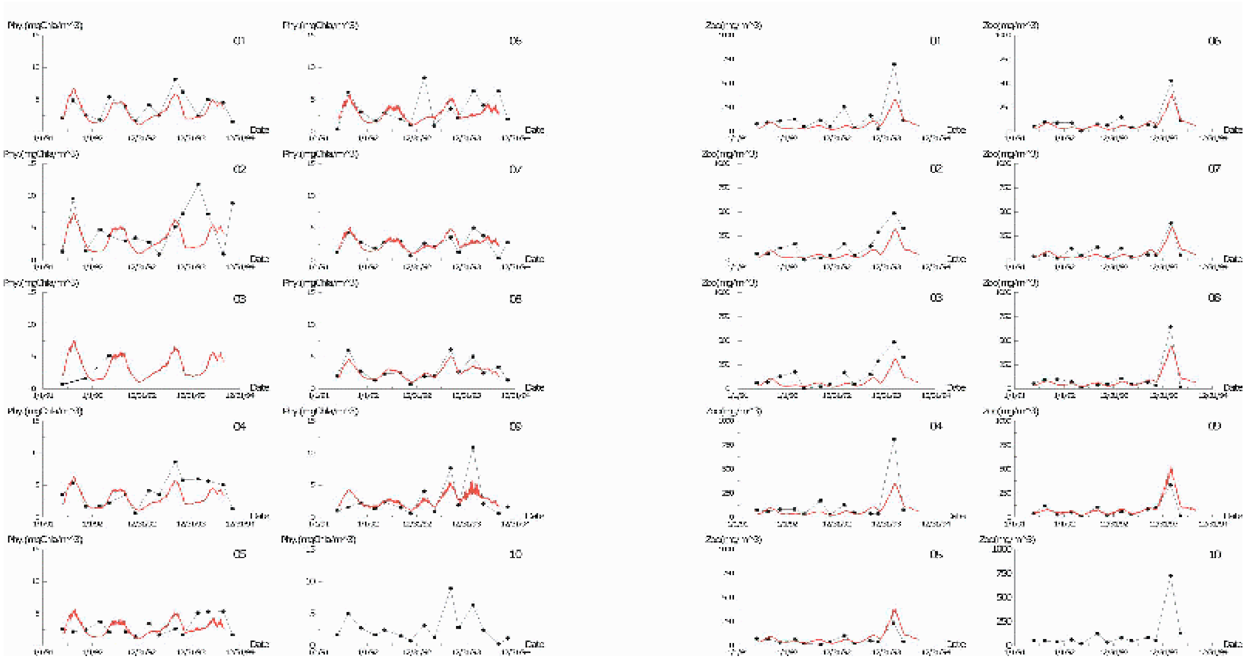


Fig. 24 Comparison of observations in Jiaozhou Bay and results from a 3-D (Princeton Ocean Model) 7-component coupled ecosystem model for phytoplankton (left panel) and zooplankton (right panel). Red lines show model results and black lines show observed data.

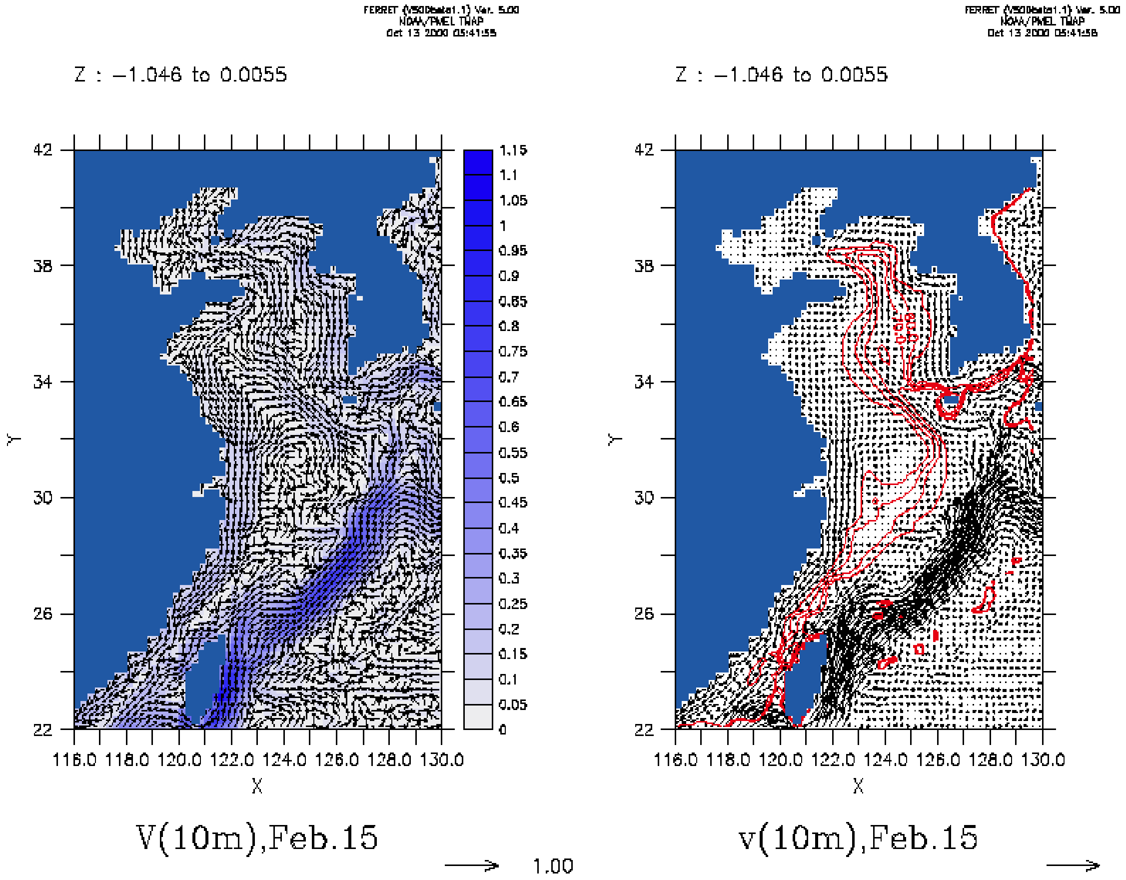


Fig. 25 Comparison of observations in the coastal seas of China and adjacent North Pacific and results from 3-D baroclinic current model for phytoplankton (left panel) and zooplankton (right panel). Red lines show model results and black lines show observed data.

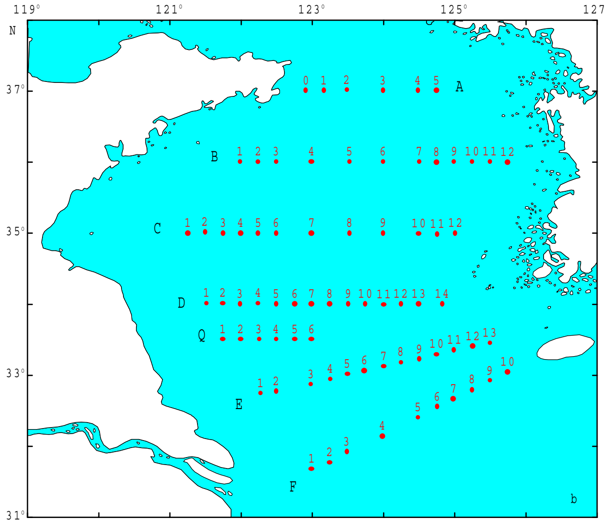


Fig. 26 Cruise tracks in the Yellow Sea.

1.1 spring of 1996: CTD (71 stations), ADCP, chemical and biological observations (71 stations);

1.2 fall of 1996: CTD (79 stations), ADCP, chemical and biological observations (79 stations);

1.3 summer of 1997: CTD (73 stations), ADCP, chemical and biological observations (73 stations);

1.4 winter of 1997: CTD (69 stations), ADCP, chemical and biological observations (69 stations); and

1.5 spring of 1998 CTD (69 stations), ADCP, chemical and biological observations (69 stations).

GROUP 2: PHYTOPLANKTON, ZOOPLANKTON, MICRONEKTON, AND BENTHOS

U.S. GLOBEC Northeast Pacific Program: Observations, retrospective studies and model products

Hal Batchelder
College of Oceanic & Atmospheric Sciences, Oregon State University, 104 Ocean Administration Bldg., Corvallis, OR 97331-5503, U.S.A. E-mail: hbatchelder@oce.orst.edu

U.S. GLOBEC is supporting oceanographic and fisheries research in two regions in the northeast Pacific (NEP): 1) within the eastern boundary of the California Current upwelling system (CCS) off Oregon and Northern California, and 2) within a predominantly buoyancy-forced, downwelling ecosystem in the coastal domain of the northern Gulf of Alaska (CGOA). Within these regions, GLOBEC is supporting: (i) retrospective data analysis of existing medium-to-long term data sets spanning hydrography through lower trophic levels to fish, birds and mammals; (ii) long-term observation programs (LTOPs, e.g., "monitoring") - regular sampling of pre-selected ocean stations for parameters ranging from physics to higher trophics; (iii) process-focussed research cruises that estimate biological and physical rate processes, and provide detailed survey descriptions of ecosystem state variables (biomass, size structure, hydrography, transports); (iv) moorings deployed at a few sites to provide time-series data of hydrographic conditions, transports, and selected biological fields; (v) drifter deployments to examine cross-shelf and along-shelf flows, and in a few cases to provide time-series observations of biological rates; and (vi) nearly continuous HF radar (CODAR) observations of surface currents in selected regions. Complementing these research elements are analysis of satellite derived ocean products (ocean color, SST, and sea level), and modeling of ocean circulation and the coupling of biological processes and state variables with physical processes. Modeling approaches vary among research groups, ranging from highly idealized process-oriented biophysical coupled models with simple external forcing to realistic geometry/bathymetry simulations of ocean circulation in regional models coupled to basin or global-scale models.

The U.S. GLOBEC program in the NEP has a limited duration of field observations (*ca*. 7±2 years) in both the CGOA and CCS. These two regions in the past have had co-varying, but of opposite phase, salmon and zooplankton population abundances through time. Since the program is interested in examining the role of climate variability on the structure and dynamics of the coastal marine ecosystems, and specifically in comparing the responses of these two regional systems, we realized that a short-duration study (<10 years) would be insufficient, by itself, to answer questions concerning longer-term, larger-scale variation. Thus, U.S. GLOBEC has devoted substantial resources to retrospective analysis of existing, but perhaps, under-exploited data sets, and to the development of coupled biophysical models. The intent is that improved models will increase our ability to integrate biological and physical observations in coastal ecosystems generally, and specifically, to provide integrated assessments of the effect of environmental variability and climate change on coastal marine ecosystems within the NEP. The data sets assembled and collected within the GLOBEC NEP program--including historical data, and newly collected data from LTOP and process studies--will provide a comparison to similar observations collected previously and provide a baseline for future data collections and comparisons.

The GLOBEC principal investigators have identified a number of historical data sets that should be re-evaluated and/or made generally available, and which would be of particular value for the NEP study (Table 1).

Data collected within the 5-7 years of the program are numerous and include:

1. CCS LTOP Program (5 cruises/year; July 1997 – Nov. 2003) (Table 2).

2. CGOA LTOP Program (6-7 cruises/year; Sept. 1997 – Dec. 2003) (Table 3 & Fig. 1).

3. Process/Survey Cruises:

3.1. CCS (spring and fall cruises, 2000 & 2002) (Fig. 2)
   - States: temperature, salinity, fluorescence, zooplankton biomass and composition, fish, birds, and mammals;
   - Rates: transports, zooplankton vital rates, feeding rates; and fish vital rates.

3.2. CGOA (late-winter, spring, summer cruises, 2001 & 2003) (Figs. 3 and 4)
   - States: temperature, salinity, fluorescence, zooplankton biomass, and composition, fish, and birds;
   - Rates: transports, zooplankton vital rates, feeding rates; fish vital rates.

4. Moorings:

4.1. CCS (3 moorings: Newport, Coos Bay, Rogue River): Hydrography, velocities, backscatter, and fluorescence.

4.2. CGOA (about 7 moorings; Seward Line, Gore Pt. Line): Hydrography, velocities, multi-frequency backscatter, fluorescence, nitrate, and surface meteorology.

5. Models:

5.1. Physics
   - Idealized Process-Oriented: Spectral Element Ocean Model (SEOM)
   - Realistic Geometry & Bathymetry: Regional Ocean Modeling System (ROMS)

5.2. Biology – Plankton
   - NPZ and NPZ+ models
   - Individual Based Models (IBMs)

5.3. Biology
   - Fish: Individual Based Models

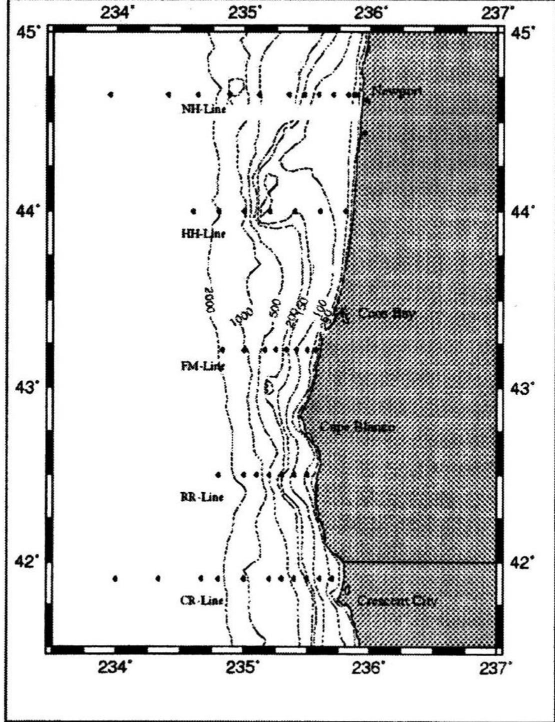
5.4. Ecosystem, esp. for higher trophics
   - ECOPATH
   - Numerical Simulation Models

Table 1 Data base availability and needs for the U.S. GLOBEC NEP program.

DATA SET	AREA	PERIOD	SOURCE
Upwelling Index	West Coast	1946- (mo) 1967-(6 h; daily)	PFEG
Freshwater	Gulf of Alaska Pacific NW	1931-(mo)	Tom Royer (ODU)
SST	No. Pacific	1946-O	Various
SST-GAK1	GAK1	1970-(mo)	Tom Royer (ODU)
Coastal Sea Level	West Coast	1945-(mo)	NOAA
Sea Level Pressure	Sitka, AK	1899-(mo)	Tom Royer (ODU)
Sea Level Pressure	Other West Coast		
Air Temperature			
CalCOFI Hydrography/Chl-*a*	So. Calif Bight	1980's?-	SIO/MLRG
CalCOFI ZP Biomass	So. Calif Bight	1951-(qtr)	Ohman/SIO
CalCOFI ZP Composition	So. Calif Bight	Spring; Reg, Avgs.	Ohman/Reb stock/SIO
MicroZP abund/comp	Line P	1987-88; 93-99; 2-3X/yr	Strom/WWU
ZP Biomass	Line P	1940-1981; intermittent since	Canadians
ZP Biomass	No. Pacific	Before and after 76 regime shift	Brodeur
Satellite Color			
CZCS	CCS	78-83; 10-d composites; mo	Andy Thomas/Maine
Sea WiFS	Baja-50N	Sept. 97- (10-d composites)	Andy Thomas/Maine
MODIS	?	?	Abbott/Letelier/OSU
Satellite Altimetry	No. Pacific		Ted Strub/OSU
Satellite SST	West Coast	1992- (<day)	Ted Strub/OSU
Gridded Ocean Fields			
COADS	No. Pacific	1945-(mo; seasonal climatologies)	PFEG

Table 2 GLOBEC long-term observation program in the California Current System.

YR		’97					’98						’99					’00					’01		
Month =>	7	9	11	2	4	5	6	8	9	11	2	4	7	9	11	2	4	7	9	11	1	3	9	10	11
Newport	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
Heceta Head													X				X	X	X						
Five Mile			X	X	X	X		X		X		X	X	X			X	X	X			X			
Rogue River																	X	X	X						
Crescent City			X		X			X		X		X	X	X			X	X	X			X			
Eureka					X			X		X			X	X											
COC			X		X			X		X															



Data Types Collected

1) Profile Data: CTD, Relative Fluorescence, Transmittance; Oxygen

2) Bottle Data: Nutrients (NO_3, NO_2, PO_4, SiO_2); Extracted Chlorophyll

3) Alongtrack Data: 150 kHz ADCP; HTI Multifreq. Acoustics; Surface Observations and Meteorology (SST, Salinity, Fluorescence, Wind D and S; Humidity; etc.)

4) Surface Drifters (drogued at 15 m) at selected Newport Line stations

5) Net Tows: a) 100 m to surface vertical, 0.5 m diameter, 202 µm; b) Depth stratified oblique 1 m^2 MOCNESS from 350 m or near bottom, if shallower, to surface. 333 µm mesh.

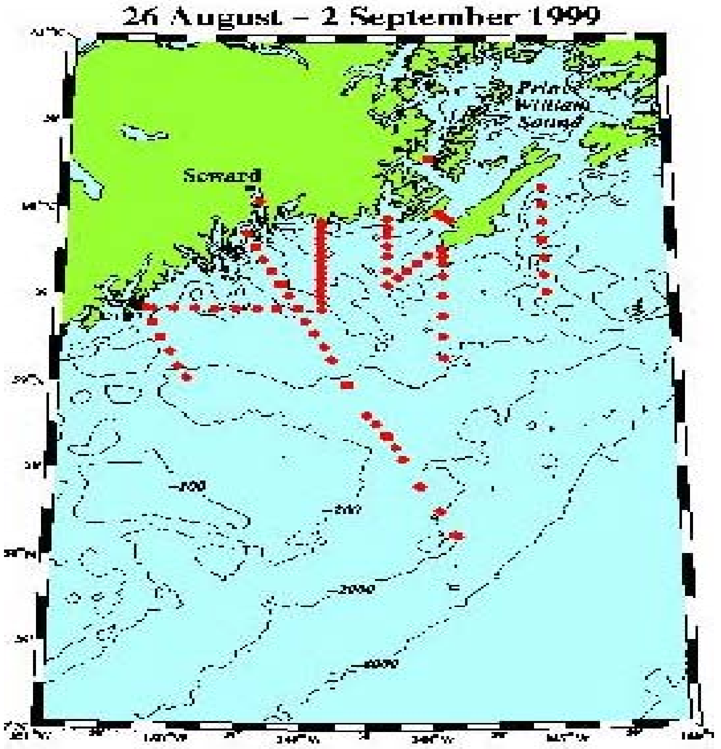


Fig. 1 Coastal Gulf of Alaska long-term observation program. (CTD, ADCP, nutrients, chlorophyll, zooplankton biomass, species composition, multi-frequency acoustics, fish abundance, composition, diet, along-track data: S, T, F, winds, etc.).

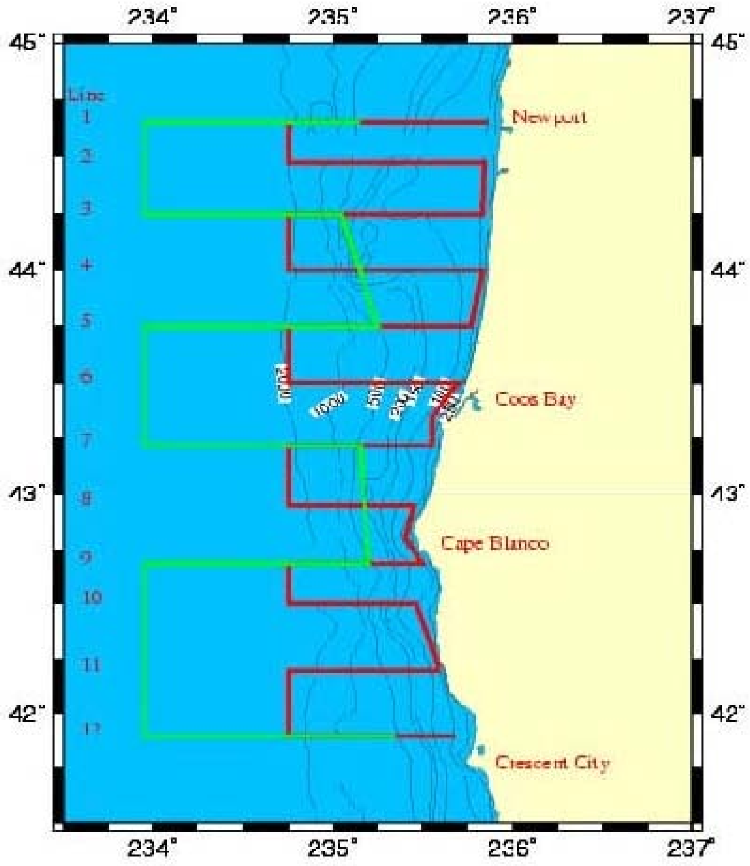


Fig. 2 *A priori* cruise lines for California Current mesoscale survey.

Table 3 U.S. GLOBEC long-term observation program in the Gulf of Alaska.

Year	**97**				**98**						**99**						**00**		
Month=>	10	3	4	5	7	10	12	3	4	5	8	10	12	3	4	5	8	10	12
Seward	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Fairfield	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cleare	X	X	X		X				X		X	X		X		X	X		
Hinchenbrook				X	X		X				X		X			X	X		
Clear SW	X		X		X						X	X							

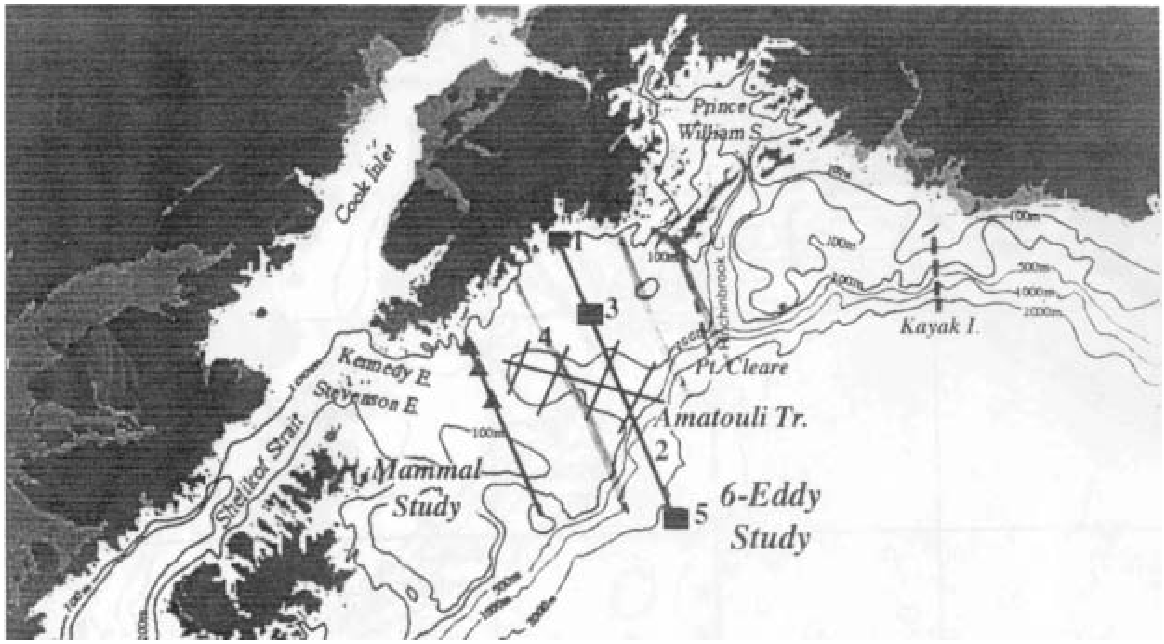


Fig. 3 Proposed sampling lines for a May 2001 cruise in the Coastal Gulf of Alaska. Squares (Seward Line) and triangles (Gore Pt. Line) are the proposed locations of moorings to be deployed on the shelf in May 2001. Transect lines parallel to the Seward line will be occupied for CTD and plankton sampling. The grid of transect lines in Amatouli Trough will be occupied for CTD and plankton sampling. Satellite tracked drifters will be released from locations in the vicinity of the moorings.

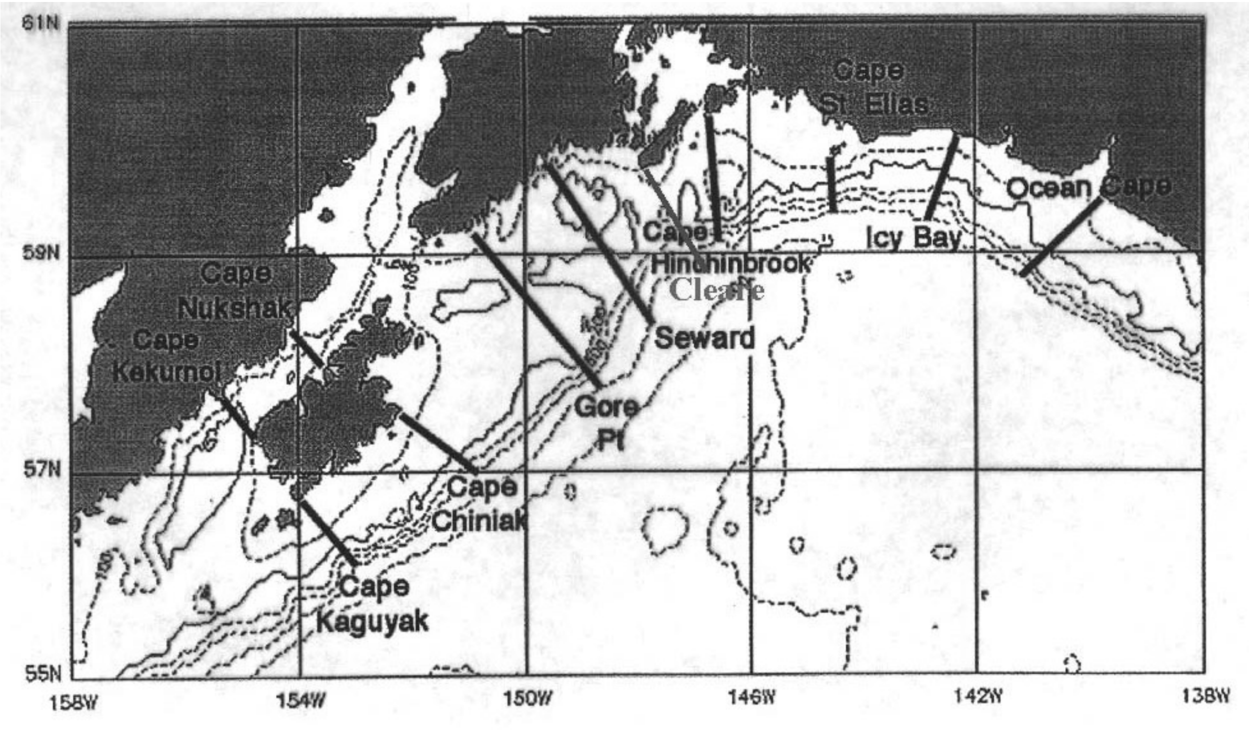


Fig. 4 GLOBEC 2000: Gulf of Alaska juvenile salmon distribution transects (Helle, Cokelet, Farley, Hollowed and Stabeno).

Table 4 Satellite data sets.

Primary Data Sets Available NOW	Other Data Sets To be ADDED
AVHRR SST • Pathfinder, 9-km SST, 18-63°N, 108-170°W, 1992-98, will be continued • 1-km and 3-km pixel SST, 18-55°N (Calif. Current), all available data 1982-present; 1982-1992: sparse temporal coverage; 1992-present: 2-4 images/day • http://coho.oce.orst.edu: get data using anonymous FTP	SeaWiFS Surface Pigments in California Current Sept 1997-present; 8-day composites from Andrew Thomas (Marine); single images from Scott Pegau (OSU) Altimeter SSH Fields from TOPEX and ERS-2 (on request from Ted Strub, OSU) QuikScat wind stress fields from Dudley Chelton, OSU (Feb.-Sept. 2000); anonymous FTP

The Continuous Plankton Recorder survey of the North Pacific

Sonia D. Batten[1] and David W. Welch[2]

[1] Sir Alister Hardy Foundation for Ocean Science, 1 Walker Terrace, Plymouth, UK. PL1 3BN E-mail: soba@wpo.nerc.ac.uk

[2] Department of Fisheries and Oceans, Pacific Biological Station, 3190 Hammond Bay Road, Nanaimo, B.C., Canada. V9R 5K6 E-mail: welchd@pac.dfo-mpo.gc.ca

Two years of funding were approved to operate a CPR survey in the North Pacific during 2000 and 2001. The resources were allocated so that the route from Alaska to California was sampled 5 times throughout the spring and summer of 2000, and the route from Vancouver west towards Japan was operated once in summer (Fig. 5). The same sampling plan will operate in 2001 and perhaps into the future if further funding can be obtained.

The CPR is towed behind merchant ‘ships of opportunity’ (in this case a crude oil carrier and a container ship) at a fixed depth of about 7 m. The filtering mesh within the CPR is 270 µm and each sample is equivalent to 18 km and about 3 m^3 of seawater filtered.

1135 samples were collected during 2000, of which about 450 have been, or will be, fully processed. The remaining samples will be archived. On most deployments every 4th sample was designated for processing, but on selected tows every 2nd, or even sequential, samples will be processed. This will enable spatial scales of variability to be better resolved.

Table 5 Taxonomic entities separately enumerated on the first 4 deployments of 2000, 137 distinct taxa were recorded.

Zooplankton	
Atlanta spp.	Harpacticoida
Bryozoan larvae	Hyperiidea
Cephalopoda larvae	Lamellibranch larvae
Chaetognatha	Larvacea
Cirripede larvae	Ostracoda
Cladocera	Polychaete larvae
Clione spp.	Radiolaria
*Copepods – 38 species/genera	Sergestidae
Decapod larvae	Siphonophora
Echinoderm larvae	Thecosomes
Euphausiidea	*Tintinnids - 4 genera
Fish eggs/larvae	*Tomopteris*
Foraminifera	
Phytoplankton	
Coccolithophores	*Dinoflagellates – 28 species/genera
*Diatoms – 39 species/genera	Silicoflagellates

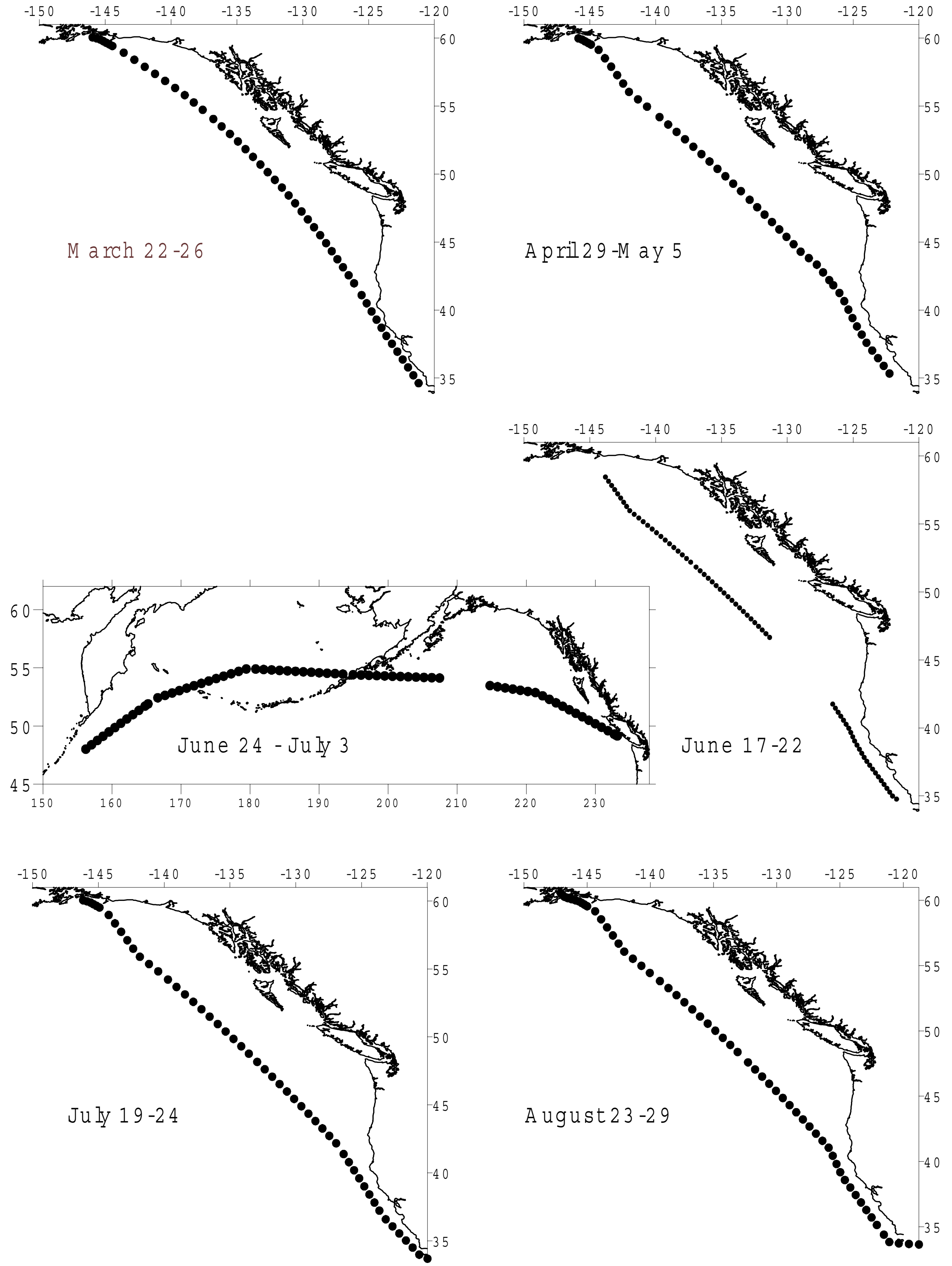


Fig. 5 The position of each processed CPR sample collected in 2000 (with dates of deployment).

Taxonomic resolution of the plankton entities on a CPR sample varies between taxa, according to the preservation of the diagnostic features by the sampling process, so that copepods and dinoflagellates are generally identified to species, but some groups are identified only to the phylum level. Table 5 indicates the taxonomic entities recorded so far on the 2000 samples.

The CPR survey is not yet a time series, however, it is already possible to describe some seasonal and spatial distribution patterns. The copepod *Neocalanus plumchrus,* for example, is one of the most numerous mesozooplanktonic organisms in the subarctic Pacific, and Figure 6 shows its abundance along the 5 north to south transects collected in 2000. This species overwinters at depth, reproduces there and ascends to reach the surface as late naupliar stages in spring. They mature through to copepodite stage 5, accumulate lipid and then descend again in late summer. Figure 6 clearly indicates that individuals were at the surface by late March in the Gulf of Alaska, with arrival probably peaking in April, and that maturation and descent started by June and was completed by late August.

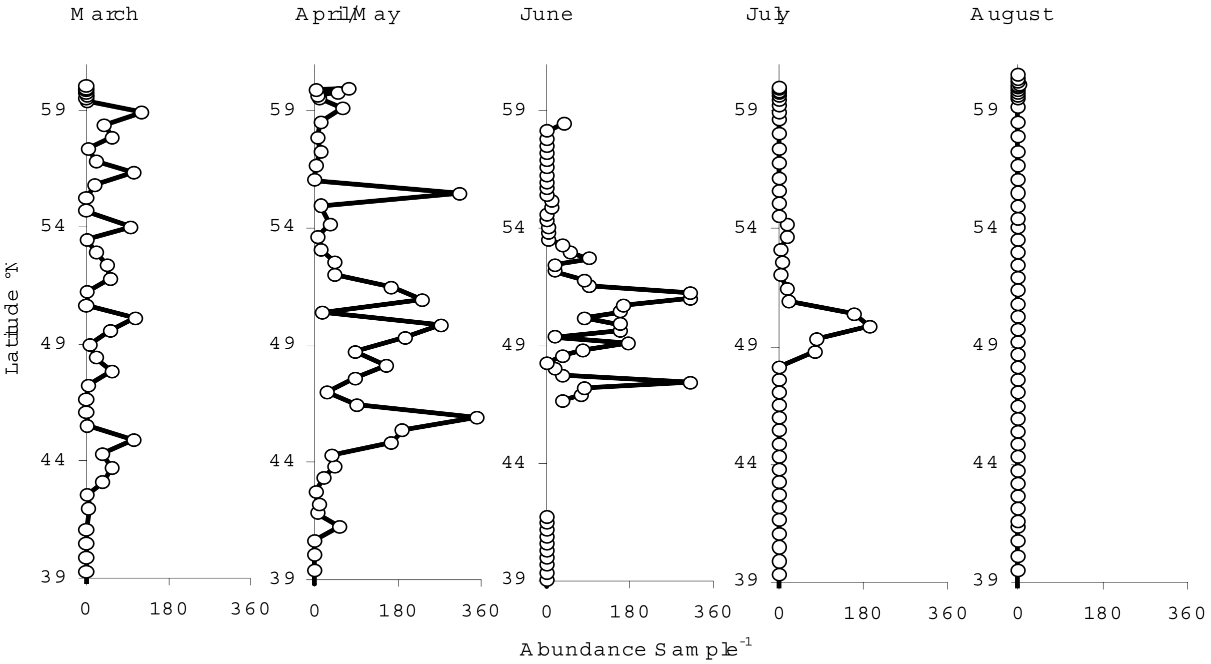


Fig. 6 The abundance of *Neocalanus plumchrus* (plus *N. flemingeri*) on each processed sample from the Alaska to California transect in 2000. Copepodite stages 2 to 5 have been combined. No individuals were found south of about 41ºN.

Micronekton data sets in North Pacific

Richard D. Brodeur
College of Ocean & Atmospheric Sciences, Oregon State University, Newport, OR 97365-5296, U.S.A.
E-mail: Rick.Brodeur@noaa.gov

The members of the PICES Micronekton Working Group (WG 14) were asked to poll the researchers from their own countries who have conducted or are presently conducting a micronekton sampling program to provide data on potential time-series of observations. Responses from Japan, Russia, China, Korea, and the United States have been received and compiled into the attached tables. In

Table 6 Summary of US sampling of micronekton in the North Pacific.

Organization	Principal Investigator	Area Studied	N of sampling times a year	Years sampled	Sampling gear used	Main purpose of study	Microneckon sampled
NMFS/SWFSC Honolulu	G. Boehlert/ M. Seki	Southeast Hancock Seamount	1	Summer 1984 Winter 1985	1.8 m IKMT	Micronekton fauna around seamounts	Myctophids
NMFS/SWFSC Honolulu	C. Wilson	Southeast Hancock Seamount	2	Summer 1987 – Fall 1998	1.8 m IKMT	Interaction of currents and micronekton	*Maurolicus, Gnathophausia*
NMFS/SWFSC Honolulu	J. Polovina	Hawaiian Archipelago	1 to 2	April 1988, June, October 1999	100 m^2 small mesh rope trawl	Examine lobster larvae distribution	*Panularis* phyllosoma
NMFS/SWFSC Honolulu	J. Polovina	Hawaiian Archipelago	3	January, July, October 1991	140 m^2 small mesh Cobb trawl	Examine lobster larvae distribution	*Panularis* phyllosoma
NMFS/SWFSC Honolulu	W. Matsumoto/ M. Seki	Subarctic Frontal and Transition Zone	1	August 1993	140 m^2 small mesh Cobb trawl	Distribution and abundance of flying squid	*Ommastrephes bartramii*
NMFS/SWFSC Honolulu	M. Seki	Subarctic Frontal and Transition Zone	1	March-April 1992	140 m^2 small mesh Cobb trawl	Examine micronekton in relation to oceanic fronts	Mesopelagic fishes and squids
NMFS/SWFSC Honolulu	M. Seki	Subarctic Frontal and Transition Zone	1	August 1991	140 m^2 small mesh Cobb trawl	Examine micronekton in relation to oceanic fronts	Mesopelagic fishes and squids
NMFS/SWFSC Tiburon	S. Ralston	California Current off Central Calif.	3	May-June 1983-2001	140 m^2 small mesh Cobb trawl	Examine juvenile fishes in relation to ocean conditions	*Sebastes*
NMFS/AFSC Seattle	R. Brodeur/ M. Wilson	Eastern Bering Sea around Pribilof Islands	1	September 1994-1999	140 m^2 small mesh Cobb trawl	Examine juvenile fishes in relation to tidal fronts	*Theragra chalcogramma*
NMFS/AFSC Seattle	R. Brodeur/ M. Wilson	Eastern Bering Sea around Pribilof Islands	1	September 1994-1999	Methot or IKMT trawl	Examine juvenile fishes in relation to tidal fronts	*Theragra chalcogramma*
NMFS/AFSC Seattle/ Hokkaido Univ.	R. Brodeur/ L. Ciannelli/ N. Shiga	Eastern Bering Sea around Pribilof Islands	1	July 1995-2001	Methot Beam Trawl	Examine shelf distribution of micronekton	*Theragra chalcogramma*
NMFS/AFSC Seattle	E. Sinclair/ P. Stabeno/ T. Loughlin	EBS, Unimak Pass, Pribilof Canyon	1	May 1999-2000	Aleutian Wing Trawl with fine liner	Examine habitat of mesopelagic fish and squid	*Stenobrachius, Bathylagus*
NMFS/AFSC Seattle	C. Wilson/ R. Brodeur	California Current from Wash.-Calif.	1	July-September 1995, 1998	Methot trawl	Mesopelagic taxa causing acoustic backscatter	*Stenobrachius, Diaphus*, euphausiids
Oregon State University	W. Pearcy/ R. Brodeur/ J. Shenker	Oceanic Gulf of Alaska	1	July 1980-1985	1.8 m IKMT and RMT	Examine prey of adult salmon	Mesopelagic fishes and squids

Table 7 Summary of Japanese sampling of micronekton in the North Pacific.

Organization	Principal Investigator	Area Studied	N of sampling times a year	Years sampled	Sampling gear used	Main purpose of study	Micronekton sampled
SNFRI (JFA)	S. Ohshimo	W Japan Sea	1	1993-1995	Midwater trawl and acoustic	SSE, jack mackerel and sardine	*Maurolicus japonicus* (*muelleri*)
SNFRI (JFA)	S. Ohshimo	E Eastern China Sea	2	1997-present	Midwater trawl and acoustic	SSE, jack mackerel and sardine	*Diaphus regani*
TNFRI (JFA)	H. Sugisaki	Off Pacific coast of N Honshu	4	1998-present	MOCNESS 4 m^2, MOHT net	Micronekton	N/S
HU (HNFRI(JFA))	K. Miyashita (H. Honda)	Off Pacific coast of NE Honshu and Hokkaido	2	1996-present	Acoustic (EK500)	Walleye pollock	N/S (*D. theta, L. jordani, S. leucopsarus*)
HU (Tottori Pref.)	K. Miyashita	Japan Sea	N/A	N/A	70kHz), KFC3000 (38, 120kHz)	N/A	*Maurolicus japonicus* (*muelleri*)
TNFRI (JFA) (HU)	D. Kitagawa (K. Uchikawa)	Off Pacific coast of NE Honshu	1	1995-present	Bottom trawl	Sampling for bottom fishes	*Diaphus watasei, Diaphus theta, Lampanyctus jordani*
HNFRI (JFA)	K. Nagasawa, A. Nishimura	Bering Sea Basin and Shelf	1	1989-1991, 1994	Acoustic, Midwater trawl	Horizontal and vertical distribution of mesopelagic fishes	*Theragra chalcogramma, S. leucopsarus*
ORI (NFRI (JFA))	T. Kikuchi (YNU)	Off Pacific coast of Honshu	1	1981-1984	KOC-net, KMT-net	Radioactivities of marine organisms	Mesopelagic shrimps
Ori (jamarc)	K. Kawaguchi	Off Pacific coast of N Honshu	1	1994-1996	Midwater trawl	Micronekton	N/S
TNFRI	K. Taki	37-41N, 142-145E	4	1997-present	130 cm Ring net, 1 m^2 MOCNESS	Ecology of Euphausiids	Euphausiids
TNFRI	H. Sugisaki	36-42N, 141-147E	1	1998-present	130 cm Ring net, 1 m^2 MOCNESS	Food availability for Cololabis saira	N/S
HNFRI	A. Tsuda	39-43N, 145-147E	6	1988-present	Bongo	Ecology of zooplankton	N/S
HU	Y. Sakurai, K. Uchikawa	NW Pacific Ocean (155E, 175.30E)	1	1995, 1997-2000	Beam trawl (5 m^2)	Ecology of micronekton and zooplankton	N/S
ORI	K. Kawaguchi	Subarctic Pacific, Bering Sea	1	1997	RMT 8+1, IKMT	Community structure of zooplankton and micronekton	Myctophids, shrimps, squids, zooplankton

Table 8 Summary of Russian sampling of micronekton in the North Pacific.

Organization	Principal Investigator	Area Studied	N of sampling times a year	Years sampled	Sampling gear used	Main purpose of study	Micronekton sampled
TINRO	A. Balanov, V. Radchenko	Western Bering Sea	1	1989, 1990	Midwater trawl	Mesopelagic Ecosystem	Bathylagidae, Myctophidae
TINRO	E. Illinsky, V. Lapko	Okhotsk Sea	1	1989-1991	Midwater trawl	Mesopelagic Ecosystem Surveys	Bathylagidae, Myctophidae
TINRO	E. Illinsky, V. Lapko	Okhotsk Sea	1	1998-1999	Midwater trawl	Epipelagic Ecosystem Surveys	
TINRO	O. Ivanov	East of Kamchatka, Kuril Islands	1	1987, 1989, 1991-1995	Acoustic Midwater trawl	Scattering Layer Identification	Myctophids, Cephalopods
TINRO	V. Savinykh	NW Pacific, Transition, Subtropical	1	1990-1991	Midwater trawl	Epipelagic Ecosystem Surveys	
TINRO	V. Savinykh	California Current	1	1988-1989	Midwater trawl	Epipelagic Ecosystem Surveys	*Ceratoscopelus*, Cephalopods
TINRO	E. Karedin	North Pacific and Gulf of Alaska	1	1989	Midwater trawl	Epipelagic Ecosystem Surveys	

Table 9 Summary of Chinese and Korean sampling of micronekton in the North Pacific.

Organization	Principal Investigator	Area Studied	N of sampling times a year	Years sampled	Sampling gear used	Main purpose of study	Micronekton sampled
YSFRI	Q, Tang, X, Jin, X, Zhoa	Bering Sea, Aleutian Basin	1	June-August	Acoustic (EK-400), midwater trawl	Acoustic and trawl	*Stenobrachius*, Bathylagids
NFRDI/WSFRI Incheon	W.D. Yoon	Yellow Sea	6	April 1997-August 2000	Omori type vertical obliqu	Distribution, composition & biomass	Euphausiids, fish larvae

some cases, micronekton were not the primary targets of the sampling but were included because micronekton were routinely collected along with the target species. Information on sampling since 1980 has been requested but in many cases programs started much earlier (back in the 1960s - sampling of Oregon State University (OSU), University of Washington (UW), Fisheries & Oceans Canada (DFO), Ocean Research Institute, Japan (ORI), and others). The attached Tables 6-9 should be considered only a provisional summary, as more data sets will be added in the coming months and hopefully augmented by data from the other WG 14 members. It is envisioned that a final table will be provided for the Micronekton Working Group Final Report that is planned to be completed in 3 years.

As shown in Tables 6-9, most of the studies were conducted over a period of less than 5 years and many are only 1-2 years in length. Few surveys were conducted more than once per year so we are not able to evaluate seasonal differences in micronekton. Due to these short time periods of observations for most of the studies, it will be difficult to examine interannual or decadal trends in biomass or species composition. The only way to do this is to compare among different studies led by various investigators, such as that done for the Gulf of Alaska by Beamish *et al*. (Progress in Oceanography, 1999, 43 (2-4): 399-442). The lack of data on long-term trends in micronekton abundance reinforces the need to maintain continuous sampling of these midwater organisms in the future.

Zooplankton in the California Cooperative Oceanic Fisheries Investigations

David M. Checkley, Jr.
Marine Life Research Group, Scripps Institution of Oceanography, 9602 La Jolla Shores Drive, La Jolla, CA 92093-0218, U.S.A. E-mail: dcheckley@ucsd.edu

The California Cooperative Oceanic Fisheries Investigations (CalCOFI) was established in 1949. The goals of CalCOFI, restated in the 1980s, are:

> …to understand the physical and chemical environment and how it changes, to determine the productivity of the California Current ecosystem, and to make this information available …. The ultimate goal is to understand and predict fluctuations in marine populations and to provide a basis for the wise use of these resources. (Hewitt 1988, p. 38)

Here, I focus on the zooplankton, with only brief reference to the phyto- and ichthyoplankton. Since 1949, more than 55,000 zooplankton samples have been collected and archived in the Pelagic Invertebrates Collection of the Scripps Institution of Oceanography (Mark Ohman, personal communication). In the following paragraphs, I present salient features of zooplankton work within CalCOFI, both historical and ongoing.

Historical

The following information is taken from Hewitt (1988). Zooplankton collections and other collections and observations have been made off the coast of California since the 1920s. The demise of the Pacific sardine (*Sardinops sagax*) in the late 1940s led to the creation of the Marine Research Committee in 1949, comprised of the California Department of Fish and Game (CDFG), the US Bureau of Commercial Fisheries (USBCF), the Scripps Institution of Oceanography (SIO), and the California Academy of Sciences. Focus was on the sardine and the ecosystem in which it lives. It was determined that "plankton and water samples be collected over a fixed grid of stations at periodic intervals". The sampling grid was adopted in 1951, following exploratory surveys in 1949 and 1950. Since then, sampling has occurred over varying intervals and extents. In 1957, the present CalCOFI Committee was created, consisting of a member from each of the CDFG, USBCF (now NOAA), and SIO.

Funding

Primary costs of CalCOFI are shiptime, personnel and equipment. Routine costs are borne primarily by the US government, through the Southwest Fisheries Science Center of NOAA, and the State of California, through the Marine Life Research Group of the University of California, San Diego, and the California Department of Fish and Game. Non-routine activities are supported, in general, extramurally, e.g. by NASA, NSF, ONR, or Sea Grant.

Sampling changes

The following is taken largely from Rebstock (2001). As with other long-term monitoring programs, the CalCOFI program has undergone several method changes since its inception (Ohman and Smith 1995). The extent of the spatial grid and the frequency of sampling have changed several times. The depth of tow and type of net have also changed. In 1951, the depth of plankton tows was changed from 70 m to 140 m and the current station spacing was adopted (Hewitt 1988).

In the first three decades of the program, the geographic extent of the sampling grid varied, especially in the northward and offshore directions (Hewitt 1988). In the mid-1980s, the grid was contracted to six lines, from north of Point Conception (line 77) to near the U.S.-Mexico boarder (line 93). In 1997, the grid was expanded again north to Monterey Bay (line 67). In almost all cruises, lines 77 to 93, the grid adopted in the mid-1980s, have been sampled.

For the first ten years of the program, samples were collected monthly with very few exceptions. Sampling frequency was at least quarterly through the mid-1960s, when it was changed to every third year, monthly or every other month during part of the year. Sampling returned to quarterly, every year, in the mid-1980s.

The sampling depth was increased in 1969 from 140 m to 212 m. Also in 1969, the silk net was replaced with a nylon net with a similar mesh size. In 1978, the 1 m diameter ring net was replaced by a 0.71 m diameter bongo net. The gear change coincided with a climatic shift in the Pacific basin that occurred in the winter of 1976-77. It also coincided with a period of infrequent sampling, which makes it more difficult to resolve zooplankton changes that might be due to the regime shift.

Present sampling

Sixty-six stations are routinely occupied and continuous, underway measurements and sampling performed on a grid consisting of six lines (in order of occupation, from south to north, 93, 90, 87, 83, 80, 77), as shown in Figure 7. In addition, on some cruises (recently in winter and spring), continuous, underway measurements and samples are taken along lines 73, 70, and 67 and, occasionally, lines still further north.

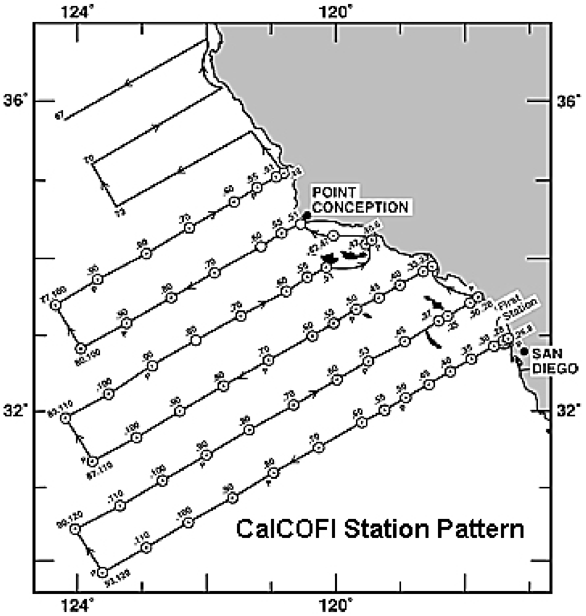


Fig. 7 CalCOFI station pattern. Shown are stations occupied during current CalCOFI cruises. Continuous, underway measurements are made between stations, along lines 93 through 77, and, recently in winter and spring, along lines 73 to 67.

1. Station sampling includes:
    1.1. CTD/rosette cast to 500 m (T, S, P; irradiance, transmission; nutrients; O_2; Chl-*a*)
    1.2. Once daily primary productivity measurements

  1.3. Bongo net (505-micron mesh; oblique to 212 m; since winter 1998, with Optical Plankton Counter on one side)
  1.4. Manta net (505-micron mesh; neuston)
  1.5. CalVET (125-micron mesh; 70 m to surface)

2. Continuous, underway measurements include:
  2.1. CUDLS (Continuous, Underway Data Logging System; T, S, Chl-*a*)
  2.2. ADCP (Acoustic Doppler Current Profiler; currents, zooplankton backscatter)
  2.3. CUFES (Continuous, Underway Fish Egg Sampler; winter and spring only; pelagic fish eggs)
  2.4. Simrad EK-500 (Acoustic echo sounder; winter and spring only; since spring 2000; fish)

Routine sample and data analysis

Physical and chemical samples are analyzed aboard ship during each cruise and ashore. Zooplankton samples (bongo) are fixed and preserved in buffered Formalin. Ashore, displacement volume is measured, ichthyoplankton is removed, and the sample is archived. Fish eggs and larvae are removed from CalVET and CUFES samples as well. Only the ichthyoplankton is routinely identified.

Data are analyzed by staff at SIO and the Southwest Fisheries Science Center of NOAA. Throughout, extreme care is taken to ensure that the quality of the data is maintained.

Non-routine programs

CalCOFI provides an excellent foundation for other plankton investigations. Examples of such programs include:

1. Bio-optics and remote sensing, including the phytoplankton
2. Phytoplankton distribution, abundance, and physiology
3. Functional studies of the zooplankton, including feeding, egg production, lipid dynamics, and diel and ontogenetic migration
4. Distribution and abundance of the zooplankton, both species and assemblages, and marine birds
5. Water column support of paleological investigations of fish and plankton

Products

Routine products of CalCOFI include:

1. Data Reports (one per two cruises; twice per year), available in hard copy and on the world wide web (http://www.calcofi.org/)
2. CalCOFI Reports (annual)
3. CalCOFI Atlas series (irregular)
4. CalCOFI CD (to obtain, contact Jim Wilkinson: jwilkinson@ucsd.edu)

Non-routine products come from special programs or analyses of routine data and are most often published in CalCOFI Reports or the peer-reviewed literature. Examples of such products germane to zooplankton time-series include:

1. Hayward and Venrick (1998)
2. Chelton *et al.* (1982)
3. Roemmich and McGowan (1995)
4. Mullin *et al.* (2000)
5. Laveniegos and Ohman (1999)
6. Checkley *et al.* 2000
7. Rebstock (2001, in press a, b)

Challenges and deficiencies

Characteristics of the CalCOFI time-series that warrant consideration include:

1. 'Gappy' time-series (uneven temporal coverage)
2. Variable spatial coverage
3. Method changes
4. Lack of sampling of microzooplankton and picoplankton
5. Lack of synthesis and modeling
6. Linkage with other time-series
7. Difficulty of maintaining support for time-series work

Conclusion

CalCOFI has routinely sampled the California Current Region since 1949, amassing time-series of physical, chemical, and biological samples and data. These time-series have been augmented by non-routine investigations. Analysis has occurred and will continue to occur. CalCOFI can be enhanced while simultaneously maintaining the continuity and integrity of the time-series.

References

Checkley, D.M., Dotson, R.C., and Griffith, D.A. 2000. Continuous, underway sampling of eggs of Pacific sardine (*Sardinops sagax*) and northern anchovy (*Engraulis mordax*) in spring 1996 and 1997 off southern and central California. Deep-Sea Research Part II-Topical Studies in Oceanography 47: 1139-1155.

Chelton, D.B., Bernal, P.A., and McGowan, J.A. 1982. Large-scale interannual physical and biological interaction in the California Current. J. Mar. Res. 40: 1095-1125.

Hayward, T. L., and Venrick, A.L. 1998. Near-surface pattern in the California Current: coupling between physical and biological structure. Deep-Sea Research Part II-Topical Studies in Oceanography 45: 1617-1638.

Hewitt, R. 1988. Historical review of the oceanic approach to fishery research. CalCOFI Rep. 29: 27-41.

Lavaniegos, B.E., and Ohman, M.D. 1998. Hyperiid amphipods as indicators of climate change in the California Current. Fourth International Crustacean Congress: Crustaceans and Biodiversity, Amsterdam, The Netherlands, Brill.

Mullin, M.M., Goetz, E., Beaulieu, S.E., and Lasker, J.M. 2000. Comparisons within and between years resulting in contrasting recruitment of Pacific hake (*Merluccius productus*) in the California Current System. Can. J. Fish. Aquat. Sci. 57: 1434-1447.

Rebstock, G. 2001. Long-term changes in the species composition of calanoid copepods off southern California. Ph.D. Dissertation, Scripps Institution of Oceanography. La Jolla, University of California, San Diego.

Rebstock, G. 2001 An analysis of a zooplankton sampling-gear change in the CalCOFI long-term monitoring program, with implications for copepod population abundance trends. Prog. Oceanogr. (in press).

Rebstock, G. 2001 Long-term stability of species composition in calanoid copepods off southern California. Mar. Ecol. Prog. Ser. (in press).

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

Japan Sea time-series: Qualitative study on lower trophic level ecosystem may reveal the process on climate - ecosystem interaction

Sanae Chiba
Frontier Research System for Global Change, Sumitomo-Hamamatsucho Building 4F, Hamamatsu-cho, Tokyo 105-0013, Japan. E-mail: chibas@frontier.esto.or.jp

Why the Japan Sea?

Despite its small size, the Japan Sea is a so-called "Mini Ocean" as it has the characteristics of an ocean. The average depth is over 1,000 m and its hydrographic conditions are influenced by large oceanic gyres. Thanks to the small size and semi-closed feature, the Japan Sea is a "Model Ocean" that may give us a good opportunity to study climate-ecosystem interaction.

PM line observation

Background

Maizuru Marine Observatory of the Japan Meteorological Agency has conducted routine oceanographic research cruises along the PM line for more than 30 years (Fig. 8). The description of the data set is given in Table 10. We are conducting a study of decadal-scale ecosystem change at three of the PM stations, which are located in the offshore Tsushima Current area.

How?

In the Japan Sea, chlorophyll-*a* was reported to have declined with a corresponding water temperature decrease (upper water column mean) during the 1980s (Fig. 9). This is the period when the climate/ecosystem regime shifts have been observed in vast areas of the North Pacific. Changes in zooplankton wet weight follow changes in water temperature. However, the observed correlation does not explain PROCESS and CONSEQUENCE of the change. By using diatoms and zooplankton species composition data of the PM line, we are trying to determine the PROCESS and CONSEQUENCE, and the "Let the plankton community tell their story" strategy.

Preliminary results

We observed a distinct change in the diatom community structure in spring during the 1980s. Chlorophyll-*a* concentration and Chl-*a* to cell ratio were markedly low (Fig. 10), and summer-adapted species including *Pseudonitzschia seriata* dominated the diatom community in spring during 1980s (Fig. 11). Mixed layer phosphate concentration was somewhat high in winter but low in spring during the 1980s, indicating that nutrient depletion occurred earlier to a level that was limiting diatom growth (Fig. 12). This change might subsequently cause a shift of the dominant diatom species from the eutrophic-adapted to the oligotrophic-adapted. The water density profile between the surface and 300 m showed the thickness of the surface Tsushima Current and the cold sub-surface water decreasing and increasing, respectively, from the late 1970s to the late 1980s, resulting in more intensive stratification of the upper water column (Fig. 13a). Increase in phosphate gradient between the surface and sub-

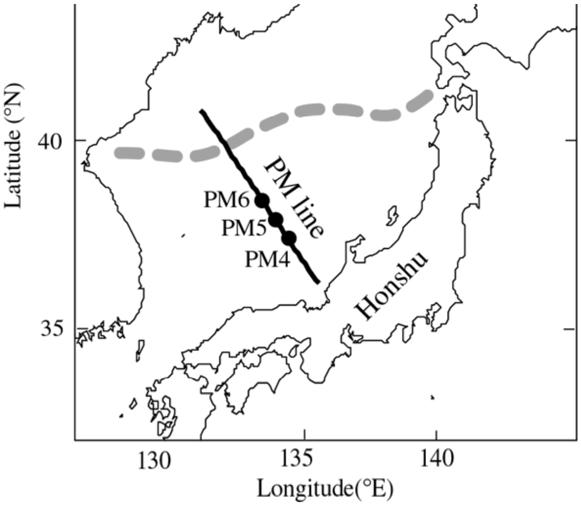


Fig. 8 Location of the PM line.

Table 10 PM line oceanographic data set [Source: Maizuru Marine Observatory, Japan Meteorological Agency (JMA); Ship Observation (*Seifu-Maru* II-III); Station PM1 - 9 (location of the stations north of the PM6 changed in 1977 and 1996)].

Observation items	Sampling depth	Period	Duration	Frequency	Sampling gear
Hydrography * water temperature and salinity * DO, * pH * PO_4, NO_3, NO_2 * Chl-*a*, pheopigment	profile (0 – up to near bottom)	1972 –	>29yr	4 times /yr	Nansen cast or CTD cast with Niskin bottle
Phytoplankton	surface			- ditto-	bucket
* diatom cell number		1972 –	>29yr		
* diatom species composition		1972-98	27yr		
Zooplankton	0-150 m tot.			- ditto-	NORPAC net (mesh: 0.33 mm)
* plankton wet weight		1972-98	27yr		
* Chaetognath species composition		1972-98	27yr		
*composition of major zooplankton taxa		1991-99	9yr		
* Copepod comp. (species & size)		1991-99	9yr		

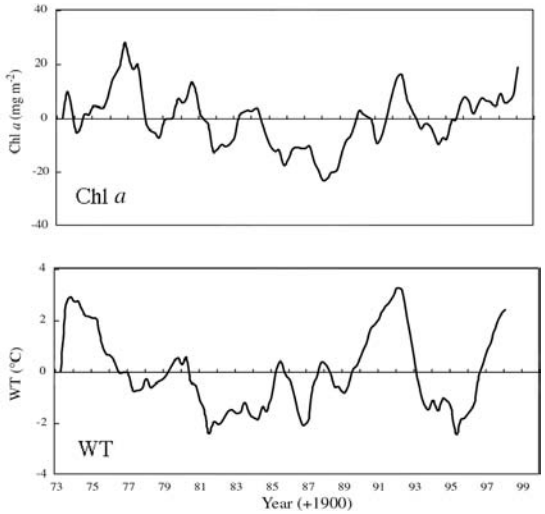


Fig. 9 Interannual variability of Chl-*a* and water temperature (5 seasons running mean).

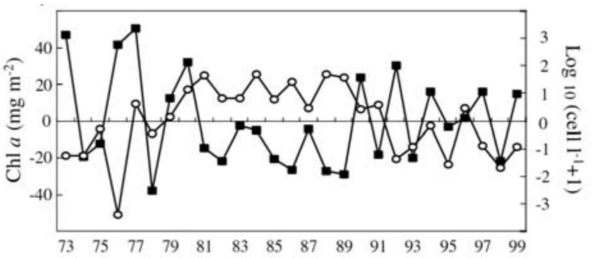


Fig. 10 Interannual variability of spring Chl-*a* (■) and diatom cell number (○).

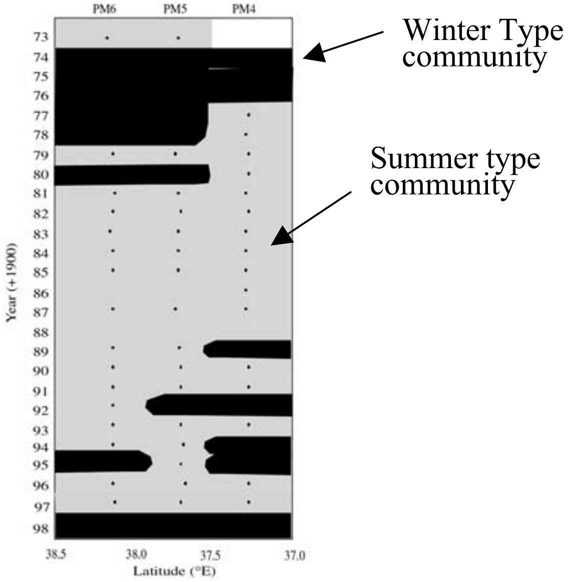


Fig. 11 Spatio-temporal distribution of spring diatom community. Black area: winter adapted species dominant; gray area: summer adapted species dominant.

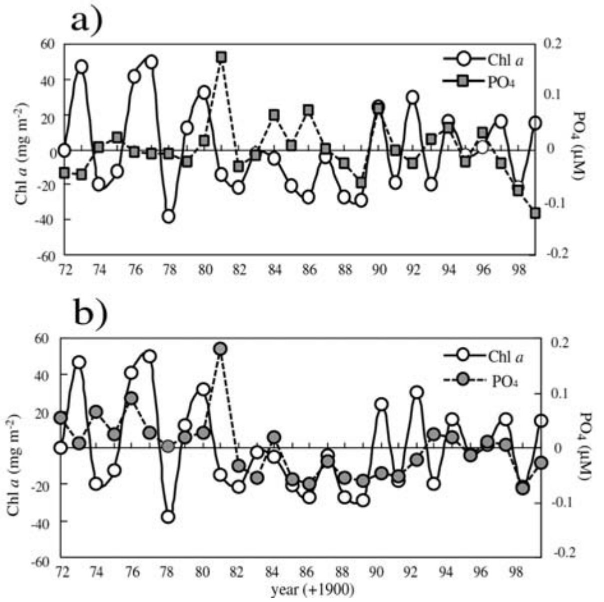


Fig. 12 (a) Winter PO_4 within a mixed layer and spring Chl a and (b) Spring PO_4 and Chl-*a*.

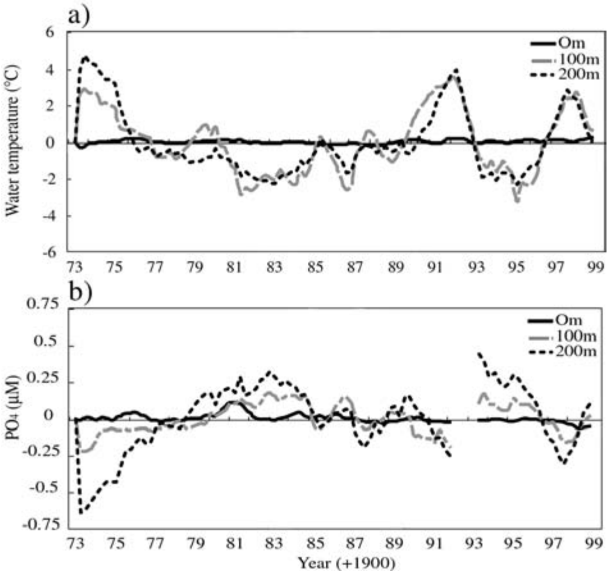


Fig. 13 Water temperature (a) and PO_4 (b) at three depths (0, 100, 200 m) (5 seasons running mean).

surface layers (Fig. 13b) suggested that the intensification of stratification might reduce nutrient supply to the surface and be responsible for the early formation of summer-like conditions.

The sizes of *Pseudonitzschia* spp. are generally smaller than centric diatoms which were exclusively dominant before and after the 1980s. In addition, *Pseudonitzschia* spp. were reported to be unfavorable food for copepods, the major secondary producer. Considering the decrease in particle size and grazing pressure by copepods, the functioning of the Biological Carbon Pump might be weakened during these periods. As a next step, we will look into the zooplankton species composition to test the hypothesis.

Collective Japan Sea data set

The PM line plankton study is based on data taken only at 3 stations. To reveal the climate change and its influence on upper water environment, we are collecting data taken in the whole area in the Japan Sea (Table 11). Our goal is to compare the Japan Sea results with what happened in the other oceanic regions of the North Pacific, and to elucidate the large-scale interaction between the climate and upper water environment.

Table 11 Japan Sea Collective data set (to be analyzed).

Observation items	Sampling depth	Source	Period	Duration	Sampling gear
Hydrography * water temperature * salinity * DO, * pH * PO_4, NO_3, NO_2, SiO_2 (less frequent)	profile (0 – up to near bottom)	Japan Oceanographic Data Center (JODC), JMA	1966-98	33yr	Nansen cast or CTD cast with Niskin bottle
* Chl-*a*, pheopigment			1974-98	25yr	
Plankton wet weight	0-150 m tot.	National & local Fisheries Research Institutes etc. (summarized in Hirota & Hasegawa 1999, Fish. Oceanogr. 8) and JODC & JMA	1966-98	33yr	Marutoku net or NORPAC net (mesh: 0.33 mm)
Climate * solar radiation * sea level pressure * wind speed, vector * wave height * cloudiness		JMA (collected by Volunteer ships)	1961-96	36yr	
* precipitation (land)		JMA, local observatories			

Phytoplankton data from the Gulf of Alaska, British Columbia and the Pacific coast of the U.S., with emphasis on harmful algal bloom species

Rita Horner
School of Oceanography, University of Washington, Box 357940, Seattle, WA 98195-7990, U.S.A. E-mail: rita@ocean.washington.edu

Gulf of Alaska

As part of the Alaskan Outer Continental Shelf Environmental Assessment Program (a program designed to provide baseline data on the Alaskan continental shelf prior to any possible petroleum development), Anderson *et al.* (1977) compiled the available baseline biological and associated physical and chemical data. The objectives were to describe the temporal and geographic variation in phytoplankton standing stock (and species), primary production, and related physical and chemical factors, and use the data in a model of phytoplankton productivity tested with changes in physiological constants and external parameters. The data go back to 1958 and include cruises to Weather Station P from 1959-1970; American Mail Line cruises along a great circle route from Seattle to Yokohama in 1968-1972; and Japanese, Russian, and U.S. cruises at various times between 1958 and 1974 (Fig. 14 and Table 12). The area was divided into geographic zones (Fig. 15) and the phytoplankton data were tabulated by season for each zone (Fig. 16). The data are available at NODC.

SUPER (SUbarctic Pacific Ecosystem Research cruises)

These cruises to Weather Station P (50°N, 145°W; Fig. 15, zone 33) in May and August 1984 and 1988, and June and September 1987, were designed to determine why there are no sustained phytoplankton blooms in this high nutrient, low chlorophyll (HNLC) region. The results of the phytoplankton sampling are found in Horner and Booth (1990) and Booth *et al*. (1993). The results of the whole project are in Miller (1993). All phytoplankton data have been submitted to NODC.

Canadian cruises

A series of cruises from 1950 to the present and often including the Station P Line (Fig. 17; between the entrance to the Strait of Juan de Fuca and Station P) involved Canadian Navy, Coast Guard and research ships (e.g., Stephens 1977). Both WOCE and Canadian JGOFS programs sampled these sites.

Records from 802 samples collected along the British Columbia coast between 1980 and 1988 were examined by Forbes and Denman (1991) for the presence of *Pseudo-nitzschia* species (formerly *Nitzschia* spp.). These potentially toxic species were most frequently found in coastal waters inshore of the shelf break off the southwest side of Vancouver Island, and were rare in the Strait of Georgia and north of Vancouver Island (Fig. 18). *Pseudo-nitzschia* spp., here including both *P. pungens* and *P. multiseries*, were most common between April and October.

Washington cruises

The Atomic Energy Commission (AEC) and Department of Energy (DOE) cruises were designed to obtain data for a year-around study of the water characteristics along the Washington and Oregon coasts, with special emphasis on the movement and dispersion of freshwater entering the system from the Columbia River, and on the probable fate of any radioactive material that might be associated with it. Cruises occurred frequently between January 1961 and December 1966 (Table 13). Phytoplankton species samples were collected, but few were analyzed and the samples are no longer available. Chlorophyll and primary productivity data have been submitted to NODC and are also available in UW Department of Oceanography Technical Reports.

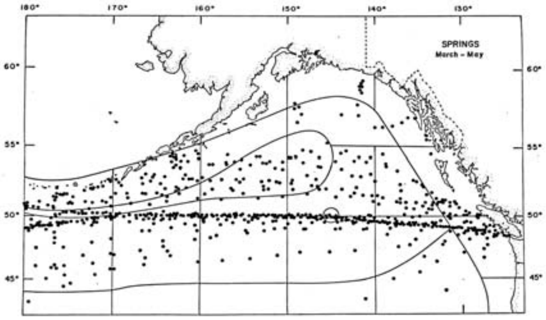


Fig. 14 Distribution of stations in the eastern subarctic Pacific where data were collected during one or more springs from 1958-1974 (from Anderson *et al*. 1974).

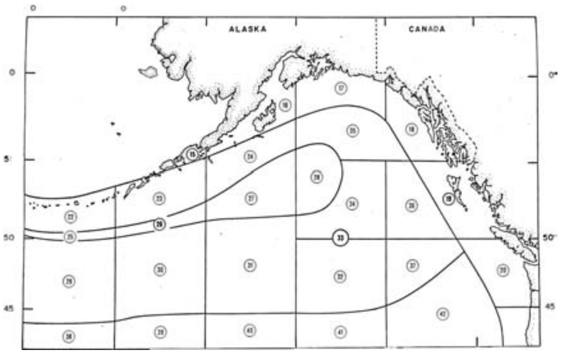


Fig. 15 Cruises along the Washington/Oregon coasts between January 1961 and December 1966 where biological data were collected.

Table 12 Cruises in the eastern subarctic Pacific between June 1958 and July 1974 used by Anderson *et al.* (1974) in their analysis of the factors affecting the processes of production in the Gulf of Alaska (from Anderson *et al.* 1974).

List of operations in the eastern subsrctic Pacific between June 1958 and July 1974 which yielded biological oceanographic data. [C=chlorophyll-*a*/m^3, C'=chlorophyll-*a*/m^2, Ph=phaeopigments/m^3, Ph'=phaeopigments/m^2, P=primary productivity/m^3, P'=primary productivity/m^2, Z=zooplankton, Sp=phytoplankton species, O=oxygen, N=nitrate, N'=nitrite, N''=ammonia, Pp=phosphate, S=silicate, D=mixed layer depth, R=total incident radiation]

Operation	Period	Zone	Type of Data	Source
Weather Station "P"				
cruises 593 to 614	1959 to 1961	33	C C' P P' Z O S R	McAllister, 1962
cruises 615 to 634	1961 to 1963	33	C C' P P' Z O S R	Stephens, 1964
cruises 635 to 655	1964 to 1966	33	C P Z O N R	Stephens, 1966
cruises 661 to 674	1966 to 1967	33	C P O N R	Stephens, 1968
cruises 681 to 706	1968 to 1970	33	C P N R	Stephens, 1970
Ships of Opportunity				
cruises 02 to 43	1968 to 1972	15, 19, 20, 22-34, 36-42	C P Sp N Pp S D R	Anderson, unpubl.
	1958			
Brown Bear 199	June to July	20, 32, 37	O Pp D	Fleming, 1959
H.M. Smith 46	Aug. to Sept.	24, 25, 29, 30, 31, 38, 39, 40	C P Z O	McGary and Graham, 1960
Vityaz 29	Oct. to Dec.	19-21, 24, 27, 29, 30, 32, 35, 37, 41, 42	P Z N Pp R	Koblentz-Mishke, 1969
	1959			
Oshoro Maru 44	June	22, 25, 29	Z O Pp	Faculty of Fisheries, 1960
Brown Bear 235	July to Aug.	15, 19, 20, 23, 24, 27, 28, 34 36	Sp Z O Pp S	Stephens, 1964
	1960			
Oshoro Maru 46	June to Aug.	18-20, 22-24, 29-32, 35, 37, 38	Sp Z O Pp S	Faculty of Fisheries, 1961 Motoda and Kawamura, 1963
	1961			
Oshawa 1961	June	19, 33, 36, 37	C O N S	Antia *et al.*, 1962
Oshoro Maru 048	June	22, 29	Z	Faculty of Fisheries, 1962
Pioneer 66	Sept. to Oct.	22, 23, 26, 29, 30, 38, 39, 42	C P Z	Doty, 1964
	1962			
Oshawa 1962	April	42	C N S	Antia *et al.*, 1962
	1964			
G. B. Reed 164	Jan. to Feb.	19, 20, 21, 24, 27, 28, 31-37 42	C	Stephens, 1964
Agassiz Ursa Major	Aug. to Sept.	16, 24, 27, 31, 40	C sp Z O N' Pp S	University of California, 1967 Venrick, 1969
	1965			
Oshoro Maru 014	June	22, 24, 25, 29	Z	Faculty of Fisheries, 1966
	1966			
Argo Zetes I	January	16, 24, 27, 31, 40	C Ph Sp Z O N N' Pp S	University of California, 1970 Venrick, 1969
Straits of Georgia	Feb. to Sept.	20	C P N N' N'' Pp S	Fulton, *et al.*, 1967
Kelez 166	March	22, 25, 29	C, C' P, P' Z Pp S D R	Larrance, 1971b
Saanich Inlet	May to July	20	C P Z N N' Pp S	Stephens, *et al.*, 1967
Paragon 266	June	22, 25, 29	C C' P P' Z Pp S D R	Larrance, 1971b
Kelez 366	September	20, 22, 29-32, 37, 38	C C' P P' Z N Pp S D R	Larrance, 1971b
	1967			
Kelez 167	Jan. to Fed.	23, 26, 30	C C' P P' Z N Pp S D R	Larrance, 1971b
T. G. Thompson 012	Feb. to Mar.	17-19, 24, 27, 28, 34-36	C C' P P' O N Pp S	Anderson, unpubl.
Kelez 367	April	19, 20, 36, 37	C D	Larrance, 1971b
Kelez 567	June to July	16, 22-25, 29	C C' P P' Z N Pp S D R	Larrance, 1971b
Kelez 667	July	22	C C' P P' Z N Pp S D R	Larrance, 1971b
Kelez 767	August	22, 25, 29	C C' P P' Z N Pp S D R	Larrance, 1971b
	1968			
Kelez 268	May	23, 26, 30	C C' Pp S D	Larrance, 1971b
Oshoro Maru 028	June to July	17, 18, 22	Z O Pp	Faculty of Fisheries, 1969

Table 12 (continued)

	1969			
Endeavour Trans Paciffic	March to April	20, 29-32, 37	C P P' Z Pp N S D R	Anon, 1970
Vityaz 045	May to June	17, 18, 23, 35	C P P'	Anon, 1973
Hakuho Maru 694	August	31	C Sp	Takahashi *et al.*, 1972 Asaoka, unpubl.
	1970			
Hakuho Maru 702	May	19, 32, 34, 37, 41	O N N' Pp S	Horibe, 1971
Oshoro Maru 037	June to July	16, 17, 18, 22- 24, 27, 31-34, 36, 37	C Z Pp N N' S	Faculty of Fisheries, 1972
Acona Cruises 113, 117, 122, 125	May to Dec.	17	C C' P P' Ph Ph' Sp O N N'' Pp S	Goering, Shiels, and Patton (1973) Goering, Patton, and Shiels (1973) Hood and Patton (1973)
	1972			
Acona 128, 131	March to April	17	C C' P P' Ph Ph' Sp O N N'' Pp S	Muench and Nebert (1973) Horner *et al.*, 1973
T. G. Thompson 072	September	24, 27, 31, 40	C C' P P' Ph Ph' O N N' N'' Pp S R	Anderson, unpubl.
	1973			
T. G. Thompson 082	August	32, 33, 41	C C' Ph Ph' O N N' N'' Pp S R	Anderson, unpubl.
	1974			
Hakuho Maru 742	May	29	C O N N' N'' Pp S	Kuroki, 1975
T. G. Thompson 091	July	36	C Ph	Anderson, unpubl.

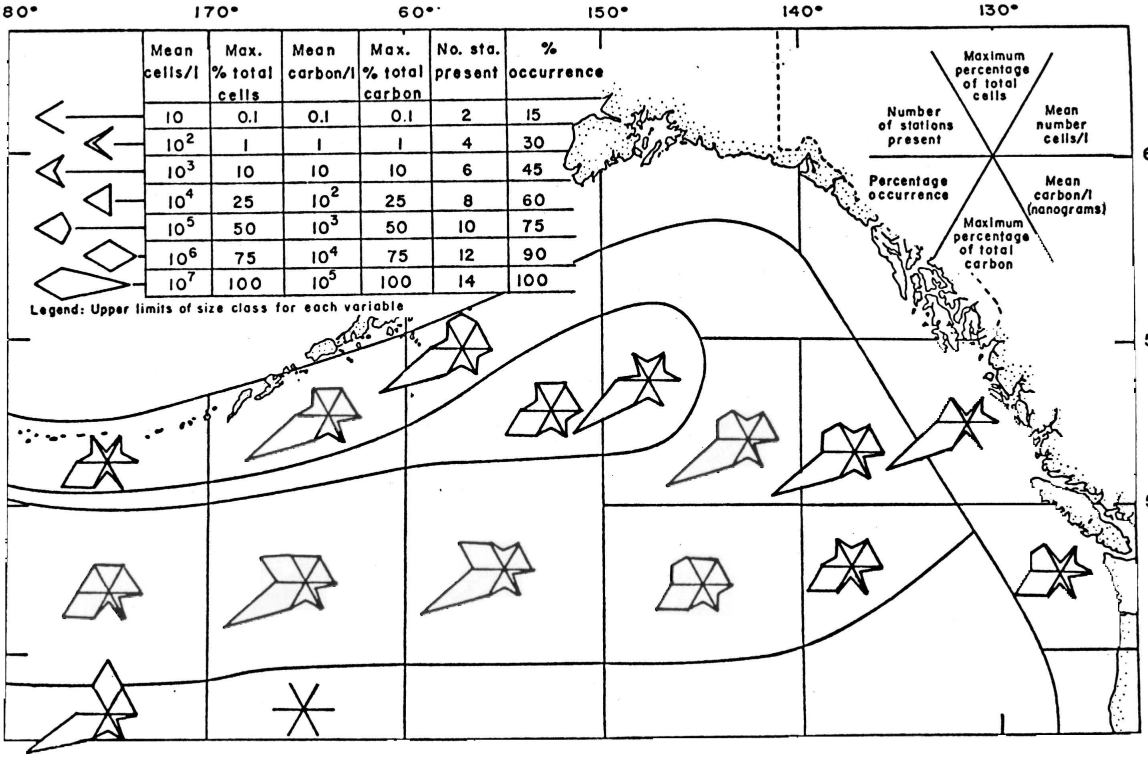


Fig. 16 Distribution of *Pseudo-nitzschia* sp. in the upper 10 m of the water column between January and July 1966 and 1969-1972 (from Anderson *et al*. 1974).

Table 13 Cruises along the Washington/Oregon coasts between January 1961 and December 1966 where biological data were collected.

List of AEC/DOE cruises, January 1961-December 1966: Washington and Oregon coast. Data have been submitted to NODC, also in University of Washington, Department of Oceanography Technical Reports. Abbreviations: T - temperature; Sal - salinity; O - dissolved oxygen; N - nitrogen; P - phosphate; S - silicate; Sp - phytoplankton species; PP - primary productivity; Ch - chlorophyll; Z - zooplankton.

Cruise	Dates	Approx. Area	Variables Sampled
Brown Bear 275	10-27/I 1961	44-48 N, 124-126 W	T, Sal, O, N, P, S, Sp, PP, Ch, Z
Brown Bear 280	7-24/III 1961	45-48 N, 124-125 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 287	8-24/V 1961	44-48 N, 124-127 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 288	9-16/VI 1961	45-48 N, 124-127 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 290	6-25/VI 1961	43-48 N, 124-128.5 W	T, Sal, O, N. P, S, Sp, PP, Ch, Z
Brown Bear 291	28/VII-13/VIII 1961	43-48 N, 124-127 W	T, Sal, O, N, P, S, Sp, PP, Ch
Brown Bear 292	14-20/VIII 1961	45-48 N, 124-128 W	T, Sal, O, N, P, S, Sp, PP, Ch
Brown Bear 293	14/IX-20/X 1961	40-48 N, 124-132 W	T, Sal, O, N, P, S, Sp, PP, Ch, Z
Brown Bear 297	28/XI-18/XII 1961	42-48 N, 124-128 W	T, Sal, O, N, P, S, Sp, PP, Ch, Z
Brown Bear 299	23/I-7/II 1962	44-48 N, 124-127 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 304	27/III-12/IV 1962	43-48 N, 124-128 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 308	7-19/VI 1962	45-48 N, 124-126 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 310	10-23/VII 1962	42-48 N, 124-130 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 311	24/VII-14/VIII 1962	40-48 N, 124-132 W	T., Sal, O, N, P, S, PP, Ch, Z
Brown Bear 312	14/IX-18/X 1962	42-48 N, 124-131 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 318	27/II-20/III 1963	44-48 N, 124-130 W	T, Sal, O, N, P, S, PP, Ch, Z
Acona 6301-E	24-25/I 1963	44 50 N, 124-126 W	Sal, N, P, S, PP, Ch
Oshawa 001	12-26/III 1963	43-48 N, 124-130 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 320	28/III-10/IV 1963	44-48 N, 124-130 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 322	16/IV-1/5 1963	43-48 N, 124-130 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 323	13-19/V 1963	45-47 50 N, 124-130 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 324	21/V-7/VI 1963	43 50-48 N, 124-128 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 326	13-23/VI 1963	45 50-48 N, 124-127 W	T, Sal, O, N, P, S, PP, Ch, Z

Table 13 (continued)

Oshawa 003	17-30/VI 1963	41 50-46 N, 124-130 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 329	8-19/VII 1963	45 N, 130 W	T, Sal, O, N, P, S, PP, Ch, Z
Hoh 73	7-25/VIII 1963	46 60-47 N, 124 W	T, Sal, O
Brown Bear 331	12-24/VIII 1963	45-47 N, 124-126 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 332	24-28/VIII 1963	46 N, 124-130 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 333	28/VIII-14/IX 1963	46-47 N, 124-124 60 W	T, Sal, O,
Brown Bear 335	20/IX - 12/X 1963	43-48 N, 124-130 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 339	3-12/XII 1963	45 50-48 N, 124-125 W	T, Sal, O, N, P, S, PP, Ch, Z
Oshawa 004	10-20/XII 1963	44-48 N, 124-139 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 341	11-27/II 1964	46 50-48 N, 124-128 W	T, Sal, O, N, P, S, Ch, Z
Oshawa 005	13-25/II 1964	46 50-48 N, 124-128 W	T, Sal, O, N, P, S
Brown Bear 344	18/V-5/VI 1964	45-48 N, 124-145 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 345	7-10/VI 1964	46 N, 124-126 W	T, Sal, O
Brown Bear 349	7-31/VIII 1964	45-48 N, 124-141 W	T, Sal, O, N, P, S, PP, Ch, Z
Oshawa 006	15-28/X 1964	45-48 N, 124-139 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 352	11-28/I 1965	45-48 N, 124-141 W	T, Sal, O, P, N, S, PP, Ch, Z
Brown Bear 353	9-19/II 1965	46-48 N, 124-125 W	T, Sal, O, N, P, S
Brown Bear 354	19-26/III 1965	46 N, 124-125 W	T, Sal, O, N, P, S
Brown Bear 355	29/III-6/IV 1965	46 N, 124-126 W	T, Sal, O, N, P, S
Brown Bear 356	9-12/IV 1965	46 N, 124-125 W	T, Sal, O
Brown Bear 357	14-28/IV 1965	45-47 50 N, 124-140 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 365	11-20/VI 1965	46-48 N, 124-125 W	T, Sal O, N, P, S
Brown Bear 367	2-7/VII 1965	46.7-48 N, 124-126 W	T, Sal O
Brown Bear 368	4-22/VIII 1965	45-48 N, 124-140 W	T, Sal, O, N, P, S, PP, Ch, Z
Brown Bear 371	14-26/IX 1965	46 N, 124-125 W	T, Sal, O, N, P, S
Brown Bear 380	3-18/XI 1965	45-47 N, 124-140 W	T, Sal, O, N, P, S, PP, Ch, Z
Oceaneer 001	15-20/VI 1966	46 N, 123-124-40 W	T, Sal O, N, P, S
Thomas G. Thompson 002	2-12/VIII 1966	44 50-48 N, 124-130 W	T, Sal O, N, P, S PP, Ch, Z
Oceaneer 006	13-23/VIII 1966	46 N, 122-124 W	T, Sal, O, N, P, S
Thomas G. Thompson 005	25/XI-1/XII 1966	46-48 N, 124-126 W	T, Sal, O

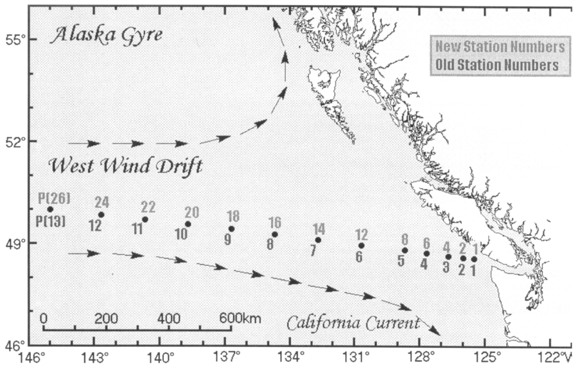


Fig. 17 Location of Ocean Weather Station P and Line P (from IOS website).

The Energy Research and Development Administration (ERDA) sponsored a biological oceanography program emphasizing waters over the continental shelf off Washington (Table 14). Cruises between July 1974 and June 1982 provided seasonal information on physical, chemical and biological properties. The Copalis Line (Fig. 19) was a series of closely spaced stations along 47°07'N from about 2 km off Copalis Head to 126°30'W, about 185 km offshore. Chlorophyll and primary productivity data have been submitted to NODC. Phytoplankton species samples were collected, but few were analyzed. These samples are also no longer available. The results of this study are in Landry and Hickey (1989).

Surf diatom studies (1970-1982)

Beach sampling of the surf diatom community occurred primarily at Copalis Beach, WA, from September 1970-1982 (Fig. 19). This study was the first attempt to achieve a comprehensive understanding of surf-diatom blooms. For most of that time, sampling was done every 3 weeks. From June 1977 to August 1978, 12 beaches in Oregon (Fig. 20) were sampled on a monthly basis. A series of papers about the physiology and ecology of the surf diatoms was published starting in 1970 (see references in Lewin *et al.* 1989). During earlier studies on surf diatoms beginning in the 1920s and throughout the Lewin study, *Pseudo-nitzschia* was never mentioned as a genus in the surf samples.

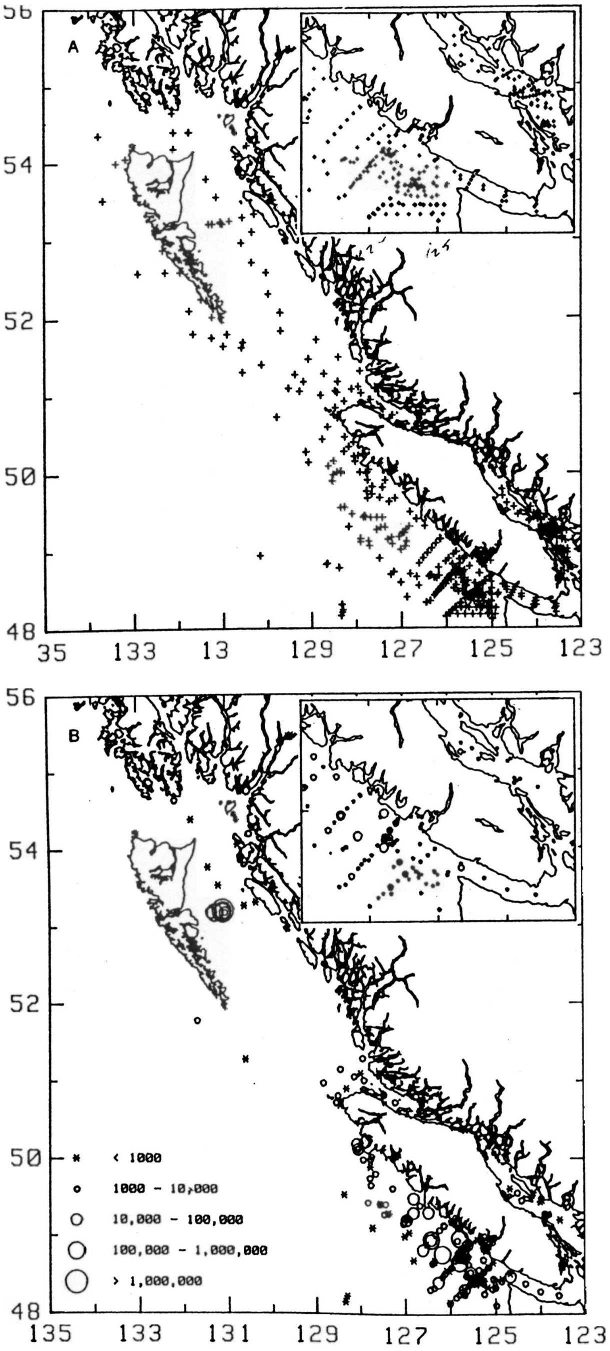


Fig. 18 Top panel: Location of all phytoplankton samples collected from 1980 to 1988 along the British Columbia coast. Inset shows detail of the southern Vancouver Island area. Bottom panel: Location of all samples containing *Nitzschia pungens* with abundances (cells L^{-1}) indicated by circle diameters. Inset as on top panel, with relative abundance indicated by circle diameters (from Forbes and Denman 1991).

Table 14 Cruises along the Washington coast between July 1974 and June 1982 (primarily the Copalis Line) where biological data were collected.

List of U.S. Energy Research & Development Administration (ERDA) cruises July 1974-June 1982, off the Washington (mostly Copalis line) and Oregon (few Newport line) coasts. Data have been submitted to NODC, also in data reports from the School of Oceanography, University of Washington. Abbreviations for variables: T - temperature; Sal - salinity, O - dissolved oxygen, N - nitrogen, P - phosphate, S - silicate, Sp - phytoplankton species, PP - primary productivity, Ch - chlorophyll, Z - zooplankton (no distinction is made here between macrozooplankton and microzooplankton), Nek - nekton.

Cruise	**Dates**	**Approx. Area**	**Variables Sampled**
TGT TT-091	8-29/VII 1974	47 07.4 N, 124 13-126 30 W	T, Sal, O, N, P, S, Sp, PP, Ch, Z, Nek
Yaquina YA 199	10-13/I 1975	46 49-47 08 N, 124 W	T, Sal, O, N, P, S, Sp, PP, Ch
TGT TT-096	29/III-3/IV 1975	47 07 N, 124 13-126 30 W	T, Sal, O, N, P, S, Sp, PP, Ch, Z
TGT TT-100	11-18/VII 1975	47 07 N, 122-126 30 W	T, Sal, O, N, P, S, Sp, PP, Ch, Z
TGT TT-105	23-27/X 1975	47 07 N, 124-125 W	T, Sal, O, N, P, S, Sp, PP, Ch, Z
TGT TT-111	15/IX-5/X 1976	47 07 N, 124-126 30 W	T, Sal, O, N, P, S, Sp (genus), PP, Ch, Z
TGT TT-112	7-13/I 1977	47 07 N, 124-126 30 W	T, Sal, O, N, P, S, Sp (genus), PP, Ch, Z
TGT TT-116	14-22/IV 1977	47 07 N, 124-126 30 W	T, Sal, O, N, P, S, Sp (genus), PP, Ch, Z
TGT TT-122	5-11/VIII 1977	47 07 N, 124-126 30W	T, Sal, O, N, P, S, Sp (genus), PP, Ch, Z
Cayuse CY-378	30/III-5/IV 1978	47 07 N, 124-125 W	T, Sal, O, N, P, S, Sp, PP, Ch
Cayuse CY 678	8-14/VI 1978	47 07 N, 124-126 W	T, Sal, O, N, P, S, Sp, PP, Ch
Cayuse CY 978	6-11/IX 1978	47 07 N, 124-126 W	T, Sal, O, N, P, S, Sp, PP, Ch
TGT TT-135	16-24/X 1978	47 07 N, 124-126 W	T, Sal, O, N, P, S, Sp, PP, Ch
TGT TT-140	16/VII-2/VIII 1979	47 32 N, 124-125 45 W 47 20 N, 124-125 45 W 47 07 N, 124-125 45 W	T, Sal, O, N, P, S, Sp, PP, Ch, Z
Wecoma W8009c	24/IX-13/X 1980	47 07-47 30 N, 124-125 45 W	T, Sal, O, N, P, S, Sp, PP, Ch, Z
TGT TT-160	17/VIII-7/IX 1981	46 40-47 40 N, 124-125 20 W	T, Sal, O, N, P, S, Sp, PP, Ch, Z
Cayuse C8206	9-26/VI 1982	46 40-47 50 N, 124-125 45 W	T, Sal, O, N, P, S, Sp, PP, Ch
Wecoma W8206	11-25/VI 1982	44 40-47 07 N, 124-125 10 W	T, Sal, O, N, P, S, Sp, PP, Ch

Horner/Postel beach samples

Net samples were collected irregularly at 5 beaches (Kalaloch North, Kalaloch South, Copalis, Ocean Shores, Grayland) from 1990 to May 1997, and twice monthly from May 1997 to January 2000 (Fig. 21). The interest was primarily in potentially toxic species, e.g., *Alexandrium* spp. and *Pseudo-nitzschia* spp., but lists were made of all species present and dominant species identified for each sample. No samples were collected for cell enumeration. Temperature, salinity and nutrients were measured at each site. *Pseudo-nitzschia* spp. were regularly found from April through October, as in British Columbia, while *Alexandrium* spp. were rare from May through August.

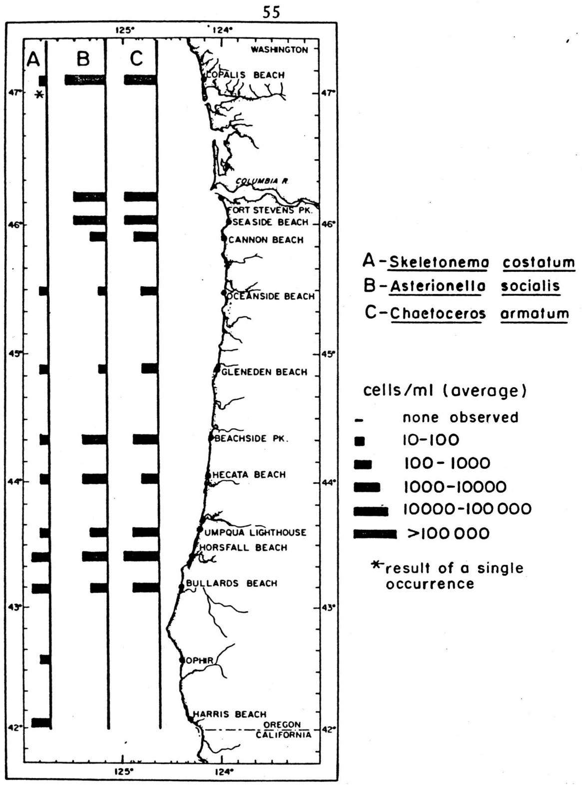


Fig. 20 Beaches sampled during surf-zone studies from 1970-1982 indicating the average cell density of the three dominant diatoms. Note names have been changed recently: *Asterionella socialis* is now *Asterionellopsis socialis; Chaetoceros armatum* is now *Attheya armatus* (from Garver 1979).

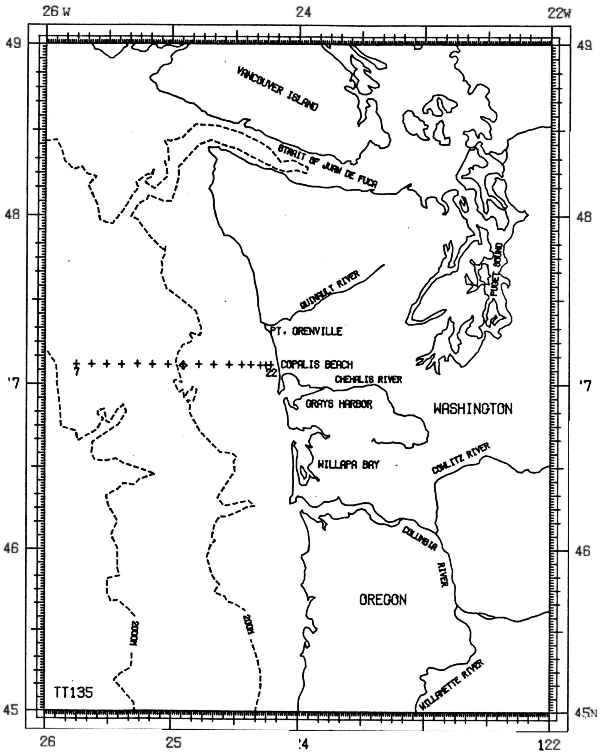


Fig. 19 Location of Copalis Line transect sampled during ERDA cruises between July 1974 and June 1982.

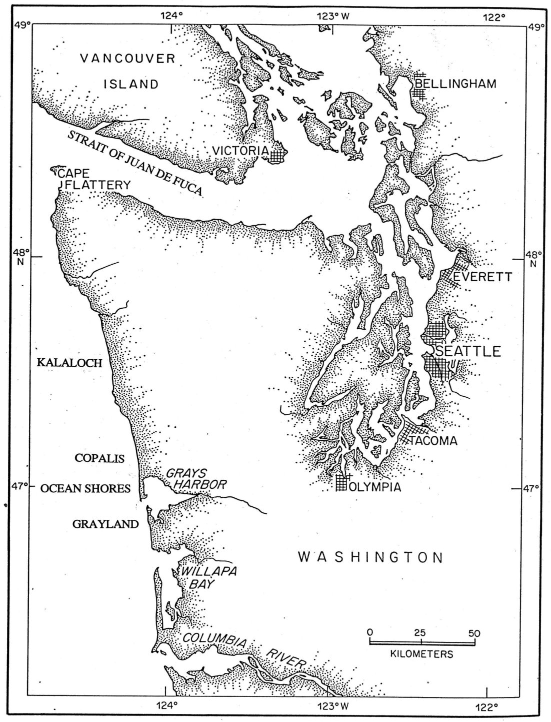


Fig. 21 Beaches sampled by Horner and Postel from 1990-2000, and by ORHAB 2000-present.

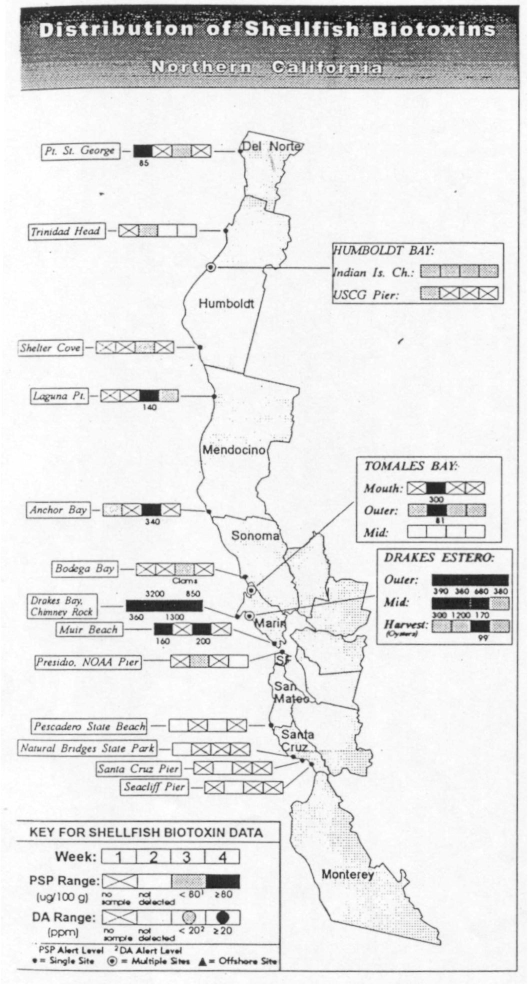


Fig. 22 Distribution of shellfish biotoxins in northern California during August 1997 (from California Department of Health Services Tech. Rep. No. 97-20, 97-21).

ORHAB (Olympic Region Harmful Algal Bloom program)

This program started in July 2000 and will run for at least 5 years. The emphasis is on the occurrence of *Pseudo-nitzschia* spp. and domoic acid, because the beaches are all major razor clam (*Siliqua patula* Dixon) recreational harvesting sites. Four beaches (4 of the 5 studied by Horner and Postel; Fig. 20) are sampled twice per week in April through November, and twice per month in December through March. In addition to species identification and cell numbers, domoic acid levels, chlorophyll concentration, temperature, salinity and nutrients are determined. The program is sponsored by NOAA.

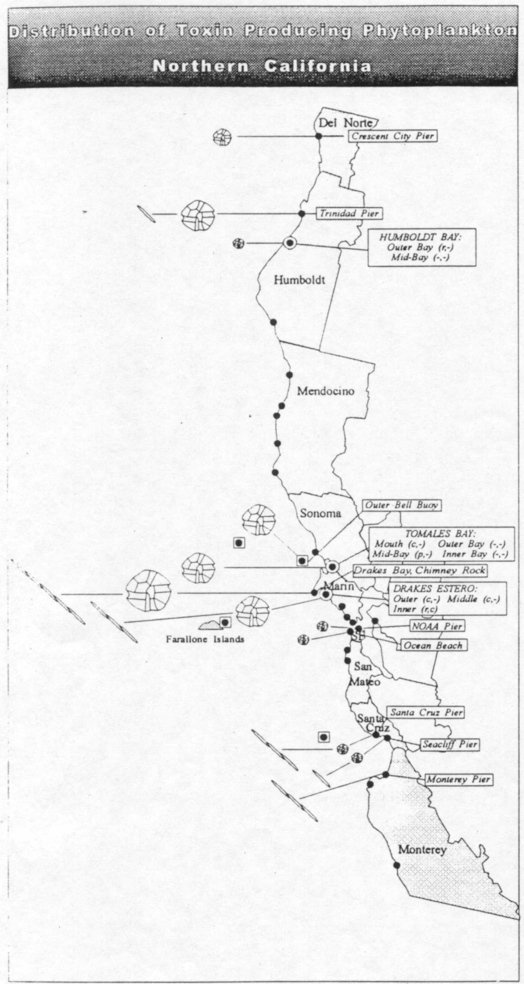


Fig. 23 Distribution of toxin-producing phytoplankton in northern California during August 1997 (from California Department of Health Services Tech. Rep. No. 97-20, 97-21).

California Department of Health Services

A phytoplankton and toxin monitoring program was started in about 1993 by the California Department of Health Services. Samples are collected on a weekly basis at a number of sites, ranging from about 24-40, depending on the availability of volunteer samplers. Samplers include state and federal agencies, academic institutions and shellfish growers. Samples are sent to the DHS lab in Berkeley where they are analyzed for phytoplankton species. A monthly, now quarterly, newsletter is published showing organism numbers and toxin levels by site (Figs. 22 and 23). Few incidences of PSP toxins have been reported since the program started, but all were indicated by higher numbers of *Alexandrium* in the monitoring samples.

Monterey Bay, CA, data

Bolin and Abbott (1963) reported on hydrography, phytoplankton settling volumes, and some identifications to genus from early CalCOFI data (1954-1960). Samples were collected more or less weekly at 6 stations throughout the bay. They compared genus abundance with temperature and found no clear indication that total phytoplankton volumes were influenced by long-term temperature trends, but some genera were more abundant in warm years. Garrison (1979) summarized early phytoplankton data and examined phytoplankton samples from 1976-1977. Data are provided on chlorophyll, recurrent species groups, species succession and species diversity. Additional data are to be found in Schrader (1981). Villac *et al.* (1993a, b) provided information on the presence of *Pseudo-nitzschia* spp. from the U.S. west coast including Monterey Bay. Walz *et al.* (1994) also included information on *Pseudo-nitzschia* spp.

Toxin in shellfish monitoring

Toxins produced by phytoplankton are monitored in shellfish (usually mussels) by state and provincial health agencies and lead to the closure of recreational and commercial harvests of shellfish when toxins reach 80 µg per 100 g of shellfish tissue for paralytic shellfish poisoning and 20 µg per gram of shellfish tissue for domoic acid. The levels are used worldwide. On the North American west coast, the regulatory agencies are the Alaska Department of Environmental Conservation, Canada Food Inspection Agency, Washington Department of Health, Oregon Department of Agriculture, and the California Department of Health Services.

References

Anderson, G.C., and Munson, R.E. 1972. Primary productivity studies using merchant vessels in the North Pacific Ocean. *In* Biological Oceanography of the Northern North Pacific Ocean. *Edited by* A.Y. Takenouti *et al.* Idemitsu Shoten, Tokyo, pp. 245-251.

Anderson, G.C., Lam, R.K. Booth, B.C., and Glass, J.M. 1977. A description and numerical analysis of the factors affecting the processes of production in the Gulf of Alaska. Special Report No. 76, Department of Oceanography, University of Washington, Seattle. 321p.

Bolin, R.L., and Abbott, D.P. 1963. Studies on the marine climate and phytoplankton of the central coastal area of California, 1959-1960. CalCOFI. Rep. 9: 23-45.

Booth, B.C. 1981. Vernal phytoplankton community in the eastern subarctic Pacific: predominant species. *In* Proceedings of the Sixth Symposium on Recent and Fossil Diatoms. *Edited by* R. Ross. Otto Koeltz Science Publ., Koenigstein, pp. 339-358.

Booth, B.C., Lewin, J., and Postel, J.R. 1993. Temporal variation in the structure of autotrophic and heterotrophic communities in the subarctic Pacific. Prog. Oceanogr. 32: 57-99.

Clemons, M.J., and Miller, C.B. 1984. Blooms of large diatoms in the oceanic subarctic Pacific. Deep-Sea Res. 31: 85-95.

Forbes, J.R., and Denman, K.L. 1991. Distribution of *Nitzschia pungens* in coastal waters of British Columbia. Can. J. Fish. Aquat. Sci. 48: 960-967.

Garrison, D.L. 1979. Monterey Bay phytoplankton. 1. Seasonal cycles of phytoplankton assemblages. J. Plankton Res. 1: 241-256.

Garver, J.L. 1979. A survey of surf diatom blooms along the Oregon coast. M.S. thesis, University of Washington, Seattle, WA. 167p.

Horner, R.A., and Booth, B.C. 1990. Temporal distribution of diatoms in the eastern subarctic Pacific Ocean. *In* Contributions to the Knowledge of Microalgae particularly Diatoms. *Edited by* U. Geissler *et al.* J. Cramer, Berlin, pp. 189-197.

Horner, R.A., and Postel, J.R. 1993. Toxic diatoms in western Washington waters (U.S. west coast). Hydrobiologia 269/270:197-205.

Landry, M.R., and Hickey, B.M. 1989. Coastal Oceanography of Washington and Oregon. Elsevier Oceanography Series 47, Elsevier, Amsterdam.

Lewin, J., Shaefer, C.T., and Winter, D.F. 1989. Surf-zone ecology and dynamics. *In* Coastal Oceanography of Washington and Oregon

Edited by M.R. Landry, and B.M. Hickey. Elsevier Oceanography Series 47, Elsevier, Amsterdam, pp. 567-594.

Miller, C.B. (ed.) 1993. Pelagic ecodynamics in the Gulf of Alaska. Results from the SUPER Project. Prog. Oceanogr. 32: 1-358.

Schrader, G.C. 1981. Seasonal cycles of phytoplankton in relation to the hydrography of Monterey Bay. Moss Landing Mar. Lab. Tech. Publ. 81-2.

Stephens, K. 1977. Primary productivity data from weatherships occupying Ocean Station P 1969 to 1975. Can. Fish. Mar. Service Data Rep. No. 38. 88p.

Villac, M.C., Roelke, D.L. Chavez, F.P., Cifuentes, L.A., and Fryxell, G.A. 1993a. *Pseudonitzschia australis* Frenguelli and related species from the west coast of the U.S.A.: Occurrence and domoic acid production. J. Shellfish Res. 12: 457-465.

Villac, M.C., Roelke, D.L., Villareal, T.A., and Fryxell, G.A. 1993b. Comparison of two domoic acid-producing diatoms: A review. Hydrobiologia 269/270: 213-224.

Walz, P.M. and others. 1994. Domoic acid producing diatom blooms in Monterey Bay, CA: 1991-1993. Nat. Toxins 2:271-279.

Physical and lower-trophic level data time-series in the Mixed Water Region

Shin-ichi Ito
Fisheries Oceanography, Tohoku National Fisheries Research Institute, 3-27-5 Shinhama, Shiogama, Miyagi 085-080, Japan. E-mail: goito@myg.affrc.go.jp

Between the Oyashio and Kuroshio fronts, there are a lot of eddies and streamers and they make complicated ocean structures. Thus, the Oyashio-Kuroshio inter-frontal zone is called the Mixed Water Region (MWR). Because the small-large scale frontal structures are good fishing grounds, many observations have been made in the MWR, of which many were cooperative. For example, all temperature data observed in the MWR have been exchanged in near-real time within four major organizations: Japan Meteorological Agency, Japan Coast Guard, Japan Defense Force, and Japan Fisheries Agency. Using these data, Tohoku National Fisheries Research Institute (TNFRI) has prepared the MWR temperature maps and identified some indices for the major ocean structures in the MWR. TNFRI has also maintained some historical observation lines and stations. These time-series are introduced below.

Physical oceanographic data time-series

Off-Tohoku temperature maps and gridded data

TNFRI has produced the off-Tohoku temperature maps (Tohoku is the district name of the north-eastern part of the main island in Japan - Honshu) using all temperature data observed in the MWR. The target domain is 140-159°E and 34-45°N (Fig. 24). Historically, 100 m depth isotherms have been drawn monthly by hand since 1944. Now we are archiving "paper" data sets to magnetic computer devices. From archived data, we are making grid data sets with a 5-minute resolution for both longitude and latitude using the flex Gaussian interpolation method (Ito and Shimizu 1997). We are also re-drawing the temperature maps at 0 m, 50 m, 200 m, 300 m, and 400 m, using those gridded data. Some temperature maps and the locations of observation points (Fig. 25) are already available on our web site (http://ss.myg.affrc.go.jp/~goito/temp/temp.html).

Time-series of indices for the water mass fronts

From the off-Tohoku temperature maps, we have created indices for the major water mass fronts: the southern limit latitude and its longitude of the Oyashio First and Second Intrusions, the northern limit latitude of Kuroshio Extension, and the eastern limit longitude of Tsugaru Warm Water Current. Kawai (1972) reported that the values of the isotherm, which indicate the Oyashio front, change seasonally from 5 to 8ºC at 100 m depth. But TNFRI has used a simpler definition of the

Oyashio front: a 5ºC isotherm at 100 m depth. We have identified the southern limit latitude and its longitude of the Oyashio First and Second Intrusions, as well as the southern limit latitude and its longitude of Oyashio water in the Oyashio First and Second Intrusion area (Figs. 26 and 27).

The seasonal and interannual variability of the southern limit latitude of the Oyashio First Intrusion has already been investigated by Ogawa (1987, 1989), and the time-series presented here is the extended version of his time-series.

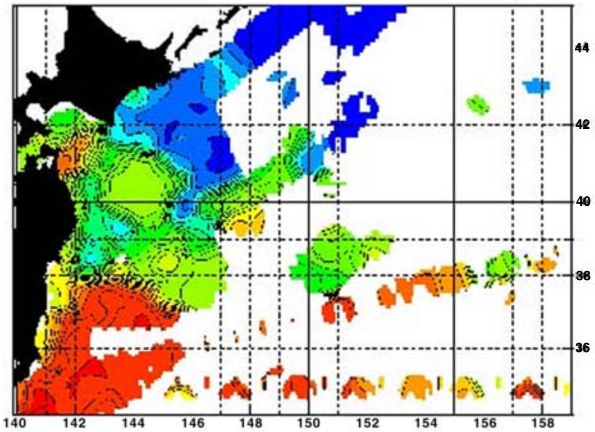


Fig. 24 An example of a off-Tohoku temperature map by TNFRI. This map shows temperature at 100 m depth in September 1999.

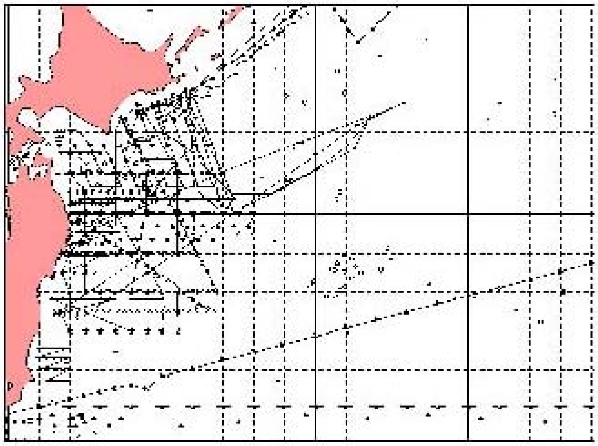


Fig. 25 An example (September 1999) of the distribution of observation points in the Mixed Water Region.

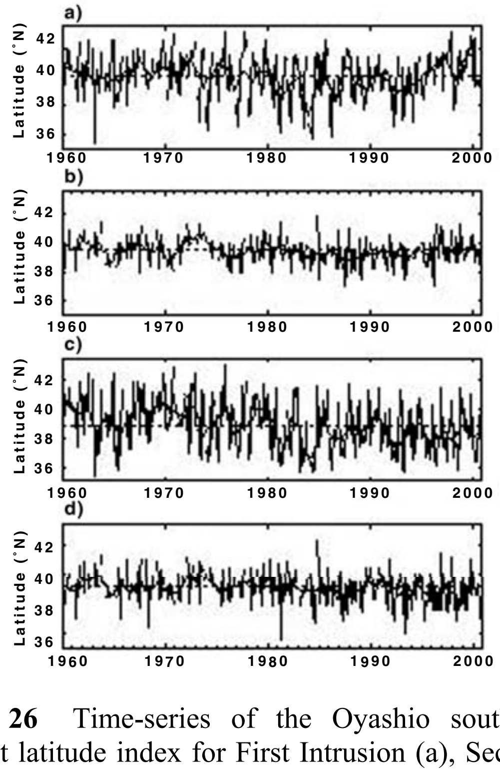


Fig. 26 Time-series of the Oyashio southern limit latitude index for First Intrusion (a), Second Intrusion (b), Oyashio water in the First Intrusion area (c), and Oyashio water in the Second Intrusion area (d).

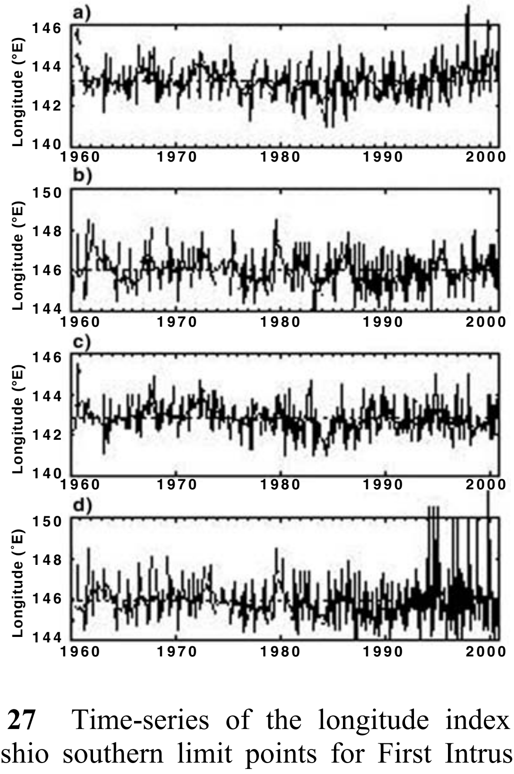


Fig. 27 Time-series of the longitude index of Oyashio southern limit points for First Intrusion (a), Second Intrusion (b), Oyashio water in the First Intrusion area (c), and Oyashio water in the Second Intrusion area (d).

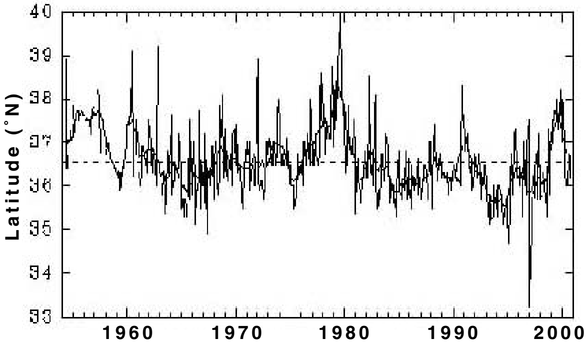


Fig. 28 Time-series of the northern limit latitude of the Kuroshio Extension in the Japan coastal area (west of 164°E).

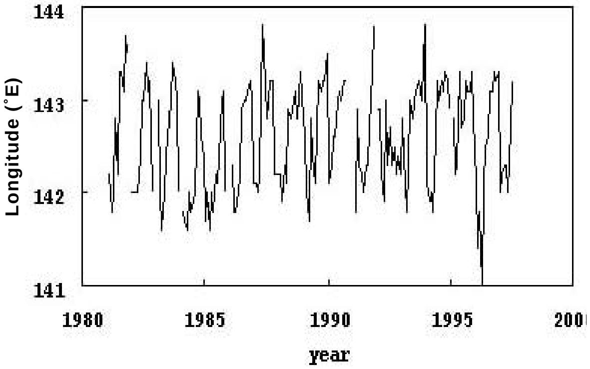


Fig. 29 Time-series of the eastern limit longitude of the Tsugaru Warm Water Current.

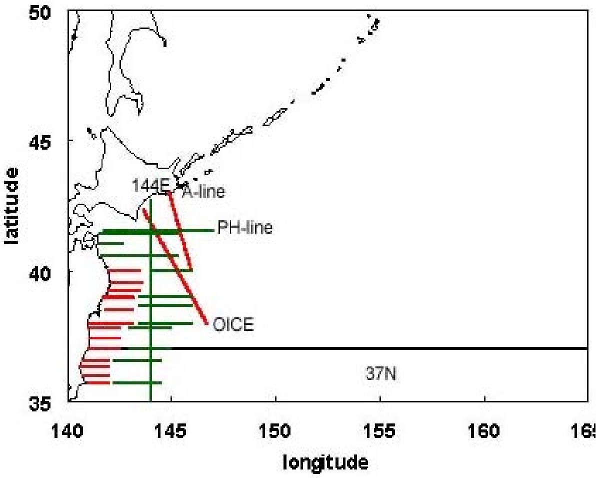


Fig. 30 Repeated observation lines in the Mixed Water Region. Red lines denote nearly-monthly-repeated observed lines, green lines denote seasonally-repeated observed lines, and the black line denotes annually observed line.

The northern limit latitude of Kuroshio Extension (KE) (Fig. 28) has been identified using a 14ºC isotherm at 200 m depth according to Kawai (1969). The characteristics of this KE index were investigated by Kawai (1969) and Murakami (1993). The eastern limit longitude of the Tsugaru Warm Water Current (Fig. 29) has also been identified from the strongest temperature gradient at 100 m depth.

Repeated observation line

TNFRI has maintained a repeated observation line along 37ºN, which extends from the coast of Japan to 164ºE. The line has been observed once a year (May-June) since 1983. TNFRI also set a repeated observation line named OICE (Oyashio Intensive observation line off Cape Erimo) that coincides with the TOPEX/POSEIDON orbit. Other organizations have also maintained repeated observation lines: A-line (Hokkaido National Fisheries Research Institute), 144ºE-line (Hakodate Marine Observatory), and PH-line (Hakodate Marine Observatory). Many prefectural fisheries institutions have maintained coastal observation lines around Japan since 1965, and these data are archived in JODC and NODC (Fig. 30).

Phytoplankton time-series data

On the 37ºN-line, we have observed surface Chl-*a* concentrations once a year (May or June) since 1988. We have routinely measured surface and sub-surface nutrients and Chl-*a* concentrations, and optionally observed other biological parameters (phytoplankton species, primarily production, micro-zooplankton abundance, zooplankton species, micronekton, etc.) on the OICE-line since 1997. Other organizations have also maintained repeated observation lines: A-line (Hokkaido National Fisheries Research Institute), PH-line (Hakodate Marine Observatory), and 144ºE-line (Hakodate Marine Observatory).

Ito *et al*. (2001) have analyzed the interannual variability of Chl-*a* concentrations along the 144ºE-line by using a principal components analysis. The results showed strong spring blooms in 1991 and 1992 in the Oyashio region (Fig. 31). In those years, the Oyashio flowed narrowly in the

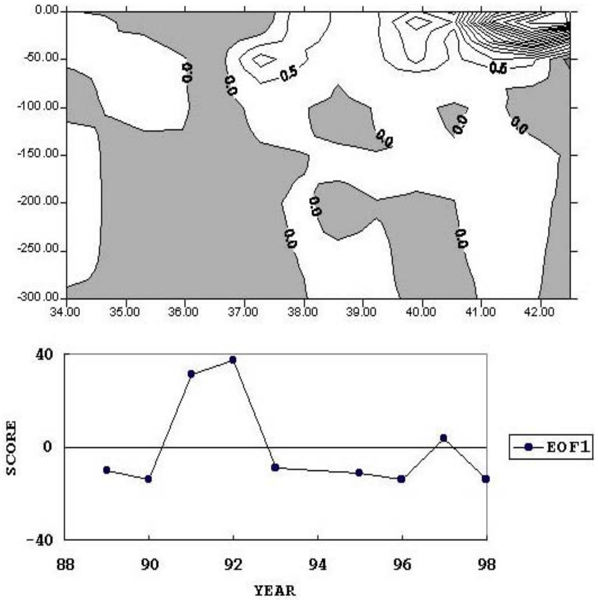


Fig. 31 The first principal component for the spring Chl-*a* concentrations on 144ºE-line and its variability. The contribution of the first component is 67%.

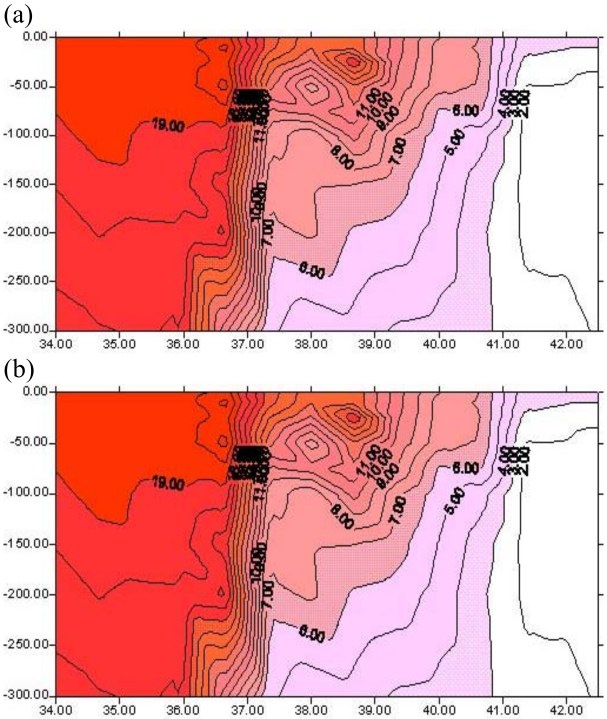


Fig. 32 Composite temperature field on the 144ºE-line for strong boom years (a) and the other years (b).

coastal region of Hokkaido, and the cold intermediate water penetrated in the sub-surface layer, while the Oyashio broadened offshore, and the area of the cold intermediate water shrunk in the other years (Fig. 32). This result shows the importance of the Oyashio structure to the spring bloom in the Oyashio region. Thus, the repeated observation lines for both physical and biological parameters are needed to clarify the mechanism of the lower trophic level activities in the MWR.

Zooplankton time-series data

TNFRI and other organizations have collected zooplankton samples since 1951. The samples were taken by vertical hauling of a conventional net, the so called Marutoku net (net opening 45 cm, mesh aperture 0.33 mm) from 150 m depth to the surface. Odate (1994) compiled a total of 17,242 zooplankton samples in the Tohoku Sea area between 1951 and 1990, and examined the seasonal and interannual variability of wet weight. The data was also archived on a CD-ROM by MIRC (Marine Information Research Center) as "Dataset of Zooplankton Biomass in the Western North Pacific Ocean 1951-1990 - K. ODATE Collection" (the distribution of the sampling points is shown in Figure 33). These observations had been carried out until 1994, but since 1997, only a small portion of observations has been maintained. Though this kind of long-term monitoring should be done by a suitable organization, in reality a few people or only one person maintains the activity solely. The system should be reconstructed to maintain the monitoring systems for the long-term.

References

Ito, S., and Shimizu, Y. 1997. Distribution patterns of temperature data and a method to draw isotherms in the Tohoku Offshore Area. Bull. TNFRI 59: 163-170.

Ito, S., Miyao, T., and Kishi, M. 2001. Interannual variability of Chl-*a* concentration and its relation to the coastal Oyashio intrusion (in preparation).

Kawai, H. 1969. Statistical estimation of isotherms indicative of the Kuroshio axis. Deep-Sea Res., Suppl. 16: 109-115.

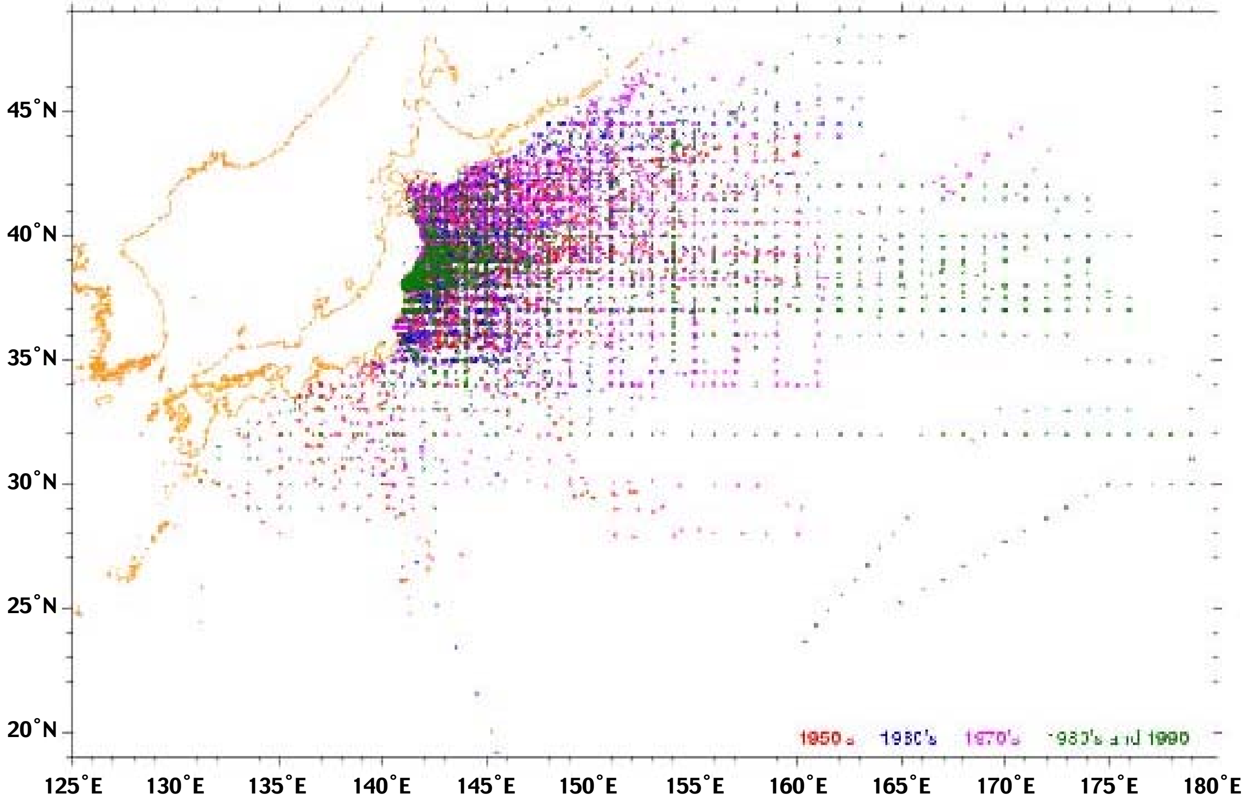


Fig. 33 Distribution of the Odate data (after “Dataset of Zooplankton Biomass in the Western North Pacific Ocean 1951-1990 - K.ODATE Collection”)

Kawai, H. 1972. Oceanography of Kuroshio and Oyashio. Physical Oceanography II: 129-321.

Murakami, M. 1993. On the 100 meter depth temperature indicative of the Kuroshio Extension axis in Tohoku area. Umi no Kenkyu 2: 343-349.

Odate, K. 1994. Zooplankton Biomass and its Long-Term Variation in the Western North Pacific Ocean, Tohoku Sea Area, Japan. Bull. TNFRI 56: 115-173.

Ogawa, Y., Hirai, M., and Yasuda, I. 1987. Fluctuations of the First Oyashio Intrusion and it’s influences on coastal fishery-resources. Bull. TNFRI 49: 1-15.

Ogawa, Y. 1989. Variations in latitude at the southern limit of the First Oyashio Intrusion.

Monitoring system and long-term trend of zooplankton in the Korean waters

Young-Shil Kang
National Fisheries Research and Development Institute, 408-1 Shirang-ri, Kijang-gun, Pusan 619-900, Republic of Korea. E-mail: yskang@haema.nfrda.re.kr

Monitoring system

Oceanographic surveys have been conducted at 175 stations (22 lines) in the Korean waters since 1965 (Fig. 34). The surveys are focused on understanding oceanographic conditions and finding fishing grounds. Additionally, many special environmental and oceanographic surveys were carried out in the limited coastal area, the East-China Sea and the Bering Sea etc., for a shorter time. These surveys were not only for extending and evaluating potential fishing grounds, but also to assess marine environmental quality. Table 15 summarizes monitoring activities in the Korean waters.

The oceanographic surveys in the Korean waters are very useful for elucidating the climate effects on the marine ecosystem. These surveys have been conducted bimonthly, in February, April, June, August, October and December, simultaneously in the East, West and South Seas of Korea, to reduce difference in time-dependent oceanographic conditions.

During the survey, temperature, salinity and dissolved oxygen were estimated at the standard depths: surface, 10 m, 20 m, 30 m, 50 m etc., with thermometer and CTD. The zooplankton were collected with NORPAC net (mouth size: 0.45 m and mesh size: 0.33 mm) from the bottom (in the West and South Seas shallower than 100 m), or 100 m depth (in the East Sea) to the surface at a speed 0.5-1.0 m/sec. Zooplankton samples were immediately preserved with 5-10% formalin. Zooplankton biomass was calculated based on the wet weight of zooplankton smaller than 3 cm/m^3. The four major zooplankton

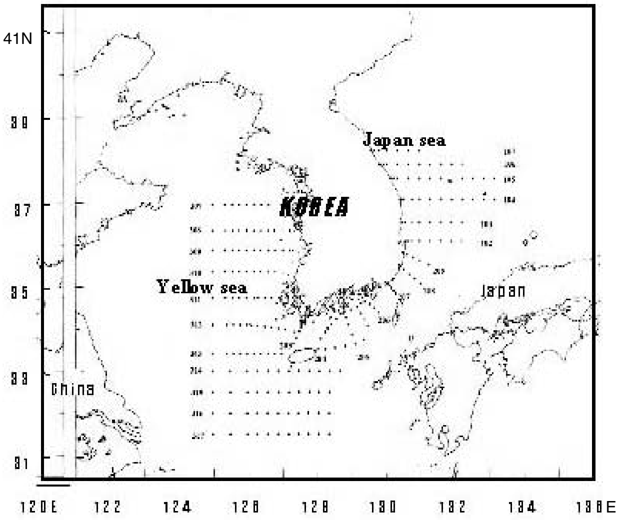


Fig. 34 Oceanographic survey area and sampling stations in the Korean waters.

Table 15 Oceanographic surveys conducted by Korea.

Site	Period	Oceanographic factors	Gears
Korean waters	1965 – Present (6 times per year)	Temperature, salinity, DO, zooplankton, nutrients (from 1995), Chl-*a* (from 1995 in the South Sea of Korea)	CTD, NORPAC net, water sampler, ADCP, field fluorometer, multi plankton sampler
East-China Sea	1995 – Present (4 times per year)	Temperature, salinity, DO, zooplankton, nutrients, Chl-*a,* fish larvae and eggs, currents	CTD, NORPAC net, water sampler, ADCP, field fluorometer, multi-plankton sampler, drifting buoys, Bongo net
Bering Sea	1994 – 1995 (once a year)	Temperature, salinity, DO, zooplankton, nutrients, Chl-*a,* fish larvae and eggs,	CTD, NORPAC net, water sampler, ADCP, field fluorometer, multi-plankton sampler, drifting buoys, Bongo net
Southern coastal area of Korea	1972 – 1981 (10–12 times per year)	Temperature, salinity, DO, phytoplankton, zooplankton	CTD, NORPAC net, Kidahara net, water sampler
Others	Less than 1 – 2 years	Temperature, zooplankton etc.	CTD, NORPAC net etc.

groups: Copepoda, Amphipoda, Chaetognatha and Euphausiid, have been individually counted since 1978.

Data obtained from the surveys have been published as "Annual report of oceanographic observations" and are available through the web site of the Korean Oceanographic Data Center (KODC).

Long-term trend of zooplankton

The observations clearly indicate that sea surface temperature in the Korean waters is steadily getting warmer in winter (December and February) since the late 1980s (Fig. 35).

The Korean waters are included into two sub-regions of PICES, the Sea of Japan (SJP) and the East China Sea (ECS). In the East Sea of Korea (PICES SJP sub-region), zooplankton biomass shows an increasing trend and major zooplankton groups reveal the alteration trend in their composition since the early 1990s. The trend in zooplankton biomass is more explicit in the north and offshore waters compared to the south and inshore areas (Fig. 36). Macro-zooplankton, such as chaethognaths, euphausiids and amphipods, gradually increased after the early 1990s. Zooplankton biomass has a large peak in February and then keeps the similar value. Among the four major zooplankton groups, copepods have their peak in April, whereas euphausiids show their peak in June.

In the West Sea of Korea (PICES ECS sub-region), zooplankton biomass has increased since the late 1980s with three large peaks in 1991, 1993 and 1997-1998. Among the four major zooplankton groups, copepods are predominant and slightly increased from the mid-1980s to the late 1990s. Zooplankton biomass exhibits seasonal variations with a large peak in June and a small peak in October. Copepods show similar seasonal variations while other zooplankton groups do not (Fig. 37). Chaetognaths occupy the next position in abundance after copepods and have a peak in August. Amphipods and euphausiids are most abundant in August and June, respectively. Judging from these facts, it is assumed that copepods are closely related to chaetognaths as prey and predator (Fig. 37).

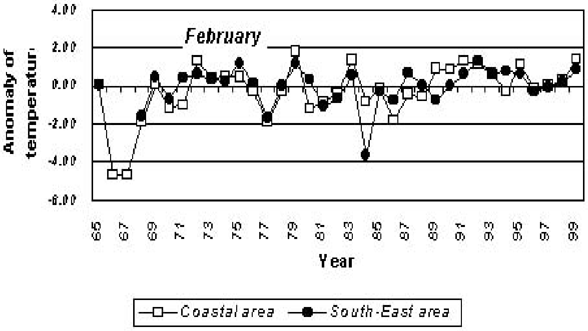


Fig. 35 Long-term changes in sea surface temperature anomaly in the Korean waters.

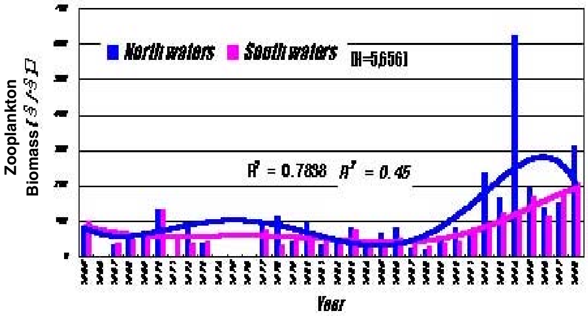


Fig. 36 Long-term changes in zooplankton biomass in the East Sea of Korea (SJP).

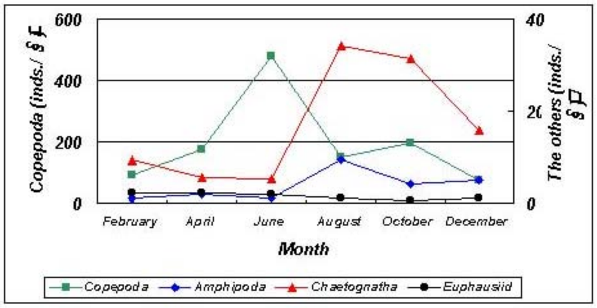


Fig. 37 Seasonal variations in abundance of zooplankton groups in the West Sea of Korea (ECS).

180° longitude – Oceanographic time-series information

Toru Kobari[1] and Tsutomu Ikeda[2]

[1] Miyagi Prefecture, Fisheries Research and Development Center, Japan Science and Technology Co., 97-6 Sodenohama, Watanoha, Ishinomaki, Miyagi 986-2135, Japan. E-mail: toru.k@f3.dion.ne.jp

[2] Faculty of Fisheries, Hokkaido University, 3-1-1 Minato-cho, Hakodate, Hokkaido 041-8611, Japan. E-mail: tom@pop.fish.hokudai.ac.jp

Sampling data

Hokkaido University has 5 sampling lines (155°E, 170°E, 175°30'E, 180° and 145°W longitude) in the North Pacific (Fig 38). The 180°-line is the longest time-series of oceanographic and fisheries data collected by T/S *Oshoro-Maru*. Zooplankton samples were collected at stations between 37° and 51°N in the summers (mid-June) of 1979-2000 (22 years) (Table 16). Corresponding to the space of sampling stations (<1°), number of stations ranged from 15 to 32. At each station, a vertical tow was made from 150 m depth to the surface with NORPAC net (45 cm mouth diameter, 0.35 mm mesh size). In some years, additional zooplankton samples were collected with a MTD, IKMT and Fish-larva nets. In the land laboratory, zooplankton wet weight was measured. Simultaneously with zooplankton sampling, hydrographic data (temperature, salinity and Secchi depth) were observed. Chlorophyll-*a* concentrations were estimated from Secchi depths using an empirical equation of Falkowski and Wilson (1992). The 180° time-series data sets have been published in the Data Record of Oceanographic Observation and Exploratory Fisheries Nos. 23-43 (Hokkaido University 1980-2000).

Example of data analysis

In most previous analyses of long-term variability of subarctic Pacific, zooplankton was considered as a single entity; e.g., biomass, which comprises a mixture of various species at diverse trophic levels (Shiomoto *et al.* 1997; Sugimoto and Tadokoro, 1997). However, the effects of long-term climate changes on a given zooplankton species' population are likely to be species-specific (Fromentin and Planque 1996; Planque and Fromentin 1996). Thus, it is assumed that analysis based on individual species rather than on total zooplankton biomass is more sensitive to climate impacts and the results are more useful for understanding pelagic ecosystems.

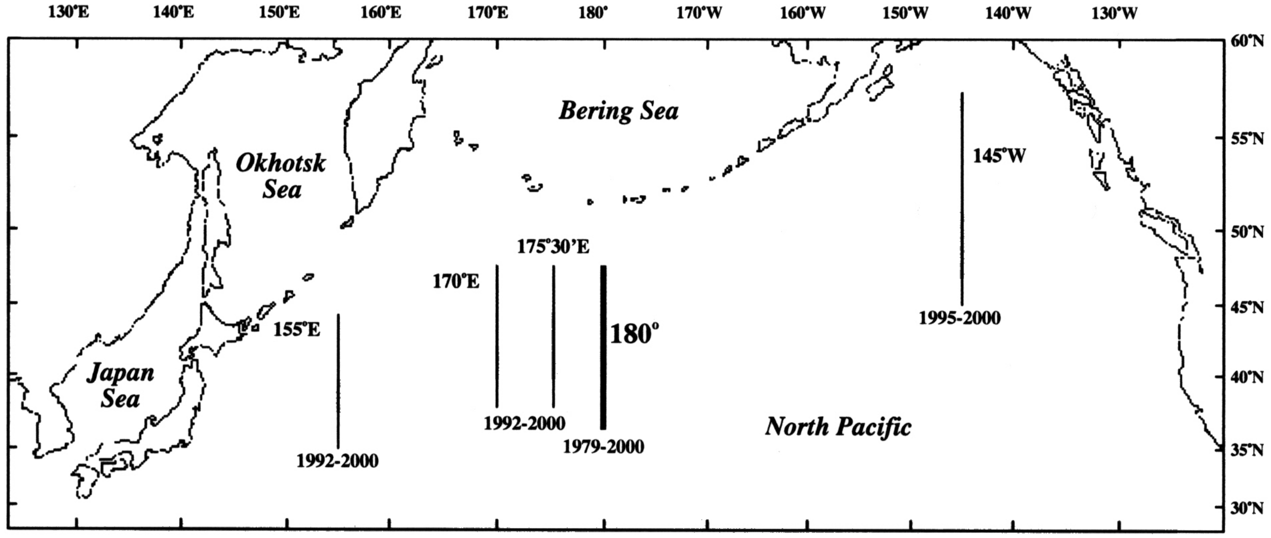


Fig. 38 Sampling lines conducted by Hokkaido University.

Table 16 Sampling data of T/S *Oshoro-Maru* time-series along 180° longitude. FL - Fish-larva net, IKMT - Isaacs-Kidd mid water trawl net, Z - Secchi depth.

Year	Date	Position	Station number	Zooplankton sampling				Other samplings	Oceanic observation
				Method	Depth	Gear	Mesh size		
1979	12-19 June	39°00'-46°00'N	15	Vertical haul	0-150m	NORPAC	0.35mm, 0.1mm		CTD, Z_d
1980	12-21 June	39°00'-49°00'N	15	Vertical haul	0-150m	NORPAC	0.35mm	FL, MTD, IKMT	CTD, Z_d
1981	11-22 June	39°00'-50°50'N	25	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d
1982	12-22 June	39°00'-51°00'N	24	Vertical haul	0-150m	NORPAC	0.35mm	MTD, IKMT	CTD, Z_d
1983	11-19 June	39°03'-47°30'N	16	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d
1984	11-16 June	38°59'-49°00'N	21	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d
1985	13-18 June	39°00'-49°00'N	21	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d
1986	12-20 June	37°00'-50°00'N	26	Vertical haul	0-150m	NORPAC	0.35mm, 0.1mm	FL, MTD	CTD, Z_d, Chl-*a*
1987	11-19 June	37°00'-48°00'N	22	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d, Chl-*a*
1988	13-20 June	37°03'-49°00'N	25	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d, Chl-*a*
1989	9-20 June	37°00'-49°00'N	24	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d
1990	9-18 June	37°01'-50°50'N	22	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d
1991	9-17 June	36°59'-50°50'N	24	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d
1992	8-19 June	37°00'-50°10'N	30	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d
1993	10-21 June	36°00'-50°50'N	28	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d
1994	9-20 June	35°00'-50°50'N	30	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d
1995	9-20 June	36°00'-50°50'N	32	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d
1996	10-21 June	37°00'-50°50'N	29	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d, Chl-*a*
1997	10-21 June	37°30'-50°50'N	28	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d, Chl-*a*
1998	9-16 June	38°00'-50°50'N	17	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d, Chl-*a*
1999	9-15 June	37°00'-50°50'N	15	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d, Chl-*a*
2000	9-14 June	37°00'-50°50'N	18	Vertical haul	0-150m	NORPAC	0.35mm	FL	CTD, Z_d, Chl-*a*

Neocalanus copepods are the most predominant components of zooplankton biomass in the subarctic Pacific and its marginal seas, and the key species in the subarctic marine ecosystems of the North Pacific. We analyzed interannual variations in abundance and body size of *Neocalanus* species (*N. cristatus*, *N. plumchrus* and *N. flemingeri*) using 180° time-series samples from the North Pacific.

Environment

According to Favorite *et al.* (1976) and Anma *et al.* (1990), the 180° time-series extends over 5 sub-areas, as determined by water temperature and salinity profiles: Alaska Current System (AS), Subarctic Current System (SA), Northern Transition Domain (TN), Southern Transition Domain (TS) and Subtropical Current System (ST). There were quasi-decadal variations in the locations of oceanic sub-areas and their boundaries (Fig. 39). The Transition Domain expanded southward in the late 1980s and 1990s due to a southward shift of the Transitional Front and Subarctic Boundary. Sea surface temperature (SST) had ENSO time-scale variations (higher in 1982, 1987-1988, 1993 and 1996) (Fig. 40). The year-to-year patterns were more pronounced in the southern areas. On the other hand, SST anomalies revealed decadal variation (higher in the late 1980s and 1990s) rather than ENSO time-scale variation (Fig. 41). Although an anomaly for chlorophyll-*a* concentrations and zooplankton wet weight did not indicate distinct changes (Fig. 41), the spatial patterns between chlorophyll-*a* and zooplankton wet weight were weakly negative: high zooplankton biomass and low chlorophyll-*a* were observed in the Transition Domain (Fig. 40).

Neocalanus

Neocalanus (C5) abundance was high in the Transition Domain (Fig. 42). Although C5 abundance anomaly showed less pronounced year-to-year variation for *N. cristatus* throughout the study period, decreasing trends of the anomalies were detected for *N. plumchrus* and *N. flemingeri* from the 1980s to 1990s (Fig. 41). The interannual variabilities were quite similar for *N. plumchrus* and *N. flemingeri* (r^2=0.942, P<0.001). *Neocalanus* size (C5 prosome length) decreased gradually southward (Fig. 43). Biennial variations (larger in odd year, smaller in even year) were predominant for all three species but interannual variations were less pronounced in the southern areas (Fig. 41). Biennial variation was synchronized (r^2=0.360-0.669, P<0.01) with

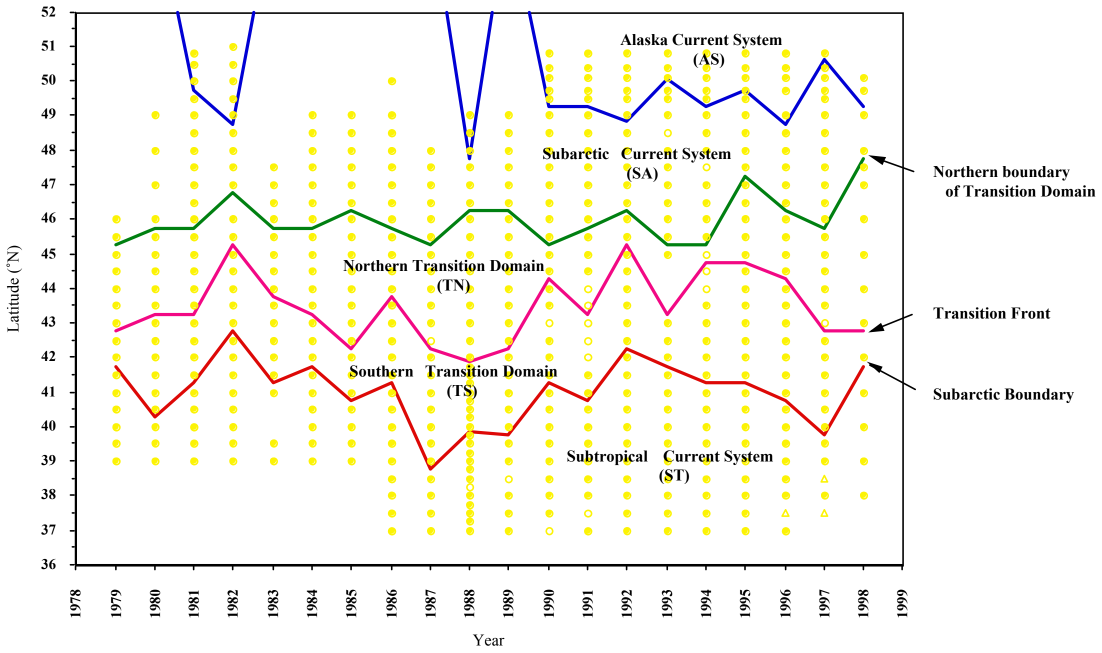
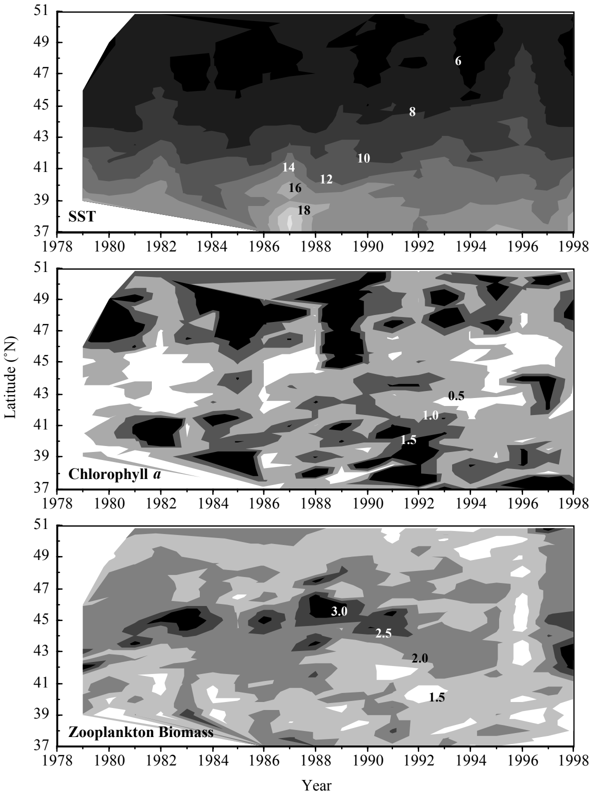


Fig. 39 Interannual variations in the locations of the oceanic sub-areas and their boundaries in the summers of 1979-1998.



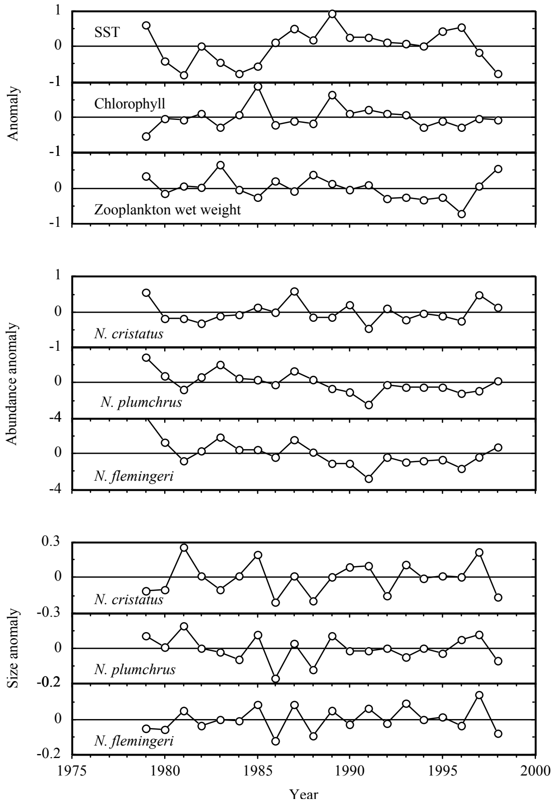


Fig. 40 Interannual variations in sea surface temperature (°C), Chl-*a* (mg/m^3) and zooplankton biomass (log mgWW m^{-3}) in 1979-1998.

Fig. 41 Interannual variations in anomalies of environmental parameters and abundance and body size of *Neocalanus* species in 1979-1998.

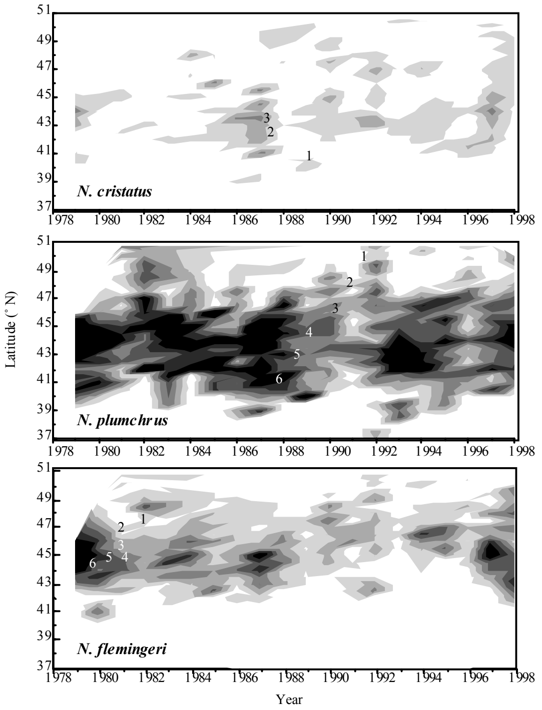


Fig. 42 Interannual variations in C5 abundance [$(n+1)^{1/2}$inds/m^3] of *Neocalanus* species in 1979-1998.

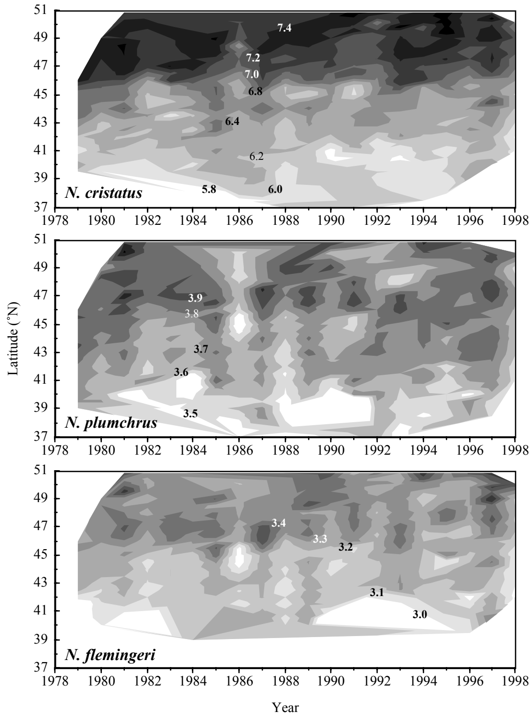


Fig. 43 Interannual variations in C5 prosome length (mm) *Neocalanus* species in 1979-1998.

the three species. In the correlation analysis, there were no parameters affecting the abundance and size variations of each *Neocalanus* species.

Analyzing the 180° longitude time-series, we detected more pronounced interannual variations in the dominant zooplankton species than in the total zooplankton biomass. The synchronized interannual variation patterns of *Neocalanus* species may be due to their identical trophic position (all grazers) and similar life history (annual life cycle and ontogenetic vertical migration) (Miller *et al*. 1984; Miller and Clemons 1988; Kobari and Ikeda 1999a, b; Tsuda *et al*. 1999). Although no significant driving force was evident, the synchronized interannual variation patterns may be mediated by common environmental variable(s) operating on large spatial and temporal scales in the North Pacific.

In conclusion, observations along the 180°-line are useful for analysis of interannual variability and climate impacts in the North Pacific ecosystem because:

- it is a long-dated time-series;
- interannual variation patterns are comparable regionally; and
- high- and low-frequency components are detectable.

References

Anma, G., Masuda, K., Kobayashi, G., Yamaguchi, H., Meguro, T., Sasaki, S and Ohtani, K. 1990. Oceanographic structure and changes around the transition domain along 180^o longitude, during June 1979-1988. Bull. Fac. Fish. Hokkaido Univ. 41: 73-88.

Falkowski, P.G., and Wilson, C. 1992. Phytoplankton productivity in the North Pacific ocean since 1900 and implications for absorption of anthropogenic CO2. Nature 358: 741-743.

Favorite, F., Dodimead, A.J., and Nasu, K. 1976. Oceanography of the subarctic Pacific region, 1960-1971. Bull. Int. North Pacific Fish. Comm. 33: 1-187.

Fromentin, J.M., and Planque, B. 1996. *Calanus* and environment in the eastern North Atlantic. II. Influence of the North Atlantic Oscillation on *C. finmarchicus* and *C. helgolandicus*. Mar. Ecol. Prog. Ser. 134: 111-118.

Hokkaido University. 1980-2000 Data Record of Oceanographic Observations and Exploratory Fishing. 23-43. Faculty of Fisheries, Hokkaido University, Hakodate.

Kobari, T., and Ikeda, T. 1999. Vertical distribution, population structure and life cycle of *Neocalanus cristatus* (Crustacea: Copepoda) in the Oyashio region, with notes on its regional variations. Mar. Biol. 134: 683-696.

Kobari, T., and Ikeda, T. 2001a. Life cycle of *Neocalanus flemingeri* (Crustacea: Copepoda) in the Oyashio region, western subarctic Pacific, with notes on its regional variations. Mar. Ecol. Prog. Ser (in press).

Kobari, T., and Ikeda, T. 2001b. Ontogenetic vertical migration and life cycle of *Neocalanus plumchrus* (Crustacea: Copepoda) in the Oyashio region, with notes on regional variations in body sizes. J. Plankton. Res. (in press).

Miller, C.B., and Clemons, M.J. 1988. Revised life history analysis for large grazing copepods in the subarctic Pacific Ocean. Prog. Oceanogr. 20: 293-313.

Miller, C.B., Frost, B.W., Batchelder, H.P., Clemons, M.J. and Conway, R.E. 1984. Life histories of large, grazing copepods in a subarctic ocean gyre: *Neocalanus plumchrus*, *Neocalanus cristatus*, and *Eucalanus bungii* in the northeast Pacific. Prog. Oceanogr. 13: 201-243.

Planque, B., and Fromentin, J.M. 1996. *Calanus* and environment in the eastern North Atlantic. I. Spatial and temporal patterns of *C. finmarchicus* and *C. helgolandicus*. Mar. Ecol. Prog. Ser. 134: 101-109.

Shiomoto, A., Tadokoro, K., Nagasawa, K., and Ishida, Y. 1997. Trophic relations in the subarctic North Pacific ecosystem: possible feeding effect from pink salmon. Mar. Ecol. Prog. Ser. 150: 75-85.

Sugimoto, T., and Tadokoro, K. 1997. Interannual-interdecadal variations in zooplankton biomass, chlorophyll concentration and physical environment in the subarctic Pacific and Bering Sea. Fish. Oceanogr. 6: 74-93.

Tsuda, A., Saito, H. and Kasai, H. 1999. Life histories of *Neocalanus flemingeri* and *Neocalanus plumchrus* (Calanoida: Copepoda) in the western subarctic Pacific. Mar. Biol. 135: 533-544.

Phytoplankton time-series in the California Current

Carina Lange

Scripps Institution of Oceanography, 9500 Gilman Drive, La Jolla, CA 92093-0244, U.S.A. E-mail: clange@ucsd.edu

The Scripps Pier time-series

Previous observations

The Scripps Institution of Oceanography (SIO, La Jolla Bight; 32°50'N, 117°10'W) has been a site of ocean monitoring since 1905, and was established as a year-round marine laboratory in 1912. Continuous records of sea surface temperature (SST) and salinity (SSS) measured at the SIO Pier have been made since 1916. Concurrently, continuous surveys were made for diatom and dinoflagellate populations (Allen, 1917-1946), and semi-continuous for occurrences of red tides (Sweeney, 1950-1960), and total phytoplankton biomass (Food Chain Group, 1960-1974). From 1983-2000, near-surface water samples were collected twice weekly at the SIO Pier for measurements of nutrients and chloro-phyll-*a* concentrations ("SIO Pier sampling program"). The sampling program also included collection and preservation of water samples for phytoplankton studies on a continuous, twice-weekly basis since February 1992, and for non-continuous years 1983-1991. However, the organisms in this recent collection have not yet been identified and/or enumerated except for a few intermittent studies.

Recent and ongoing observations from Scripps Pier

C. Lange and M. Latz are principal investigators for a new project analyzing an 8-year time-series (1992-2000) of variability in the biodiversity and abundance of diatoms and thecate dinoflagellates from Scripps Pier. The scope of this pilot project is limited to the generation of a biological database structured to follow Ocean Biogeographical Information System (OBIS) standards, for eventual inclusion in the Census of Marine Life (CoML) program (http://core.cast.msstate.edu/censhome.html). This time-series will lead to an updated descriptive record of regional diatom and dinoflagellate species.

This dataset will exist in spreadsheet format. It will include: (1) a complete list of diatom and dinoflagellate species identified from the SIO Pier samples; (2) updated nomenclature including complete Latin names, synonyms for each species and authorship; (3) citations; (4) abundance data for total diatoms and total thecate dinoflagellates; (5) abundance data for individual species; (6) data on diatom and dinoflagellate diversity; and (7) photographic documentation of species by means of light microscopy illustrations, and to a limited extent, scanning electron micrographs.

Retrospective analyses of Scripps Pier samples and comparisons with other coastal stations

In the early 1900s, W.E. Allen collected phytoplankton samples on a daily basis, enumerated species and provided weekly counts (generated by mixing aliquots of daily samples) of diatoms and dinoflagellates for several coastal stations along the California coast. The longest (20+ years) of Allen's time-series data were obtained from SIO (1917-1939) and Port Hueneme (1923-1939) piers. Daily hydrographic data (SST and SSS) complement his phytoplankton data (these can be accessed through SIO FTP and web sites, http://meteora.ucsd.edu/weather.html). Allen published several papers using these time-series. Particularly noteworthy are two summaries: a 10-year statistical study of Southern California diatoms (Allen 1936) and a 20-year statistical study of dinoflagellates from these waters (Allen 1941). Thomas *et al.* (1998) also published an analysis of Allen's time-series (Fig. 44).

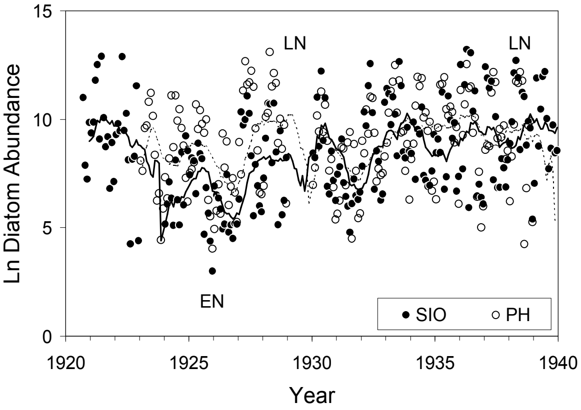


Fig. 44 Variability of diatom abundance measured at the SIO (thick lines and solid symbols) and Port Hueneme (thin lines and open symbols) piers (from Thomas *et al.* 1998). Abundance data are natural log transformed. Lines represent a 12-month running average for the data. Note synchrony of fluctuations at both sampling stations. EN = El Niño (1926); LN = La Niña (1929 and 1939).

Lange and Hewes (manuscript in prep.) have recently applied PCA ordination to the full species-identification time-series, and found that groups of diatom species (e.g. Upwelling, Warm Neritic, Warm Oceanic, Temperate Oceanic, etc.) cluster strongly in ordination space. The upwelling group was the dominant diatom group, many times composing more than 50% of the total assemblage. The specific composition of the diatom assemblage of Allen's time is similar to that of the 1980s and 1990s observed by Reid *et al.* (1985) and Lange *et al.* (1994). However, a major difference between the early and late part of the 20th century lies in the abundance of species, which are commonly associated with warm water masses (Lange *et al.* 1990, Lange and Hewes in prep.). While their average relative abundance in the Southern California Bight during 1920-40 never exceeded 6% of the total assemblage, their average contribution has increased to 10% in the past three decades (Lange, unpubl. observation).

Ongoing projects at the Scripps Pier

1. A 1983-2000 dataset of twice weekly measurements of temperature, salinity, chlorophyll and nutrients collected by J.A. McGowan.
2. Continuous measures which are obtained by sensor array: air temperature, relative humidity, barometric pressure, wind direction and velocity, water temperature, rainfall, tide level, wave height and period, and photosynthetically active radiation. Sponsored by Center for Coastal Studies and Climate Research Division at SIO.
3. Plant pigment analysis to determine phytoplankton community structure by R. Goericke at SIO. This is a biweekly time-series of taxon-specific pigments as measured by HPLC which started in the summer of 1997. For the last 5 months an ADCP was added to measure internal bores and relate these to blooms.
4. Flow cytometer measurements of the cyanobacterium *Synechococcous* and picoeukaryote abundance by B. Palenik at SIO. This work has included a continuous, weekly sampling since September 1997.
5. A study of bacteria and viral abundance, bacterial species composition, and bacterial production by F. Azam at SIO. This includes weekly sampling for 1997-98, and irregular sampling over the past decade.
6. The California Department of Health Services carries out a Marine Biotoxin Monitoring Program designed to detect toxin-producing species of phytoplankton in ocean water before they impact fisheries and consumers.

CalCOFI Program, California Current

The California Cooperative Fisheries Investigations (CalCOFI) program is an ongoing oceanographic program carried out by the California Department of Fish and Game, the National Marine Fisheries Service of NOAA, and SIO. It is concerned with all of the elements of the pelagic ecosystem that can be measured routinely on a quarterly basis. It allows for spatial averaging of time series, covers a large oceanic area off California and Mexico, and is of a 50-year duration (Fig. 45). Frequencies of change from monthly to decadal periods are resolved with these data, which are now available on-line (NEMO.ucsd.edu). Abundances and distributions of phytoplankton species from CalCOFI stations for designated depths and times of the year are being studied by E. Venrick at SIO. Satellite-

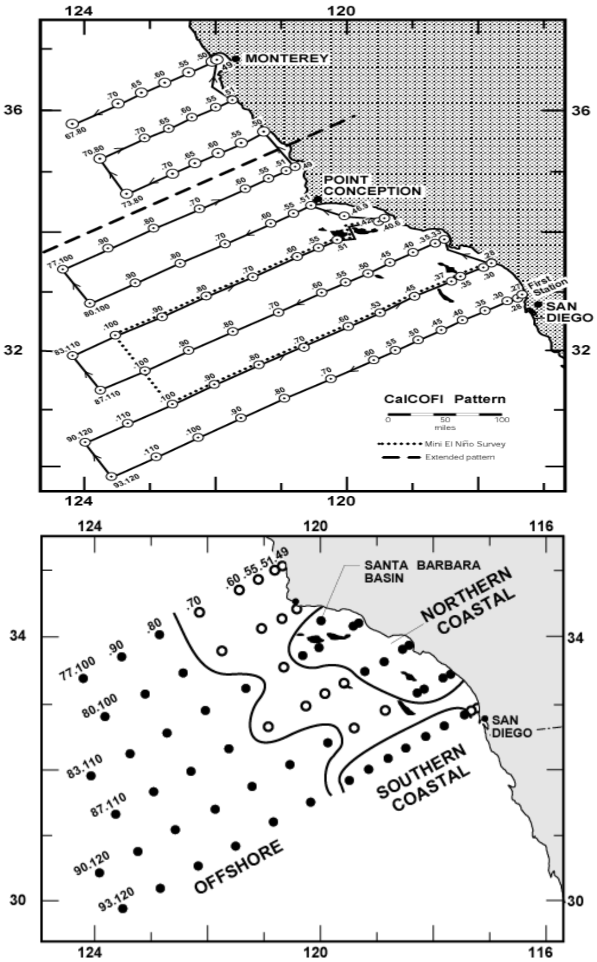


Fig. 45 The present CalCOFI sampling region. Top panel: station plan showing station designations (digits before the decimal point indicate line numbers; digits following the decimal give station numbers). Bottom panel: locations of the three environmental regimes defined by Hayward and Venrick (1998). The near-surface chlorophyll concentrations at stations within each regime have similar patterns of fluctuations over time. The boundary between regimes fluctuates, so that 16 stations (open circles) are alternately in one regime or another and cannot be classified. Santa Barbara Basin station refers to trap site and CalCOFI sta. 82.47.

derived chlorophyll concentrations for the SCB and the CalCOFI grid are being examined by B.G. Mitchell at SIO.

Santa Barbara Basin (SBB) – Water column

SBB sediment traps

An ongoing trapping program in the SBB (34°14'N, 120°02'W) is being carried out by the University of South Carolina (PI: R. C. Thunell): (i) to monitor seasonal changes in sediment fluxes, (ii) to evaluate seasonal and interannual variability in response to El Niño (La Niña) events, and (iii) to appraise sediment formation and accumulation in the SBB. Weinheimer and Lange have been involved in this project since 1993, currently funded in part by Vetlesen and Tode Foundations. Another trapping program in the SBB (34°15.33'N, 119°56.29'W) was active from June 1995 to August 1999 (PIs: A. Alldredge, M. Brzezinski and J. Kennett). Trap samples were analyzed for POC, PON, $CaCO_3$, lithogenic and biogenic silica, TEP, foraminiferal flux and stable isotopes, and trace metals. In addition, the program consisted of bi-weekly water sampling of the upper 75 m for chlorophyll-*a*, nutrient concentrations, temperature, salinity and density.

Near-surface flora of the Santa Barbara Basin

This project is being carried out by E. Venrick at SIO, who is studying abundances and distributions of phytoplankton species in the mixed layer from CalCOFI station 82.47 in the SBB, since October 1993.

Plumes and Blooms: Studying the color of the Santa Barbara Channel

The Plumes and Blooms project is a coordinated time-series project of field observations and satellite imagery analysis, with the goal of understanding the driving mechanisms and impacts of sediment plumes and phytoplankton blooms in the Santa Barbara Channel. *In situ* optical quantities and in-water constituents are collected since 1996, along a seven-station transect across the Santa Barbara Channel. Scientists involved in this effort include D.A. Siegel, R.C. Smith, M. Brzeziniski, L. Mertes, D.A. Toole, L. Washburn, D. Fernamburg, O. Polyakov and J. Warrick. Information about this program can be found at http://www.icess.ucsb.edu/ PnB/PnB.html.

Santa Barbara Coastal LTER

The Santa Barbara region (34°N, 119°W) has recently been selected as one of the major sites within the LTER effort. Research includes (i) the effects of land use on the processing and transport of nutrients and carbon to the coastal ocean; (ii) the role of runoff and oceanic forcing in structuring kelp forest communities; and (iii) controls on reef food webs by nutrients and predation. Site Principal Investigator is D.C. Reed (UCSB). Most relevant sampling includes basin wide surveys of the SBB using a combination of CTD rosette casts and a towed fish to assess the distribution of chemical, physical and biological variables across the basin. LTER measures primary production and characterizes the particulate matter three times a year, in the spring, summer and fall, within a grid of stations spanning the entire Basin. Analyses include nutrients (nitrate, phosphate, silicate), chlorophyll, biogenic and lithogenic silica, particulate carbon and particulate nitrogen (Mark Brzezinski, D. Siegel, L. Washburn, UCSB).

Santa Barbara Basin – Paleoclimatology and paleoceanography from laminated sediments

For the past 10+ years, T. Baumgartner, J. Kennett, C.B. Lange, A. Schimmelmann, R.C. Thunell, A. Weinheimer, and several others, have been involved in studies (funded by NSF, NOAA, and DOE) of the varved sediments of the SBB (Fig. 46) to appraise sediment formation and accumulation. These include: varve chronology, preservation of biogeochemical signals, land-derived components and flood events, and interannual-centennial variability of siliceous (diatoms, silicoflagellates, radiolarians) and calcareous (foraminifers) microplankton.

References

Allen, W.E. 1936. Occurrence of marine plankton diatom in a ten years series of daily catches in Southern California. Amer. Jour. Botany 23: 60-63.

Allen, W.E., 1941. Twenty years statistical studies of marine plankton dinoflagellates of southern California. Am. Midl. Nat. 26: 603-635.

Lange, C.B., Reid, F.M.H., and Vernet, M. 1994. Temporal distribution of the potentially toxic diatom *Pseudonitzschia australis* at a coastal site in Southern California. Mar. Ecol. Prog. Ser. 104: 309-312.

Lange, C.B., Burke, S.K., and Berger, W.H. 1990. Biological production off Southern California is linked to climatic change. Climatic Change 16: 319-329.

Reid, F.M.H., Lange, C.B., and Whitem, M.M. 1985. Microplankton species assemblages at the Scripps Pier from March to November 1983 during the 1982-1984 El Niño event. Botanica Marina 28: 443-452.

Thomas, W.H., Hewes, C.D., and Zavoico, T. 1998. Historical phytoplankton species time-series data (1917-1939) from the North American Pacific coast. SIO Ref: No. 98-17.

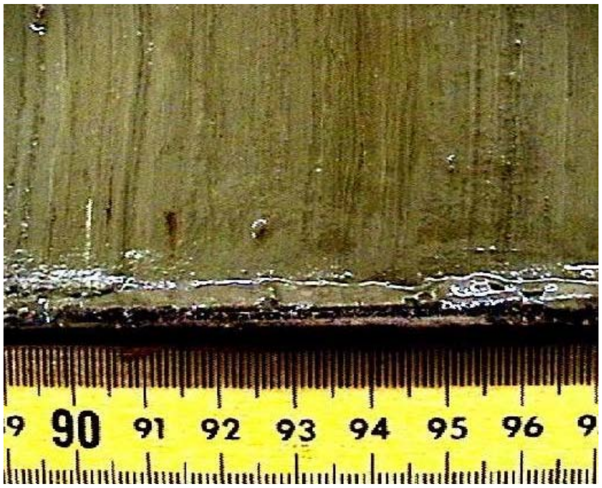


Fig. 46 Color photograph showing exposed varved structure of a piston core from the Santa Barbara Basin. This particular sediment is about 250 years old, with increasing age from left to right. Each varve is composed of one dark/light couplet. Scale is in cm. From http://php.indiana.edu/~aschimme/.

Canadian activities and plans for zooplankton, phytoplankton, micronekton, and benthos monitoring in the Pacific Ocean

David L. Mackas

Fisheries and Oceans Canada, Institute of Ocean Sciences, P.O. Box 6000, Sidney, B.C., Canada. V8L 4B2 E-mail: MackasD@pac.dfo-mpo.gc.ca

Geographic distribution, time-series duration, and present sampling frequency

Sustained time-series are located in three regions (Table 17, Fig. 47):

1. The Alaska Gyre, primarily at Station P (50°N 145°W) and at 5 locations along Line P (between Stn P and the mouth of Juan de Fuca Strait). The Stn. P zooplankton time-series dates back to 1951, although sampling frequency has varied greatly. Dedicated Line P cruises now usually occur 3 times per year (May-June, August-September, and February). Instrumented sequencing sediment trap moorings are maintained at Stn P and at Line P04 (continental slope).

2. British Columbia outer continental margin (continental shelf, shelf break and slope). Net tow and water sampling, 2-4 dedicated surveys per year along a set of cross-shelf lines extending seaward of Vancouver Island, plus opportunistic sampling at additional locations.

3. "Inland seas" - primarily the Strait of Georgia, Juan de Fuca, and a few adjoining inlets. Frequent sampling surveys since the mid-1990s, plus various instrumented moorings.

Table 17 Regions, variables, and temporal coverage for Canadian lower trophic level time-series in the NE Pacific.

Region	Variables/Platforms	Duration	Frequency	Comments
Alaska Gyre				
Line P- Stn P	research cruises: macro-nutrients (N, P, Si) mesozooplankton pigments and productivity moorings: sequential sediment trap	1970-present 1956-present 1959-present 1982-present	3/year 2/month	methodology changes during time series pigment/productivity data have many gaps, winter-fall nutrient drawdown used to estimate annual new production
Trans-Pacific ships of opportunity	surface nutrients, pCO_2, chl	1995-present	approx. monthly	MV *Skaugran*; some earlier data from other platforms
British Columbia continental margin (outer coast of Vancouver Island at present)	Research cruises: mesozooplankton macro-nutrients chlorophyll & prim. prod. seabird reproductive biology Ocean color: CZCS, SeaWIFS Offshore met buoy network	1985-present (as above, but gaps) 1975-present mid 1980s; late 1990s	4-5/year	Good zoopl. seasonal climatology and anomaly time series for west coast of Vancouver Is.; other data 1978-1985. Local archival & analysis; quantification bias issues re cloud cover and high pigment regions Opportunity (not yet exploited) for addition of biological sensors
British Columbia continental margin (central and northern BC)	Mesozooplankton, occasional macro-nutrients (opportunistic sampling from research and stock assessment cruises)	1990-present	1-3 /year	Very sparse spatial and temporal coverage, especially pre-1998
Inland seas and inlets (mostly Strait of Georgia)	Research cruises: mesozooplankton nutrients phytoplankton biomass and productivity	1966-68, 1975-77, 1990s-present	4+ /year	Changes in sampling grid and methodologies

In most cases, funding of time-series sampling programs has been year-to-year. Maintenance of the time-series has therefore been largely at the initiative of individuals or small teams of researchers, and often under a sequence of project names and funding sources. There is a growing awareness among science managers that this funding model is precarious and unsatisfactory, and Canada is now planning/proposing a sustained monitoring program for the Pacific.

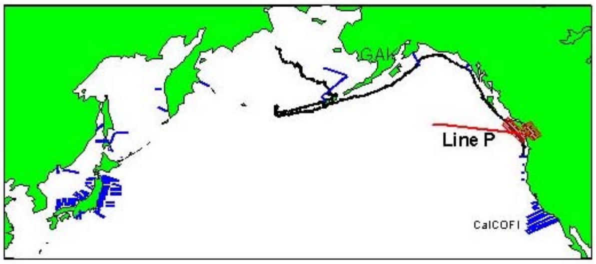


Fig. 47 Location of Canadian lower-trophic-level time-series, in relation to other North Pacific monitoring programs (adapted from Welch, this report).

Methodology and archival status for different trophic levels

Phytoplankton

Research cruise surveys of Line P-Stn P, the continental margin of Vancouver Island, and the Strait of Georgia obtain measurements of phytoplankton biomass as *in vivo* fluorescence profiles, plus occasional bottle samples for floristic analysis and extracted fluorescence. For the Strait of Georgia, pilot studies are exploring fluorescence monitoring using moored buoys and vessels of opportunity. All programs suffer from serious spatial and temporal aliaising of phytoplankton bloom dynamics. Alternate approaches, useful in offshore regions where spatial gradients and advection are weaker, use seasonal depletion of upper layer nutrients (Whitney *et al*. 1998) and seasonal sediment flux (Wong *et al*. 1999) as indicators of variability in cumulative new production.

Zooplankton

For microzooplankton, there is at present no time-series sampling program. For the mesozooplankton, time-series samples are primarily vertical net tows with 0.2 mm mesh nets. For consistency with past practice in each region, depth ranges for net hauls are 0-150 m for open ocean (Alaska Gyre) sites, 0-250 m or 0-near bottom for coastal and continental margin sites. Additional deep (0-1,000 m) and vertically stratified (usually 8 layers 0-250 m) samples have been collected to aid interpretation of vertical distributions. An electronic-format archive of the 1956-1980 Stn P time-series has been published by Waddell and McKinnell (1995). For more recent data, continental margin, and LineP-Stn P samples from 1985-present, identification and enumeration data are available as a Microsoft Access database (S. Romaine and D. Mackas, Institute of Ocean Sciences). Two completed analyses have demonstrated important interannual-decadal zooplankton variability: Mackas, Goldblatt and Lewis (1998) described changes in seasonal timing of the Alaska Gyre zooplankton maximum, and Mackas, Thomson and Galbraith (in press) described long-scale annual anomalies of zooplankton community composition for continental shelf and slope regions off the southwest coast of Vancouver Island (Fig. 48). Prerequisites for useful zooplankton anomalies include a prior description of the average zooplankton seasonal-cycle, and a relatively large number of independent samples each year (about 20-30) to average out "noise" from small-scale spatial and temporal patchiness.

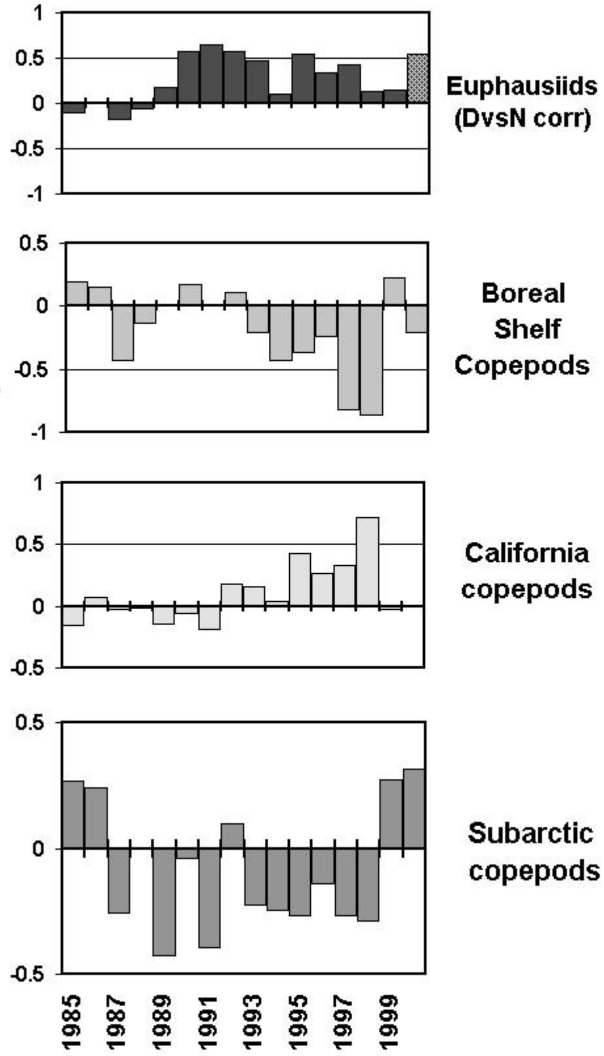


Fig. 48 Annual zooplankton anomalies for the British Columbia continental margin, averaged within groups of similar species (adapted from data in Mackas *et al.* in press).

Micronekton

At present, there is no Canadian time-series sampling of micronekton, except for estimates of euphausiid biomass and species/stage composition obtained using hydroacoustics and zooplankton net tows. This is a topic in which Canadians have considerable scientific interest, but relatively little scientific capacity.

References

Mackas, D.L., Thomson, R.E., and Galbraith, M. 2001. Changes in the zooplankton community of the British Columbia continental margin, and covariation with oceanographic conditions, 1985-1999. Can. J. Fish. Aquat. Sci. (in press).

Mackas, D.L., Goldblatt, R., and Lewis, A.J. 1998. Interdecadal variation in developmental timing of *Neocalanus plumchrus* populations at Ocean Station P in the subarctic North Pacific. Can. J. Fish. Aquat. Sci. 55: 1878-1893.

Waddell, B.J., and McKinnell, S. 1995. Ocean Station 'Papa' detailed zooplankton data: 1956-1980.

Whitney, F.A., Wong, C.S., and Boyd, P.W. 1998. Interannual variability in nutrient supply to surface waters of the NE Pacific Ocean. Mar. Ecol. Progr. Ser. 170: 15-23.

Wong, C.S., Whitney, F.A., Crawford, D.W., Iseki, K., Matear, R.J., Johnson, W.K., Page, J.S., and Timothy, D. 1999. Seasobnal and interannual variability in particle fluxes of carbon, nitrogen and silicon from time series of sediment traps at Ocean Station P, 1982-1993: relationship to changes in subarctic primary productivity.

Monitoring of coastal pelagic ecosystems off Oregon, Washington and N. California - Hydrographic and plankton time-series

William T. Peterson, Julie Keister, Leah Feinberg and Cheryl Morgan
Estuarine & Ocean Ecology, Hatfield Marine Science Center, National Marine Fisheries Service, 2030 S. Marine Science Drive, Newport, OR 97365, U.S.A. E-mail: bill.peterson@noaa.gov

Surveys off Newport Oregon – 1960s

Oceanographic time series data are available from the Newport Hydrographic Line (44°40'N, Fig. 49) due to efforts by scientists from the Oregon State University (Corvallis, Oregon) and the National Marine Fisheries Service (Newport, Oregon). Frequent sampling of the hydrography and plankton occurred during the 1960s and early 1970s. Climatology of the salinity, temperature and density from 1961-1971 can be seen at the website: http://ltop.oce.orst.edu/~ctd/index.html.

Euphausiids and larger zooplankton were sampled at night from 1962-1967, at monthly intervals at stations located 5 miles to 85 miles from shore with a 1 m diameter 570 µm mesh net (Smiles and Pearcy 1970). From 1974 through 1995, a very limited number of CTD measurements and plankton tows were made off the Oregon coast. However, beginning in 1996, the Newport Line was once again sampled on a regular basis. Thus we have available for study a disjunct time-series of physical oceanographic data and plankton abundances that represents two time periods, the 1960s-early 1970s, and the late 1990s to present.

High-frequency sampling off Newport

Hydrographic stations located 1, 3, 5, and 10 miles offshore of Newport OR, were sampled for zooplankton and ichthyoplankton at biweekly intervals from June 1969-August 1972 (Peterson and Miller 1975, 1976). Water depths at these stations are 20 m, 45 m, 60 m, and 80 m. In addition zooplankton were sampled on a biweekly-monthly basis during May-September 1973, May and August 1974, July-August 1977, May-August 1978, and May-September 1983. Most of this work was carried out using 20 cm bongo nets fitted with 240 µm mesh nets and towed obliquely throughout the water column. The only hydrographic data available are sea surface temperature and salinity. In addition, the 5-mile station was sampled year-round in 1991 and during summer months of 1990 and 1992, using 0.75 m diameter 333 µm mesh nets towed vertically (Fessenden, 1992).

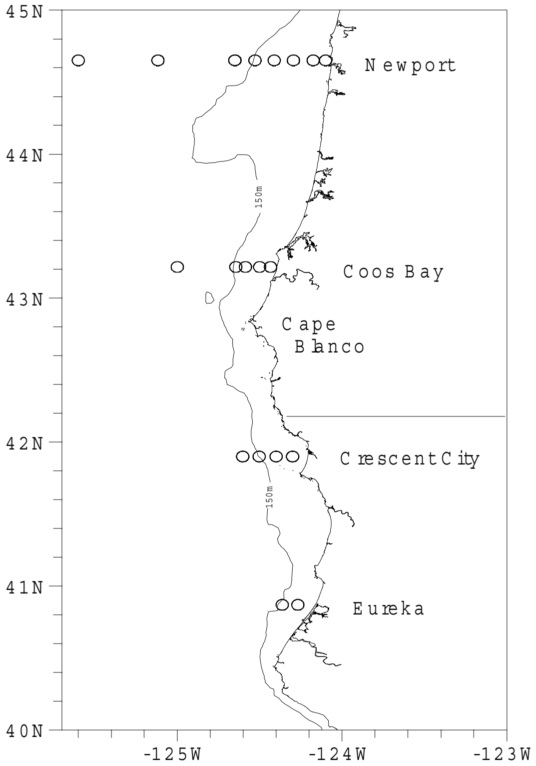


Fig. 49 Newport Hydrographic (NH) line and stations sampled during the 1960s and early 1970s. The line is now regularly sampled with 5 cruises per year along the whole line and biweekly cruises to five of the innermost shelf stations. The U.S. GLOBEC samples transect lines off Newport, Coos Bay and Crescent City three times per year; scientists at Humboldt State University sample off Eureka during spring and summer.

Sampling off Newport Oregon (44°40'N) resumed in May 1996, with sampling at stations 1, 5, 10 and 15 miles from shore at biweekly intervals (Fig. 49). The work will continue at least through 2004. At each station a CTD profile is made with a Seabird-19 CTD, Secchi depth is measured and a water sample is collected from the sea surface with a bucket for later analysis of nutrients (nitrate, nitrite, phosphate, silicate) and chlorophyll. Zooplankton is sampled with a 50 cm diameter 202 µm mesh net hauled vertically from near the sea floor to the sea surface at a speed of 30 m/min. Zooplankton is also sampled with a 1-m diameter 333 µm mesh net that is towed obliquely from 20 m to the surface. Beginning in 2001, the 1-m net was replaced with a 60 cm Bongo net with 200 µm mesh.

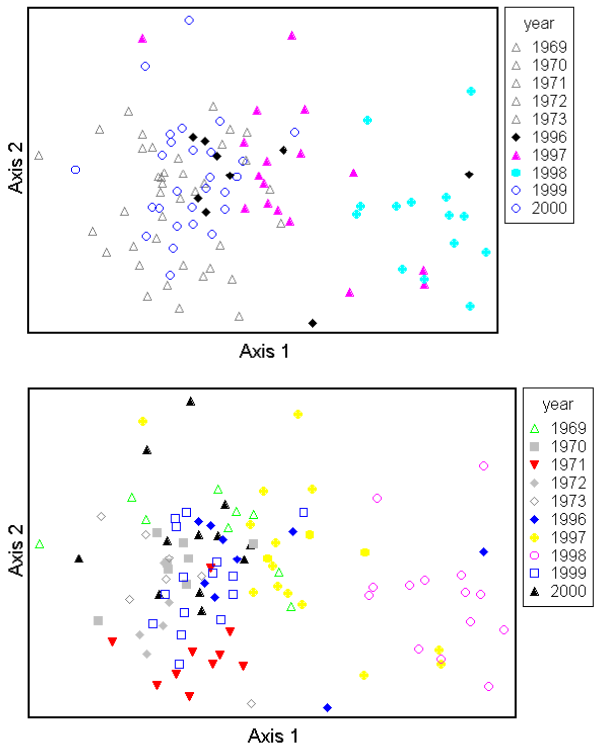


Fig. 50 Ordination of zooplankton samples collected from 1969-1973 and 1996-2000 at the station NH-5 (five miles off Newport OR). Upper panel compares the 1970s (open symbols) to the late 1990s (closed symbols); lower panel shows each year separately. Samples from the "warm period" of the 1990s cluster on the right side of the ordination; samples from the "cool period" of the 1970s and 1999/2000 cluster to the left side of the ordination.

We analyzed a subset of these data (1969-1973 and 1996-2000) using Non-Metric Multidimensional Scaling (an ordination technique) and found differences in the zooplankton community structure between the two time periods. This technique calculates a similarity index for each sample, groups samples by the degree of similarity, then orders all samples in species space using the Sorensen Distance Measure. Figure 50 shows that the community observed from 1969-1973 was fundamentally different from the community observed from 1996-1998. Examination of the species abundance data shows that the community in the 1970s was composed of species with sub-arctic affinities, whereas the community observed from 1996-1998 was composed of a mixture of species of sub-arctic and sub-tropical affinities. This is attributed to an extended period of El Niño conditions that persisted along the Pacific Northwest waters from 1992 through 1998, 1999 was a period of transition, and 2000 showed that the zooplankton community switched to one dominated by sub-arctic species.

Figure 51 shows the seasonal cycle of chlorophyll concentration and the abundance of one of the dominant copepod species, *Calanus marshallae* at the five-mile station (designated NH 5). The annual spring bloom occurs in April; large blooms occur during summer associated with relaxation of coastal upwelling (July/August); and in some years there is a fall bloom, in September or October. Changes in abundance of *C. marshallae* track phytoplankton biomass in that the initial increase in copepod numbers is in spring, possibly in association with the spring bloom. Peak numbers are seen during the summer upwelling season. The population disappears from the water column during the first week of October, presumably because individuals enter diapause.

Quarterly broad-scale surveys off central/southern Oregon and northern California

4 transect lines off Oregon and northern California are sampled three times per year as part of the U.S. GLOBEC program (Fig. 49), in April, July and September. The time series began in July 1997 and will continue through 2003. Transect lines include Newport OR (44°40'N), Coos Bay OR (43°13'N), Rogue River OR (42°30'N) and Crescent City CA (41°54'N). The transect lines extend beyond the continental shelf to 160 km from shore (2900 m water depth) off Newport; Coos Bay to 63 km from shore (1700 m); Rogue River to 64 km from shore (3060 m depth); and Crescent City to 150 km from shore (3400 m depth). At each station CTD casts are made. At most stations nutrients and chlorophyll are sampled from 9 discrete depths, and zooplankton is sampled with the vertical tow net from 100 m to the surface as described above. Bongo tows were made at most stations in 1998 and 1999. Beginning in March 2000, we collected zooplankton from discrete depths using a 1 sq. m MOCNESS system. WOCE drifters are released at five stations along the Newport Line (10, 15, 25, 45 and 65 miles from shore). On each cruise, underway measurements are made of currents (ADCP), and fish and zooplankton acoustics using an HTI 244 system. In addition to the coast-wide sampling, the Newport Line is sampled in February and November, giving us five visits per year to the deep ocean along that line.

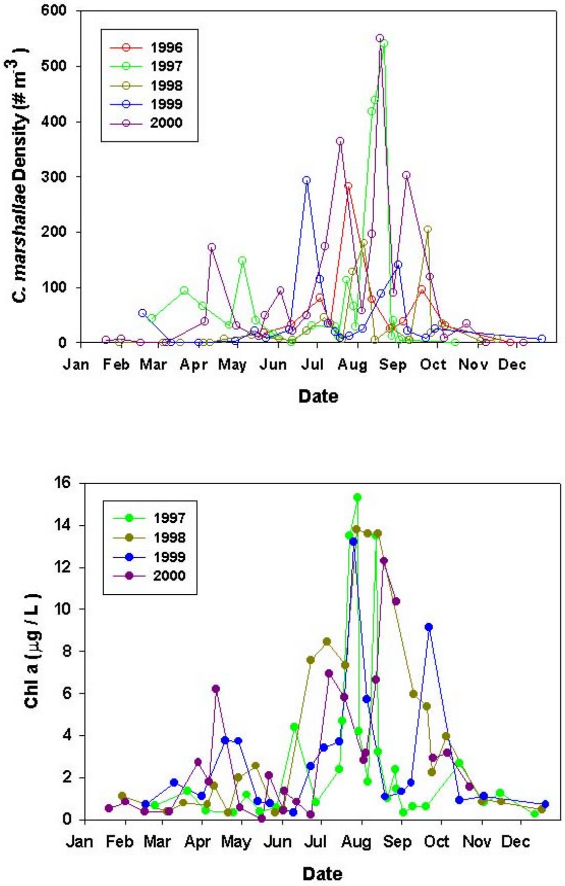


Fig. 51 Seasonal cycle of chlorophyll and *Calanus marshallae* (Copepoda) at NH 5 in the late 1990's.

Juvenile salmonid and zooplankton surveys in the vicinity of the Columbia River plume

Juvenile salmonids are sampled along 5-8 transects off the Washington and Oregon coasts in May, June and September (Fig. 52). This work began in 1998 and will continue for approximately five more years. Pelagic fish are sampled with a Nordic 264 rope trawl (30 m wide by 20 m high by 200 m long) fitted with a 0.8 cm cod end liner. At each trawl station, zooplankton is sampled with a 0.5 m diameter 202 µm mesh net towed vertically from 100 m to the surface, with a 1-m^2 mouth neuston (manta) net (333 µm mesh net) and with a 1-m diameter 333 µm mesh net from 20 m to the surface.

Zooplankton sampling off Northern California

Scientists from Humboldt State University (Arcata CA) conduct cruises off Eureka CA (40°50'N) during spring and early summer, as part of a program which trains undergraduates in oceanographic techniques. Cruises are carried out approximately monthly, weather permitting. Several stations over the continental shelf are sampled (out to a distance of 25 miles from shore). At each station standard measurements are taken including CTD profiles, Secchi depths, and chlorophyll. Zooplankton is sampled with a 60 cm bongo net fitted with 333 µm mesh nets.

Broad-scale zooplankton surveys in 1994-1998

Fish eggs and larvae and zooplankton were sampled along 15-20 transect lines off the southern Washington and Oregon coasts, from 2 to 100 miles from shore by Bob Emmett (NMFS, Newport OR) during July 1994 and 1995, June 1996, and July 1997 and 1998. The purpose of the cruises was to map the distribution and abundance of anchovy and sardines eggs and larvae in relation to hydrography and zooplankton abundance (Bentley *et al.* 1996). Plankton sampling was done with a 25 cm CalVET net fitted with 150 µm mesh nets. CTD casts to 70 m were done and nutrient and chlorophyll samples were collected from 3 m depth at each station.

Zooplankton species from three of these cruises have been compared using ordination techniques (the NMS technique described above). We found distinct zooplankton communities on the shelf as compared to deeper water offshore -- there was a regular progression of change in community structure along a bathymetric gradient (Fig. 53).

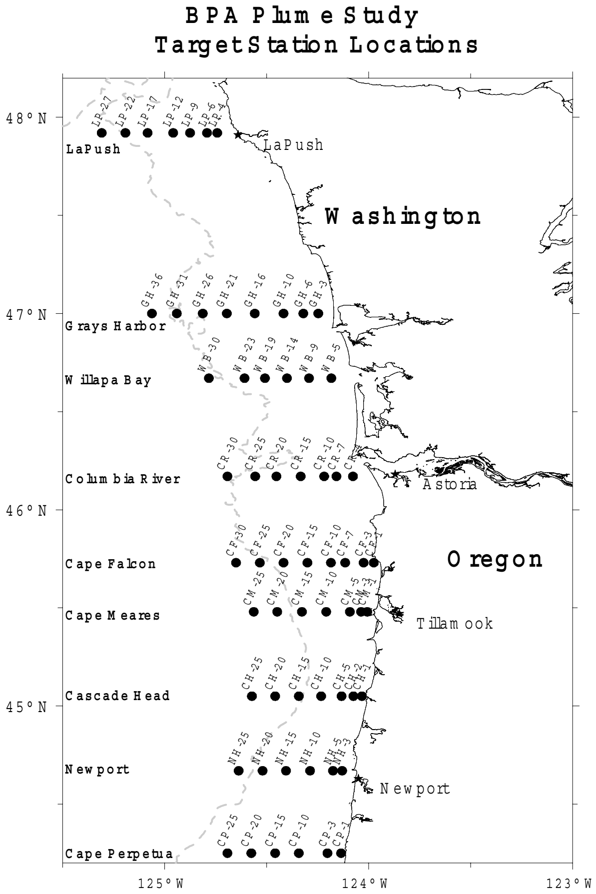


Fig. 52 Chart showing location of stations sampled during surveys of hydrography, nutrients, chlorophyll, zooplankton and juvenile salmon in May, June and September of each year.

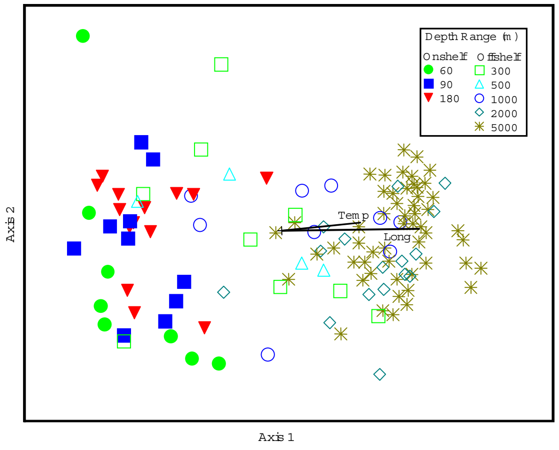


Fig. 53 Ordination of zooplankton samples collected in July 1994, June 1996 and July 1997, showing distinct changes in copepod community structure along a gradient extending from shallow (left side of ordination) to deep water (right side).

References

Bentley, P.J., Emmett, R.L., Lo, N.C.H., and Moser, G. Egg production of Pacific sardine (*Sardinops sagax*) off Oregon in 1994. CALCOFI Rep. 37: 193-200.

Fessenden, L.M. 1995. Calanoid copepod diet in an upwelling system: phagotrophic protists vs. phytoplankton. Ph.D. Thesis, Oregon State University, 136p.

Peterson, W.T., and Miller, C.B. 1975. Year-to-year variations in the planktology of the Oregon upwelling zone. Fish. Bull. U.S. 73: 642-653.

Peterson, W.T., and Miller, C.B. 1976. Zooplankton along the continental shelf off Newport Oregon, 1969-1972: distribution, abundance, seasonal cycle and year-to-year variations. Oregon State University Sea Grant College Program, Pub. No. ORESU-T-76-002, 111p.

Smiles, M.C., and Pearcy, W.G. 1971. Size structure and growth rate of *Euphausia pacifica* off the Oregon coast. Fish. Bull. U.S. 69: 79-86.

East-west variability of primary production in the subarctic North Pacific derived from Multi-Sensor Remote Sensing during 1996-2000

Sei-ichi Saitoh and Kosei Sasaoka
Laboratory of Marine Environment and Resource Sensing, Graduate School of Fisheries Sciences, Hokkaido University, 3-1-1 Minato-cho, Hakodate, Hokkaido 041-8611, Japan. E-mail: ssaitoh@salmon.fish.hokudai.ac.jp

The two gyres in the subarctic North Pacific are known as Western Subarctic Gyre (WSG) in the NW subarctic, and Alaskan Gyre (AG) in the NE subarctic Pacific. Comparative studies on the primary production of the WSG and AG have been carried out in order to grasp the different effects of iron (Harrison *et al.* 1999). Understanding the role of iron fertilization of HNLC (High Nutrients Low Chlorophyll) water, satellite monitoring of temporal-spatial variability of chlorophyll-*a* (Chl-*a*) distribution is very important (e.g. Abraham *et al.* 2000).

Ocean color remote sensing is a new useful tool for continuous monitoring temporal and spatial variability of Chl-*a* concentration. OCTS on ADEOS satellite (Saitoh 1995) provided valuable data from November 1996 to June 1997. SeaWiFS on orbview2 (Hooker and Esaias 1993) launched successfully on August 1997, and its operation is very stable so far. In the past, Banse and English (1994, 1999) have already discussed phytoplankton seasonality in this region using CZCS data sets. Recently, Shiomoto *et al.* (1998, 1999a and 1999b) have described the distribution pattern of Chl-*a* and primary productivity in this region based on ship observations. However, some questions still remain about seasonal changes and year-to-year variability of Chl-*a* distribution and primary productivity in this area at long-term scale.

Now, we have ocean color data sets of OCTS and SeaWiFS for about three years. The objectives of this study are: to grasp the temporal and spatial variability of Chl-*a* distribution and primary productivity in the subarctic North Pacific, and to understand the mechanisms regulating Chl-*a* distribution in 1996-2000.

Satellite observations

Temporal and spatial distributions of Chl-*a* in the study area (Fig. 54) were analyzed using the OCTS and SeaWiFS data. We employed OCTS Level3 Binned Map (weekly and monthly mean images) from November 1996 to June 1997, and SeaWiFS level3 gridded data (8-day and monthly mean images) from September 1997 to June 2000. The OCTS and SeaWiFS data were provided by NASDA and NASA-DAAC, respectively. The AVHRR/NOAA data were applied to study the distribution and temporal variability of sea surface temperature from January 1996 to June 2000.

Data sets were provided by NASA JPL PO-DAAC. In addition, we attempted to calculate primary productivity by a modified VGPM Model (Behrenfeld and Falkowski 1997) developed by Kameda and Ishizaka (2000) using ocean color and SST satellite data sets. The Special Sensor Microwave Imager (SSM/I) data were applied to study the distribution and temporal change of wind stress from January 1996 to June 2000. Monthly sea wind speed anomalies were calculated from wind data sets obtained from the SSMI data web site (http://www.ssmi.com) (Remote Sensing Systems).

Ship observations

Ship observations were carried out by R/V *Mirai*, T/S *Oshoro-Maru* and T/S *Hokusei-Maru* in the northern North Pacific and the Bering Sea during 1996 to 2000 (Fig. 54). From June 1998 to May 2000, Station KNOT has been visited monthly except for winter season. To match *in situ* Chl-*a* and satellite-estimated Chl-*a*, ship observations were also carried out by other research vessels in adjacent seas around Japan.

Salinity, temperature and depth were measured using a CTD profiler. Water samples for Chl-*a* and pheopigment determinations were collected using Niskin bottles attached to a rosette on the CTD instrument. 200 ml of seawater was filtered through a Whatman GF/F filter on board for Chl-*a* and phaeophytin measurements. Filtered samples were extracted in 6 ml of N,N-dimethylformamide, under cold and dark conditions for a later analysis. Chl-*a* and phaeophytin were determined by the fluorometric method (Parsons *et al.* 1984) with a Turner Designs Fluorometer (Model 10-AU).

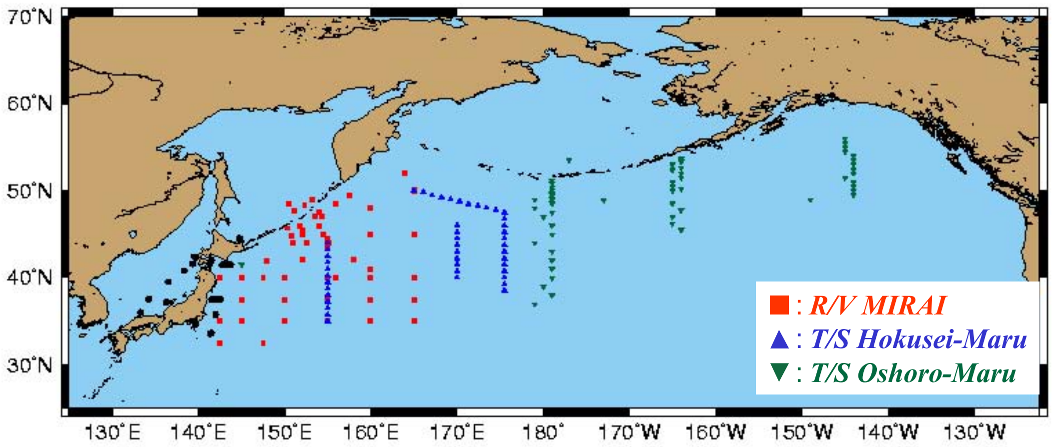


Fig. 54 Map of ship observation stations in the northern North Pacific.

The relationship between SeaWiFS and *in situ* Chl-*a* concentration

Figure 55 shows comparison between *in situ* Chl-*a* and the weekly SeaWiFS Chl-*a* concentration for waters around Japan including the NE Pacific, NW Pacific, Kuroshio Region, Japan Sea, and offshore Sanriku. Total number of samples and r^2 are 77 and 0.77, respectively. Chl-*a* concentration estimated by SeaWiFS has a tendency to be lower than *in-situ* Chl-*a* concentration in the NW Pacific and to be higher in the NE Pacific. However, there is small scattered pattern between SeaWiFS Chl-*a* and *in situ* Chl-*a*. In fact, we can conclude that a SeaWiFS in-water algorithm is working well in this study area, and the results support the validation of the algorithm.

Time-series observation using ocean color data sets

Figure 56 shows variability of Chl-*a* in the WSG (50°N, 165°E) and at Station Papa (50°N, 145°W) obtained from the OCTS and SeaWiFS weekly data sets from November 1996 to November 1999. Chl-*a* concentration in the WSG and at Stn. P was relatively low (about 0.3 - 0.8 mg/m^3) throughout the year, and there is no signal of a spring and fall bloom at both stations. Seasonal variability of Chl-*a* in the WSG is greater than that at Stn. P. It is probably due to the appearance of the spring bloom in the WSG. Chl-*a* in the WSG (about 0.5 mg/m^3) was relatively high compared to that at Stn. P (about 0.3 mg/m^3) in spring. Remarkable peaks of Chl-*a* were observed at Stn. P in October 1997 and in the WSG in September 1998. High Chl-*a* concentration (1.0 mg/m^3) in the WSG continued for about two months from August to October in 1998. Spring blooms were observed only in the WSG and fall blooms were observed at both Stn. P. and WSG, as it was pointed out earlier by Banse and English (1999). SST anomaly at Stn. P in August 1997 was relatively high (about 2°C) compared with other years. SST in the WSG in August 1998 was also relatively high compared with other years. SST variability corresponded to Chl-*a* variability in each region.

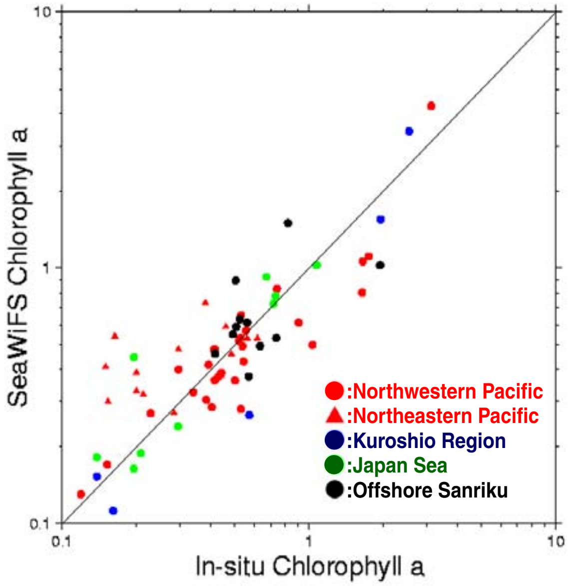


Fig. 55 Comparison between *insitu* and satellite chlorophyll-*a* concentration.

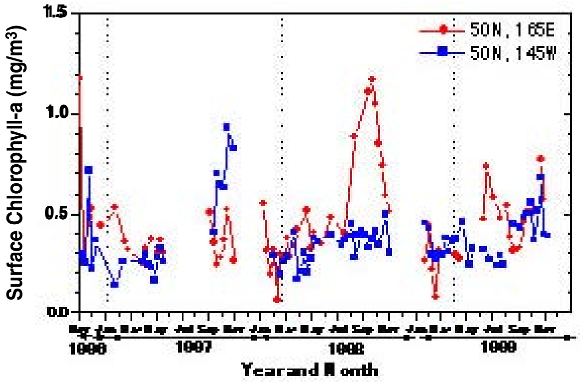


Fig. 56 Variability of Chl-*a* in the WSG (50 N, 165 E) and at Stn. P (50 N, 145 W) obtained by the OCTS and SeaWiFS weekly data sets from November 1996 to November 1999.

Figure 57 shows variability of primary productivity (PP) obtained from the OCTS and SeaWiFS monthly data sets from January 1998 to October 1999. In spring, from February to May, PP at Stn. P was relatively high compared to that in the WSG. First peak of PP in the WSG appeared in July, and one month later the peak of PP at Stn. P appeared in August of both years. A remarkable peak in the WSG was observed in September 1998. From May to June, PP at Stn. P was clearly decreasing.

Shiomoto *et al*. (1998) pointed out that Chl-*a* concentration is higher in the west and lower in the east in the subarctic North Pacific during spring and summer. However, primary productivity does not always show the same trend and daily primary productivity was not substantially different between the western region (278-1397 mgC/m^2/d) and eastern region (290-1550 mgC/m^2/d). These satellite observations support Shiomoto *et al.* suggestions. In order to understand the mechanism of year-to-year variability of ocean color, we must apply OGCM (Ocean General Circulation Model) and wind stress data sets to grasp physical processes in this region, especially during the 1997-1998 El Niño (Mutrugudde *et al.* 1999).

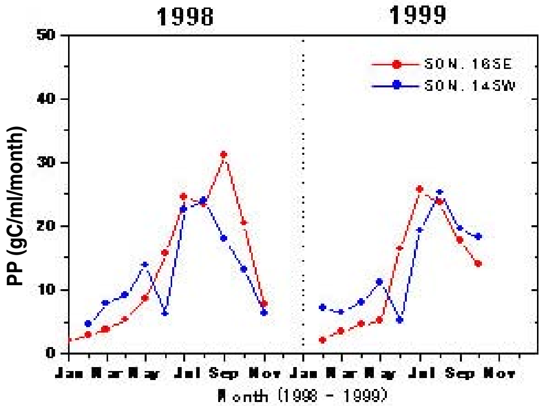


Fig. 57 Time-series variability of primary productivity (PP) from satellite obtained by OCTS and SeaWiFS monthly data sets from January 1998 to October 1999.

Long-term variations of plankton biomass in the North Pacific

Kazuaki Tadokoro
Ecosystem Change Research, Frontier Research System for Global Change, 1-18-16 4F, Hamamatsu, Minato-ku, Tokyo 105-0013, Japan. E-mail: denden@frontier.esto.or.jp

There are many papers published on the long-term variations of plankton biomass in the eastern subarctic North Pacific related to the 1976/1977 climatic regime shift. However, to estimate the effect of the climate change on biological productivity in the whole area of subarctic North Pacific, one must consider the geographical differences in this parameter. Therefore, I analyzed and compared regional differences in long-term variations of the plankton biomass related to the 1976/1977 climatic regime shift in the subarctic North Pacific.

Data and methods

Long-term variations of plankton biomass in the eastern, central Pacific, and eastern Bering Sea (Fig. 58) were estimated using data published by the University of Hokkaido (1956-2000). Details of data processing are described in Sugimoto and Tadokoro (1997). Three data sets were used to analyze long-term variations of plankton biomass in the Oyashio water (Fig. 58): data collected by the Tohoku National Fisheries Research Institute; data set by the Hakodate Marine Observatory; and data downloaded from the JODC web site. Description of these data sets is given in Table 18.

Results

After the 1976/77 climatic regime shift, Chl-*a* concentration of the central and western North Pacific (Fig. 59, upper panel) and the Oyashio water (Fig. 60, upper panel) decreased. On the other hand, Chl-*a* concentration in the eastern Bering Sea increased (Fig. 59, lower panel). Annual mean Chl-*a* concentrations at Stn. P were taken from Brodeur *et al.* (1996). Although their paper only indicated 4 or 5 years of observations after the regime shift, all Chl-*a* concentrations after 1976 are lower than the total mean (Fig. 61).

Zooplankton biomass in the central North Pacific (Fig. 62, upper panel) and in the eastern Bering Sea (Fig. 62, lower panel) gradually decreased after the regime shift. On the other hand, zooplankton biomass in the eastern North Pacific (Gulf of Alaska) increased after 1980 (Fig. 63: Brodeur and Ware 1992). Zooplankton biomass in the Oyashio water decreased since 1976 but showed a tendency to increase after 1982/83 (Fig. 60).

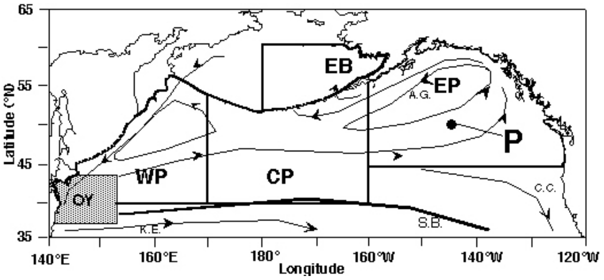


Fig. 58 Observation area and sub-regions: Oyashio water (OY), western North Pacific (WP), central North Pacific (CP), eastern North Pacific (EP), and eastern Bering Sea (EB).

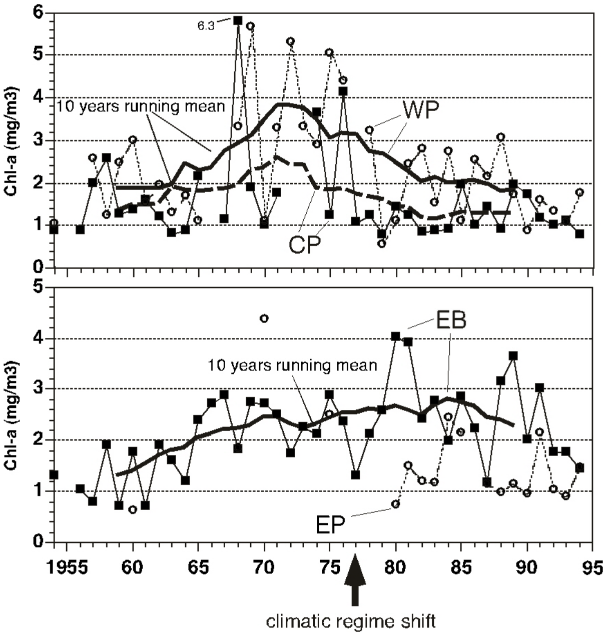


Fig. 59 Interannual variations of summer Chl-*a* concentration in the North Pacific. Original figure from Sugimoto and Tadokoro (1997).

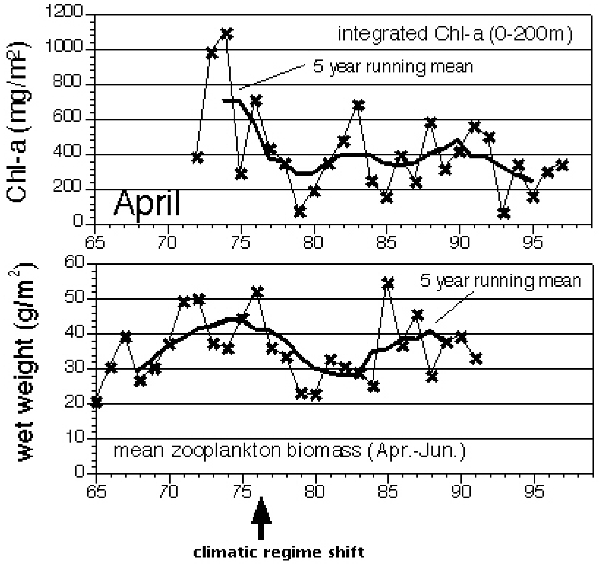


Fig. 60 Interannual variations of integrated Chl-*a* (0-200 m) in April, and meso-zooplankton biomass from April to June in the Oyashio water.

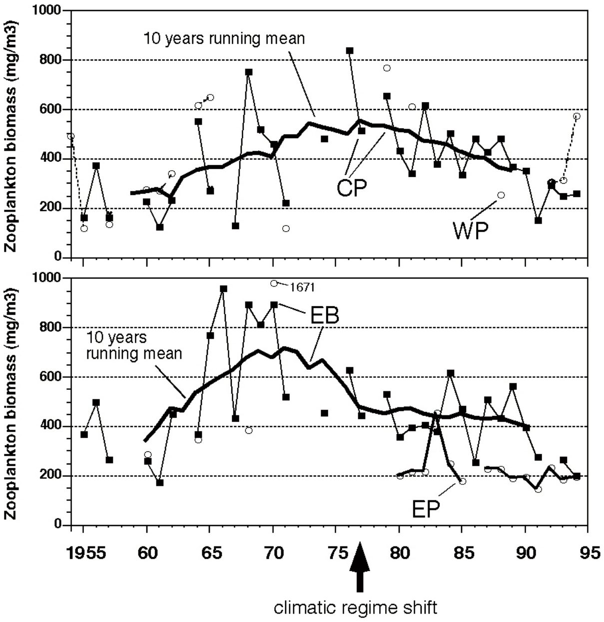


Fig. 62 Interannual variations of summer zooplankton biomass in the North Pacific. Original figure from Sugimoto and Tadokoro (1997).

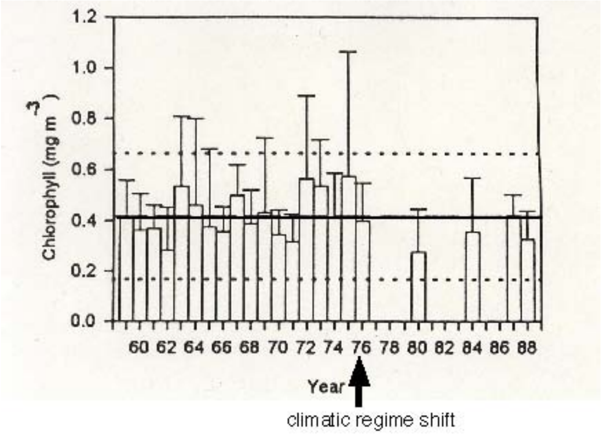


Fig. 61 Interannual variations of Chl-*a* concentration at the Ocean Stn. P. Original figure from Brodeur *et al.* (1996).

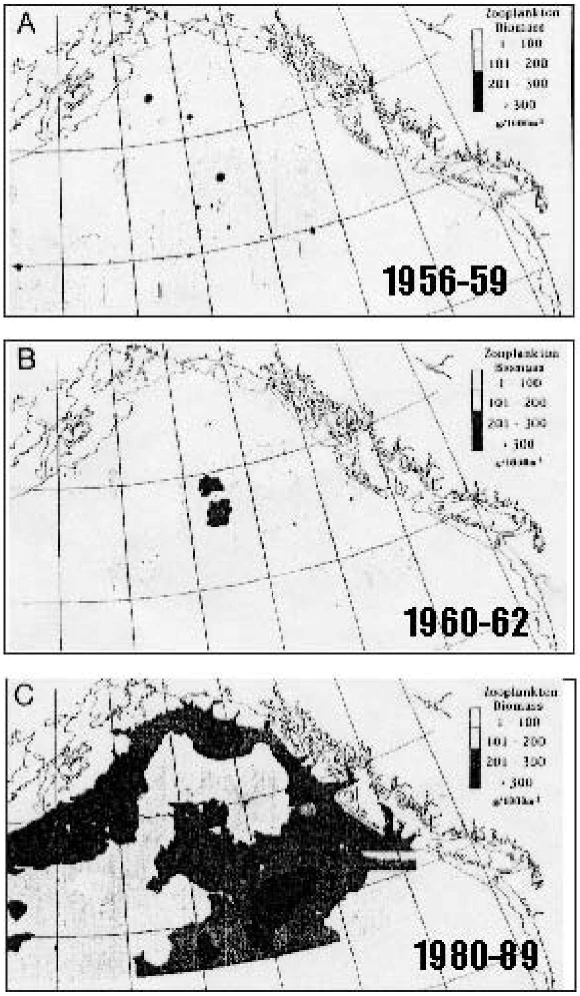


Fig. 63 Distribution of zooplankton biomass in the Gulf of Alaska for 1956-1959 (A), 1960-1962 (B), and 1980-1989 (C). Original figure from Brodeur and Ware (1992).

Table 18 Description of the data sets used for the study of long-term variations of plankton biomass in the Oyashio water.

Data set	area	period	season	total Number	sampling items									
					temp.	sal.	Transparency	Zooplankton	Diatom cell N	Chl-a	PO4	NO3	SiO4	
Hokkaido University	Offshore	1954-present	May-September	5326	●	●	●	●		●	●	●	●	*1
K Odate Zoo Plankton Biomass Sataset	Oyashio	1949-1990	year-round	17293	●	●		●						*2
PH line	Oyashio	1972-present	four seasons	593	●	●	●	●	●	●	●	●	●	*3
JODC down loaded data	Oyashio	1946-1991	whole	6238	●	●	●			●	●			

No 1 Data are published in Faculty of Fisheries, Hokkaido University (1956-2000) Data record of oceanographic observations and exploratory fishing. No. 1-43.
Zooplankton was collected by using the NORPAC net. NORPAC net have 45cm in diameter, 0.33 mesh size (NGG54 and pylon 60), and 180cm in lateral length.
When the bottom depth is deeper than 150m, the zooplankton was collected by vertical haul between 0m and 150m.
When the topography is less than 150m, W the zooplankton was collected by vertical haul between 0m and top of the bottom.
Nutrients are only collected at a monitoring transect (date line) since 1979. Chl-a concentration is not published.

2 zooplankton was collected by using Marukotku net. Marutok net have diameter in 45cm, 0.33mm mesh size (NGG54), and 80cm in lateral length.

3 Zooplankton was collected by using the NORPAC net.

* MIRC Ocean Data set 2001 CD-ROM synthesis the data set of JODC, meteorological Agency, and Fisheries Agency of Japan.
It will be available 20000 yen for scientific use and 150000 yen for company use.
The data set contain the hydrographic and chemical, and chl-a data. It not contain the zooplankton information.
http://www.mirc.jha.or.jp/en/

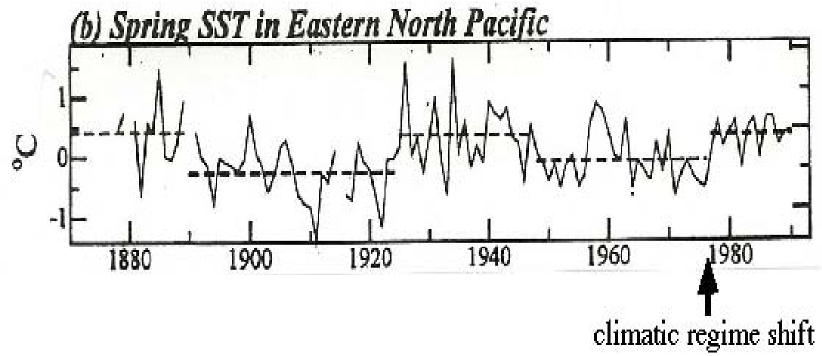


Fig. 64 Interannual variations of spring SST in the eastern North Pacific. Original figure from Minobe (1997).

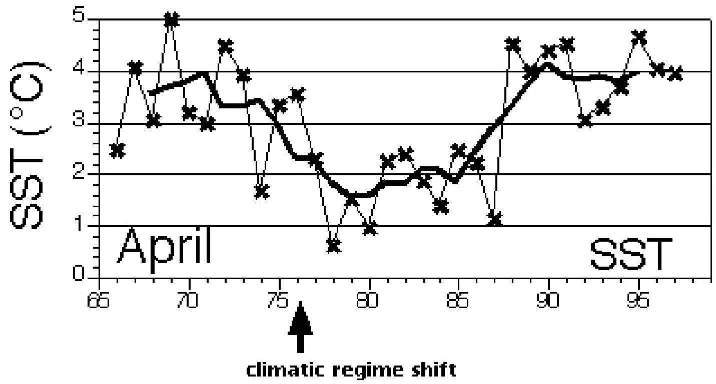


Fig. 65 Interannual variations of spring SST in the Oyashio water.

Discussion

After the climatic regime shift, zooplankton biomass increased in the eastern North Pacific, but decreased in the central North Pacific, eastern Bering Sea, and Oyashio water. Why did the regional differences occur? Here, we mainly compare the west-east differences in zooplankton biomass in the subarctic North Pacific.

The subarctic circulation is counterclockwise, and supplies warm water to the eastern subarctic Pacific from the south and cold water to the western subarctic Pacific from the north. The Aleutian Low is a driving force for the subarctic circulation, and therefore, the intensification of the Aleutian Low accelerated the subarctic circulation at the time of the 1976/77 regime shift. Consequently, warm water was transported to the eastern North Pacific from the southern area (Fig. 64), and cold water form the northern area was transported to the Oyashio water (Fig. 65). Polovina (1995) hypothesized that the shallower MLD after the regime shift caused the increase in plankton biomass in the eastern Pacific, because the solar radiation is a limiting factor for primary production in the Central and North Pacific. If this is correct, we can explain the west-east differences in zooplankton biomass in the subarctic Pacific (Fig. 66). El Niño also results in higher SST and shallower MLD in the eastern subarctic Pacific; however, primary production decreases during an El Niño period (Whitney *et al*. 1998). Therefore the warming and related changes in MLD will not cause an increase of zooplankton biomass in the eastern North Pacific.

Iron is the limiting micronutrient for large phytoplankton in the subarctic waters. Wong *et al*. (1996) suggested that stronger atmospheric circulation, due to the intensification of the Aleutian Low, could enhance the iron input with dust and aerosols from the Chinese desserts and thus would increase. However, there is no evidence to support this hypothesis. The supply of iron to the eastern North Pacific may also come from iron-rich coastal waters transported by mesoscale eddies formed on the edge of the continental shelf of Alaska and west coast of Canada.

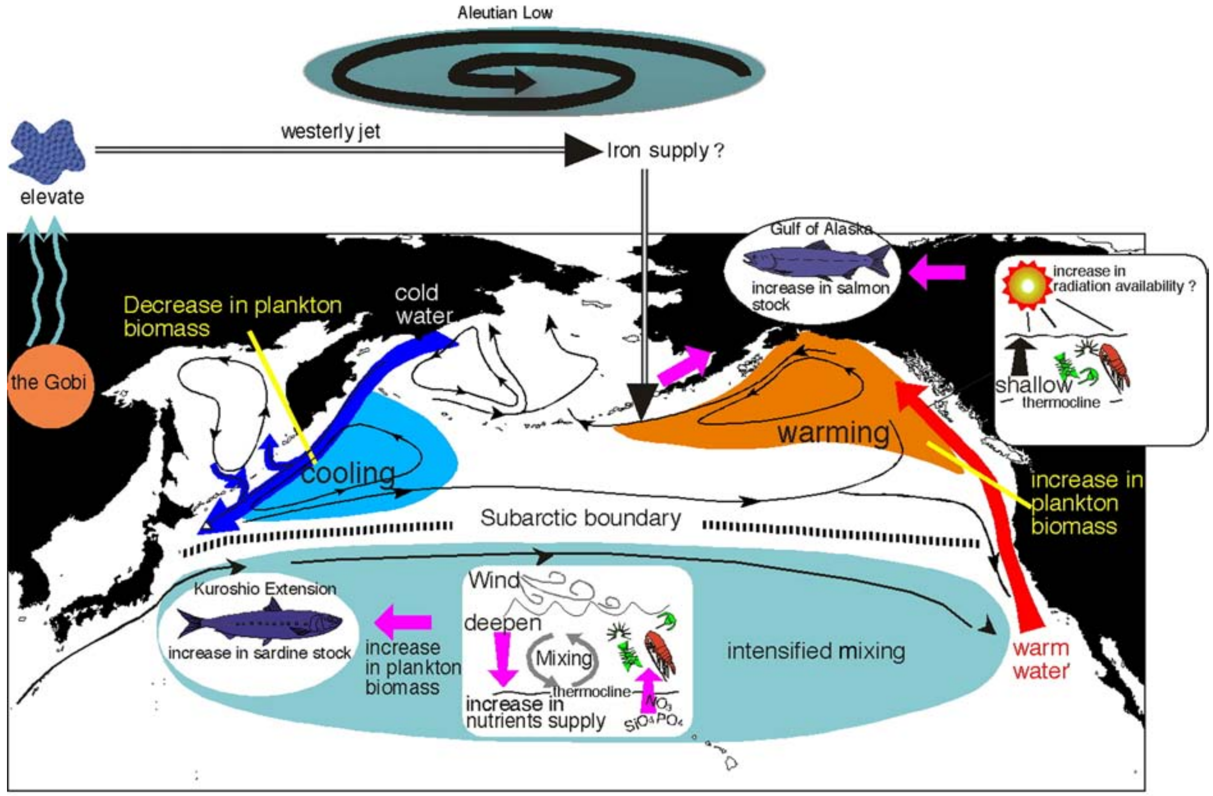


Fig. 66 Effect of climatic regime shift on the North Pacific ecosystem (schematic diagram).

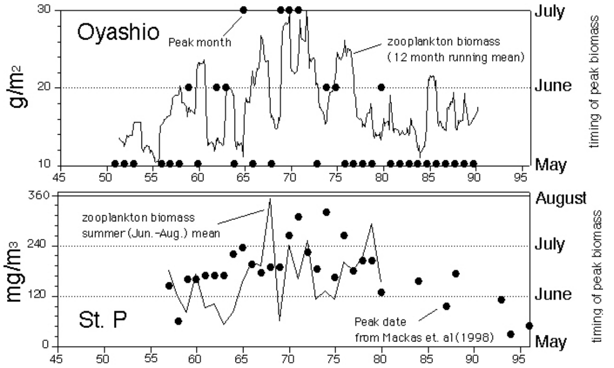


Fig. 67 Interannual variations of timing of peak zooplankton biomass in the Oyashio water and at Stn. P.

Interannual variations of Chl-*a* concentration correspond to changes in zooplankton biomass in the central North Pacific and the Oyashio water, but have an inverse relationship with zooplankton biomass in the eastern North Pacific and the eastern Bering Sea. The subarctic North Pacific is a HNLC (High Nutrients Low Chlorophyll) area, and interannual variations of Chl-*a* may not reflect those in primary production in this region (Banse and English 1999; Tadokoro 2000).

Timing of peak biomass shifted earlier after the regime shift in both the Oyashio water and eastern Pacific Ocean (Fig. 67). The period from 1965-1975 having a late peak timing also had high zooplankton biomass in the Oyashio water. On the other hand, there is no clear relationship between timing of the peak and zooplankton biomass at Stn. P.

References

Banse, K., and English, D.C. 1999. Comparing phytoplankton seasonality in the eastern and western subarctic Pacific and the western Bering Sea. Prog. Oceanogr. 43: 235-288.

Brodeur, R.D., and Ware, D.M. 1992. Long-term variability in zooplankton biomass in the subarctic Pacific Ocean. Fish. Oceanogr. 1: 32-38.

Brodeur, R.D., Frost, B.W., Hare, S.R., Francis, R.C., and Ingraham. W.J. Jr. 1996. Interannual variations in zooplankton biomass in the Gulf of Alaska, and covariation with California Current zooplankton biomass. CalCOFI Rep. 37: 80-99.

Hokkaido University. 1956-2000. Data record of oceanographic observations and exploratory fishing No.1-43.

Mackas, D.L., Goldblatt, R., and Lewis, A.G. 1998. Interdecadal variation in developmental timing of Neocalanus plumchrus populations at Ocean Station P in the subarctic North Pacific. Can. J. Fish. Aquat. Sci. 55: 1878-1893.

Minobe, S. 1997. A 50-70 year climatic oscillation over the North Pacific and North America. Geophs. Res. Lett. 24: 683-686.

Polovina, J.J., Mitchum, G.T., and Evans, G.T. 1995. Decadal and basin-scale variation in mixed layer depth and the impact on biological production in the Central and North Pacific, 1960-88. Deep-Sea Res. 42: 1701-1716.

Sugimoto, T., and Tadokoro, K. 1997. Interannual-interdecadal variations in zooplankton biomass, chlorophyll concentration and physical environment in the subarctic Pacific and Bering Sea. Fish. Oceanogr. 6: 74-93.

Tadokoro K. 2000. Geographical variation of Chl-a seasonality in the subarctic North Pacific Ocean. Bull. Plankton Soc. Japan 47: 111-115 (in Japanese with English abstract).

Whitney, F.A., Wong, C.S., and Boyd, P.W. 1998. Interannual variability in nitrate supply to surface waters of the Northeast Pacific Ocean. Mar. Ecol. Prog. Ser. 170: 15-23.

Wong, C.S., Whiteney, F.A., Iseki, K., Page, J.S., and Zeng, J. 1995. Analysis of trends in primary productivity and chlorophyll-a over two decades at Ocean Station P (50°N, 145°W). *In* Subarctic Northeast Pacific Ocean. *Edited by* R.J. Beamish. Can. Spec. Publ. Fish. Aquat. Sci. Ottawa: National Research Council of Canada, pp. 107-117.

GROUP 3: FISH, SQUID, CRABS AND SHRIMPS

North Pacific multispecies and ecosystem models of the Alaska Fisheries Science Center (and selected others)

Kerim Aydin
Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, U.S.A. E-mail: Kerim.Aydin@noaa.gov

Single-species stock assessment models that include predation

So far two models have been developed: one for EBS (Eastern Bering Sea) pollock (Livingston and Methot 1998) and one for GOA (gulf of Alaska) pollock (Hollowed *et al.* 2000). Another one for Aleutian Islands Atka mackerel might be developed in the future. The purpose of these models is to understand more clearly the sources and time trends of natural mortality for pollock, by explicitly incorporating predation mortality induced by their major predators into an age-structured fish stock assessment model. We have learned that not only natural mortality at younger ages is much higher than for adults, but also that it varies across time depending on time trends in predator stocks. This has given us better ideas about the influences of predation on fish recruitment over time and helps to separate predation and climate related effects on recruitment. Now we can more effectively show the demands of other predators such as marine mammals for a commercially fished, and how it might influence the dynamics of that stock (although we still need to make progress in understanding the effects on the marine mammals).

Bering Sea Multispecies Virtual Population Analysis (MSVPA)

We presently have a multispecies virtual population analysis model (MSVPA) for the Bering Sea (Livingston and Jurado-Molina 2000). This model includes predation interactions among several commercially important groundfish stocks, and also predation by arrowtooth flounder and northern fur seal on these stocks. This model can give a better idea of the predation interactions among several stocks. Outputs from this type of model can help to understand what the possible multispecies implications are of our single-species oriented fishing strategies. Results from these forecasting exercises show that a particular fishing strategy may have an effect that is opposite to what was intended if multispecies interactions are taken into consideration. We have also done multispecies forecasting with this model using different hypotheses about regime shifts and associated fish recruitment patterns.

Boreal Migration and Consumption Model (BORMICON) for the eastern Bering Sea

We have developed the first version of a spatially explicit model of pollock movement and cannibalism in the Eastern Bering Sea to understand the differences in spatial overlap of predators and prey, and how that affects the population dynamics of each. The model we have modified for the Bering Sea is one being used in other boreal ecosystems, BORMICON (Boreal Migration and Consumption Model). Migrations are prescribed at present with the hope that we can prescribe movement based on physical factors in the future. The influence of spatial overlap of cannibalistic adult pollock with juveniles on the population dynamics of pollock is investigated. Hypotheses about larval drift positions and the resulting overlap and cannibalism are also being explored. This model could be linked in the future to an individual-based larval pollock model and to NPZ model that could prescribe zooplankton abundance by area as alternate food for adults and as the primary food for juveniles.

Analytical approach to evaluating alternative fishing strategies with multiple gear types

The analytical approach for simulating current groundfish management in the North Pacific U.S. EEZ involves considering interactions among a large number of species (including target, non-target, and prohibited), areas, and gear types. To evaluate the consequences of alternative management regimes, modeling was used to predict the likely outcome of management decisions using statistics on historical catch of different species by gear types and areas. Management of the Alaska groundfish fisheries is complex given the large numbers of species, areas, and gear types. The managers schedule fisheries openings and closures to maximize catch subject to catch limits and other constraints. These actions are based on expectations about the array of species likely to be captured by different gear types and the cumulative effect that each fishery has on the allowable catch of each individual target species and other species groups. Management decisions were simulated by an in-season management model that predicts capture of target and non-target species by different fisheries based on historical catch data by area and gear type. Groundfish abundance for each alternative regime was forecast for a five-year period beginning from the present. This approach provides a reasonable representation of the current fisheries management practice for dealing with the multi-species nature of catch in target fisheries.

In addition to the model and its projected results, agency analysts also used the scientific literature, ongoing research, and the professional opinion of fishery experts in their respective fields to perform qualitative assessments.

Influence of advection on larval pollock recruitment

This model investigates the environmental relationship between surface advection during the post-spawning period (pollock egg and larval stages) and pollock survival. Wespestad *et al.* (1997) found that during years when the surface currents tended north-north westward along the shelf, year-class strength was improved compared to years when currents were more easterly. They used the OSCURS surface advection model to simulate drift. Subsequently (Ianelli *et al.* 1998) their analysis was extended to apply within a stock assessment model. The model uses surface advection over a 90-day period to determine the “goodness” of the advective field for juvenile pollock.

Shelikof Pollock Individual-Based Model (IBM)

This IBM was designed to run in conjunction with the 3-D physical model (SPEM) and the Shelikof NPZ model. Its purpose is to examine, at a mechanistic level, hypotheses regarding recruitment of pollock in Shelikof Strait, especially as these relate to transport, growth and (somewhat) mortality of pollock from spawning through the fall of the 0-age year.

GLOBEC Nutrient-Phytoplankton-Zooplankton (NPZ) 1-D and 3-D Models

This modeling effort (the 3-D NPZ model coupled with a physical model of the circulation of the region) is designed to test hypotheses regarding the effect of climate change/regime shifts on production in the coastal region of the Gulf of Alaska, including effects on cross-shelf transport, upstream effects, local production, and effect on suitability of the region as habitat for juvenile salmon.

Steller Sea Lion Individual-Based Model (IBM)

This IBM will be designed to examine how sea lion energy reserves change through foraging and bioenergetics depending on the distribution, density, patchiness and species composition of a dynamic prey field (as influenced by factors such as potential local depletion by fishing). It should be applicable to any domain surrounding a specific sea lion rookery or haul-out in the Bering Sea, Aleutian Islands or Gulf of Alaska. Sea lion characteristics such as age, location, lifestage, birthdate, etc., are recorded. Caloric balance is the main variable followed for each individual.

Shelikof Nutrient-Phytoplankton-Zooplankton (NPZ) Model, 1-D and 3-D versions

This NPZ model was designed to produce a temporally and spatially explicit food source (*Pseudocalanus* stages) for larval pollock, and to be input to the pollock IBM. This set of coupled (biological and physical) models was constructed to be used to examine hypotheses about pollock recruitment in the Shelikof Strait region.

Gulf of Alaska Walleye Pollock Stochastic Switch Model

This model was developed as a mathematical representation of a conceptual model presented in Megrey *et al*. (1996). It is a numerical simulation of the recruitment process. A generalized description of stochastic mortality is formulated as a function of three specific mortality components considered important in controlling survival (random, wind mixing events, and prevalence of oceanic eddies). The sum total of these, under some conditional dependencies, determines the overall survival experienced by the recruits.

North Pacific Ecosystem Model for understanding regional oceanography (NEMURO)

This model was designed to determine the minimum state variables needed to represent a generic NPZ marine ecosystem model for the North Pacific. Ecosystem fluxes are tracked in units of both nitrogen and silicon. Carbon flux process equations have been added recently. The purpose is to examine the effects of climate variability on the marine ecosystem, through regional comparisons by means of using the same ecosystem model structure and process equations.

Mass-Balance Ecosystem Models (ECOPATH) for North Pacific regions of interest (multiple models)

Mass-balance food web models provide a way for evaluating the importance of predator/prey relationships, the roles of top-down and bottom-up forcing in modeled ecosystems, and the changes in ecosystem structure resulting from environmental perturbations (natural or anthropogenic). Additionally, the models may allow comparing natural predation mortality with respect to predator biomass and fishing levels, and determining the quality of data available for a given system.

Eastern Bering Sea Shelf ECOPATH Model 1

Although many of these models were done in the past for the Alaska region, the most up-to-date published model is Trites *et al*. (1999) for the Eastern Bering Sea. These models are highly aggregated over age groups and species groups and best highlight our gaps in understanding of how ecosystems function and our lack of data on certain ecosystem components. Walleye pollock is broken into two biomass groups: pollock ages 0-1 and pollock age 2 and older. The model is useful for testing ecosystem hypotheses about bottom-up and top-down forcing and to examine system level properties and energy flow among trophic levels. The Eastern Bering Sea model extent includes the main shelf and slope areas north to about 61°N and excludes near-shore processes and ecosystem groups.

Eastern Bering Sea Shelf Model 2 and Western Bering Sea Shelf ECOPATH Model

The second Eastern Bering Sea Shelf model breaks down the earlier model into more detailed species groupings to tease apart the dynamics of individual species, especially in the commercially important groundfish. Spatial extensions to the model include sub-dividing into Inner, Middle, and Outer Biophysical Domains. The model will be calibrated with respect to top-down and bottom-up forcing using “checkpoint” food webs for several years in the 1990s, and using 1979-1998 time-series of trawl data and MSVPA/other assessment analyses. The primary purpose of this model is to investigate the relative role of natural and anthropogenic disturbances on the food web as a whole. A Western Bering Sea Shelf Model, build as a joint US/Russian Project, is currently being completed.

Gulf of Alaska, continental shelf and slope (excluding fjord, estuarine and intertidal) ECOPATH Model

Throughout the 1990s, there have been extensive commercial fisheries in the GOA for groundfish, as well as crab, herring, halibut, and salmon. Removals of both the target species and bycatch by these (and historical) fisheries have been suggested as a possible cause for the decline of the western stock of Stellar sea lions, which are now listed as an endangered species. An ECOPATH/ECOSIM model for the GOA could test the hypothesis that fishery removals of groundfish and bycatch during the 1990s have contributed to the continued decline of Stellar sea lions.

In addition, a community restructuring in which shrimp populations declined dramatically and commercial fish populations increased between the 1960s and the 1990s may have occurred, according to small mesh trawl surveys conducted by National Marine Fisheries Service and Alaska Department of Fish & Game. An additional hypothesis, which could be tested with this model, is that this trophic reorganization has had a negative impact on marine mammal and bird populations in the GOA. Finally, the effects on an apparent increase in shark populations on their prey and the relative importance of these effects in the whole system could be evaluated with an ECOPATH model.

Aleutian Islands and Pribilof Islands ECOPATH models

While the Eastern Bering Sea and Gulf of Alaska model may capture broad-scale dynamics of widespread fish stocks, their scale is too large to address local depletion. This may be an important issue for island-based fish such as Atka mackerel, and may be critical for determining the effect that changes in the food web may have on the endangered Steller sea lion. This smaller-scale ECOPATH model will be used in conjunction with larger-scale models to examine the possibility of linking the models across scales.

Prince William Sound (PWS), Alaska ECOPATH model

An ECOPATH model of Prince William Sound was constructed by a collaboration of experts from the region during 1998-1999 (Okey and Pauly 1999). The Exxon Valdez Oil Spill Trustee Council (EVOS) funded this effort for the purpose of "ecosystem synthesis". The project was coordinated by the UBC Fisheries Centre and overseen by NMFS Office of Oil Spill Damage Assessment and Restoration. Prince William Sound is well defined geographically; spatial definition of the system consisted of drawing lines across Hinchenbrook Entrance, Montague Strait, and smaller entrances. The time period represented by the model is 1994-1996, as this is the post-spill period with the broadest and most complete set of ecosystem information. This food web model consists of 48 functional groups ranging from single ontogenetic stages of special-interest species to highly aggregated groupings. A variety of hypotheses are being addressed with the PWS model—most relate to the 1989 EVOS and the fisheries in the area.

Table 1 summarizes region, time period, contact person and status for models developed by the Alaska Fisheries Research Center and Table 2 provides information on model special domains, inputs and outputs.

References

Hollowed, A., Ianelli, J.N., and Livingston, P. 2000. Including predation mortality in stock assessments: A case study for Gulf of Alaska pollock. ICES J. Mar. Sci. 57: 279-293.

Ianelli, J.N., Fritz, L., Honkalehto, T., Williamson, N., and Walters, G. 1998. Bering Sea-Aleutian Islands Walleye Pollock Assessment for 1999. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, Anchorage, AK, section 1: 1-79.

Livingston, P.A., and Methot, R.D. 1998. Incorporation of predation into a population assessment model of eastern Bering Sea walleye pollock. *In* Fishery Stock Assessment Models. University of Alaska Sea Grant, AK-SG-98-01, Fairbanks, pp. 663-678.

Livingston, P.A. and Jurado-Molina, J-J. 2000. A multispecies virtual population analysis of the eastern Bering Sea. ICES J. Mar. Sci. 57: 294-299.

Megrey, B.A., Hollowed, A.B., Hare, S.R., Macklin, S.A., and Stabeno, P.A. 1996. Contributions of FOCI research to forecasts of year-class strength of walleye pollock in Shelikof Strait. Fish Ocean. 5: 189-203.

Okey, T. A., and Pauly, D. 1999. A mass-balanced model of trophic flows in Prince William Sound: de-compartmentalizing ecosystem knowledge. *In* Ecosystem approaches for fisheries management. *Edited by* S. Keller. University of Alaska Sea Grant, Fairbanks, pp. 621-635 .

Trites, A.W., Livingston, P., Mackinson, S., Vasconcellos, M.C., Springer, A.M., and Pauly, D. 1999. Ecosystem change and the decline of marine mammals in the eastern Bering Sea: Testing the ecosystem shift and commercial whaling hypotheses. Univ. British Columbia, Fisheries Centre Research Reports 1999, Vol. 7.

Wespestad, V.G., Fritz, L.W., Ingraham, W.J., and Megrey, B.A. 1997. On Relationships between Cannibalism, climate variability, physical transport and recruitment success of Bering Sea Walleye Pollock, *Theragra chalcogramma.* ICES International Symposium, Recruitment Dynamics of exploited marine populations: physical-biological interactions. Baltimore, MD, Sept 22-24.

Table 1 Model areas, time period, contact person, and model status.

Model Name/ Model Region	**Time Period**	**Contact**	**Status**
Single-species stock assessment models that include predation	EBS: 1964-95 GoA: 1964-97 (Annual)	Patricia Livingston	Working
Bering Sea MSVPA	1979-98 3 Months (quarterly)	Patricia Livingston Jesus Jurado-Molina	Working
BORMICON for the Eastern Bering Sea	1979-97 1 Month	Patricia Livingston	Planning/Construction
Evaluating Alternative Fishing Strategies	Current	Jim Ianelli	Working
Advection on larval pollock recruitment	90 Days of Larval Drift 1970s-present	Jim Ianelli	Working
Shelikof Pollock IBM	YD 60-270 Daily	Sarah Hinckley	Working
GLOBEC NPZ 1-D and 3-D Models	YD 60-270 (eventually year-round). Daily	Sarah Hinckley	In progress
Steller Sea Lion IBM	Summer or Winter, Minutes to Days	Sarah Hinckley	Planning/Construction
Shelikof NPZ Model, 1-D and 3-D Versions	YD 60-270 (eventually year-round). Daily	Sarah Hinckley	In progress
GoA Pollock Stochastic Switch Model	32 years (replicates) Daily	Bern Megrey	Working
NEMURO	1 Full Year, Daily	Bern Megrey	In progress
Eastern Bering Sea Shelf Model 1 Ecopath	1950s and early 1980s Annual	Patricia Livingston	Completed
Eastern Bering Sea Shelf Model 2 Ecopath	1979-1998 Annual	Kerim Aydin	In progress
Western Bering Sea Shelf Ecopath	Early 1980s Annual	Kerim Aydin Victor Lapko	In progress

Table 1 (continued)

Model Name/ Model Region	**Time Period**	**Contact**	**Status**
Gulf of Alaska Shelf Ecopath	1990-99 Annual	Sarah Gaiches	In progress
Aleutian Islands, Pribilof Islands Ecopath	1990s-2000s Annual	Patricia Livingston, Lorenzo Ciannelli	Proposed
Prince William Sound, Ecopath	Pre- and Post 1989 oil spill Annual	Tom Okey	Completed

Table 2 Model spatial domains, currencies, inputs and outputs.

Model Name/ Model Region	**Model Spatial Domain**	**Inputs**	**Outputs/currency**
Single-species stock assessment models that include predation	Across EBS and GOA Pollock distributions	Fisheries data and predator biomass	Pollock population and mortality trends—number at age (and biomass at age).
Bering Sea MSVPA	The modeled region is the eastern Bering Sea shelf and slope north to about 61°N	Fisheries, predator biomass, and food habits data. This model requires estimates of other food abundance supplied by species outside the model.	Age-structured population dynamics for key species—numbers at age
BORMICON for the eastern Bering Sea	The model is spatially explicit with 7 defined geographic regions that have pollock abundance and size distribution information.	Temperature is included and influences growth and consumption.	Spatial size distribution of pollock.
Evaluating Alternative Fishing Strategies	US EEZ	Gear-specific fishing effort including bycatch	Biomass of managed fish species.
Advection on larval pollock recruitment	Southeast Bering Sea Shelf	OSCURS surface currents (wind-driven).	Index of pollock recruitment.
Shelikof Pollock IBM	Western GOA from just southwest of Kodiak Island to the Shumagin Islands, shelf, water column to 100 m.	From Physical model: Water velocities, wind field, mixed-layer depth, water temperature and salinity, Pseudocalanus field (from NPZ model).	Individual larval characteristics such as age, size, weight, location, lifestage, hatchdate, consumption, respiration.
GLOBEC NPZ 1-D and 3-D Models	Water column (0-100 m) Coastal GOA from Dixon Entrance to Unimak Pass, 100 m of water column over depths < 2000 m 5 m depth bins x 20 km horizontal grid.	Irradiance, MLD Temperature, diffusivity, bottom depths, water velocities (u, v, w)	Diffusivity, ammonium, nitrate, detritus, small and large phytoplankton, dinoflagellates, tintinnids, small coastal copepods, neocalanus and euphausiids (nitrate and ammonium): mmol/m^3 (all else): mg Carbon/m^3

Table 2 (continued)

Model Name/ Model Region	Model Spatial Domain	Inputs	Outputs/currency
Steller Sea Lion IBM	Should be applicable to any domain surrounding a specific sea lion rookery or haul-out in the Bering Sea, Aleutian Islands or GOA	The main input to the SSL-IBM will be a 3D field of prey (fish) distribution, derived either from hypothetical scenarios or (later) modeled based on acoustic data	Individual sea lion characteristics such as age, location, lifestage, birthdate, etc are recorded. Caloric balance is the main variable followed for each individual.
Shelikof NPZ Model, 1-D and 3-D Versions	water column (0-100 m), GOA from southwest of Kodiak Island to Shumagin Islands. 1 m depth bins for 1-D version, 1 m depth x 20 km for 3-D version	Irradiance, MLD, Temperature, Bottom depths, water velocities (u, v, w).	Nitrogen, phytoplankton, *Neocalanus* densities, *Pseudocalanus* numbers/m^{-3} for each of the 13 stages (egg, 6 naupliar, 6 copepodite)s
GoA Pollock Stochastic Switch Model	Shelikof Strait, Gulf of Alaska	Number of eggs to seed the model. Base mortality, additive and multiplicative mort. adjustment parameters for each mort. Factor.	number of 90 day old pollock larvae through time
NEMURO	Ocean Station P (50°N 145°W), Bering Sea (57.5°N 175°W), and station A7 off the east of Hokkaido island, Japan (41.3°N 145.3°W)	Fifteen state variables and parameters including 2 phytoplankton, 3 zooplankton, and multiple nutrient groups.	Ecosystem fluxes are tracked in units of nitrogen and silicon.
Eastern Bering Sea Shelf Model 1 Ecopath	500,000 km^2 in eastern Bering Sea south of 61°N	Biomass, Production, Consumption, and diet composition for all major species in each ecosystem	Balance between produced and consumed per-area biomass (t/km^2). Future work will explore energy ($kcal/km^2$) and nutrient dynamics.
Eastern Bering Sea Shelf Model 2 Ecopath	500,000 km^2 in eastern Bering Sea south of 61°N		
Western Bering Sea Shelf Ecopath	300,000 km^2 on western Bering Sea shelf		
Gulf of Alaska Shelf Ecopath	NPFMC management areas 610, 620, 630, and part of 640		
Aleutian Islands, Pribilof Islands Ecopath	Not determined		
Prince William Sound, Ecopath	Whole Prince William Sound		

Life history of Pacific halibut (*Hippoglossus stenolepis*)

Steven R. Hare
International Pacific Halibut Commission, P.O. Box 95009, Seattle, WA 98145-2009, U.S.A. E-mail: hare@iphc.washington.edu

Distribution

Pacific halibut (*Hippoglossus stenolepis*) are found throughout the coastal waters of Alaska, British Columbia, Washington, Oregon and into northern California. The center of abundance is the central Gulf of Alaska, particularly near Kodiak Island. The depth range for adult halibut is from 50 m in the summer, to 600 m during winter spawning. Pacific halibut are generally found in temperatures from 3-9°C.

Reproduction and migration

Pacific halibut mature at approximately 8 years of age. During the spawning season - generally November to March - adult fish move to deeper waters near the edge of the continental shelf. Halibut are broadcast spawners with fertilization occurring by random external contact. Halibut eggs and larvae drift in the surface currents for 6-7 months after spawning. During this long pelagic phase, halibut are moved generally west in the Gulf of Alaska and north into the Bering Sea by the dominant surface currents, before settling to the bottom in shallow waters in late spring and summer. The relative distribution of recruited halibut (i.e. fish age 8 and older) biomass by area remains relatively constant from year to year. To achieve this continuity, juvenile halibut migrate back to the south and east towards their spawning grounds. This counter migration usually takes place between ages 2 and 6. Adult halibut show seasonal migration (to deeper water for spawning) but very little directed migration.

Age and growth

Pacific halibut is the largest flatfish in the world, reaching a length of 2.7 meters and weight of 300 kg. It has a flat, diamond shaped body; the colored side is a mottled brown, and over 99% are dextral, i.e., the eyes are on the right side of the fish. The oldest identified halibut was a 55-year old male, however, fish over 25 years of age are uncommon. Females grow to much larger sizes than males.

The fishery

A commercial fishery for halibut has existed since 1888. During the 20th century, annual landings ranged between 17,000 and 40,000 metric tons. The current health of the fishery is attested to by the fact that some of highest landings on record were taken in the last 5 years of the 1990s. Since 1995, the fishery has been managed under an Individual Transferable Quota system. Currently, the ex-vessel value of the fishery is around $US 175 million. In addition to the commercial fishery, there is a growing sport fishery and halibut are also captured incidentally in other North Pacific groundfish fisheries.

Climate influences

During the 20th century, there have been dramatic and persistent changes in the growth and recruitment of Pacific halibut that cannot be readily explained by changes in stock size. Over the last 15 years, the growth of halibut has decreased substantially, especially in Alaska (Fig. 1). An eleven-year-old female halibut landed

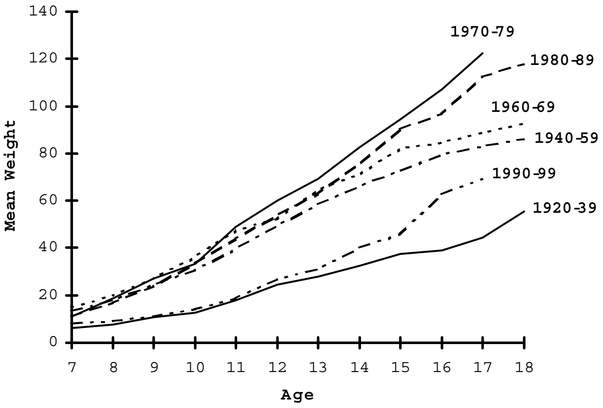


Fig. 1 Changes in mean weight at age for female Pacific halibut in Alaska, 1925-2000.

in Kodiak, Alaska, averaged 40 pounds in weight in 1980. In 1995, the average weight for the same age female halibut was less than 20 pounds. Fifteen years ago fish of a given age were substantially larger in Alaska than in British Columbia; now there is no difference. In both respects, halibut growth is similar to what was observed in the 1920s and 1930s. An increase occurred sometime during the 1940s, and the present decrease began in the mid-1970s. Fish are also maturing at a smaller size now than they used to, while the age at maturity is quite close to what it has always been.

There have also been clear decadal variations in halibut recruitment all through the century, or at least since about 1935 (Fig. 2). Most recently there was a run of good year-classes spawned in the late 1970s through late 1980s, apparently followed by a run of poor year-classes. This kind of alternation has sometimes been viewed as a cycle, but could just as well reflect distinct periods of different environmental conditions. Recent work has strongly suggested that halibut recruitment is driven primarily by the Pacific Decadal Oscillation (Fig. 3). Stock size explains very little of the variability in recruitment; use of the PDO as a covariate explains much of the observed variation however. The PDO has alternated between positive (productive for halibut) and negative (unproductive) phases every 25-35 years (Fig. 4).

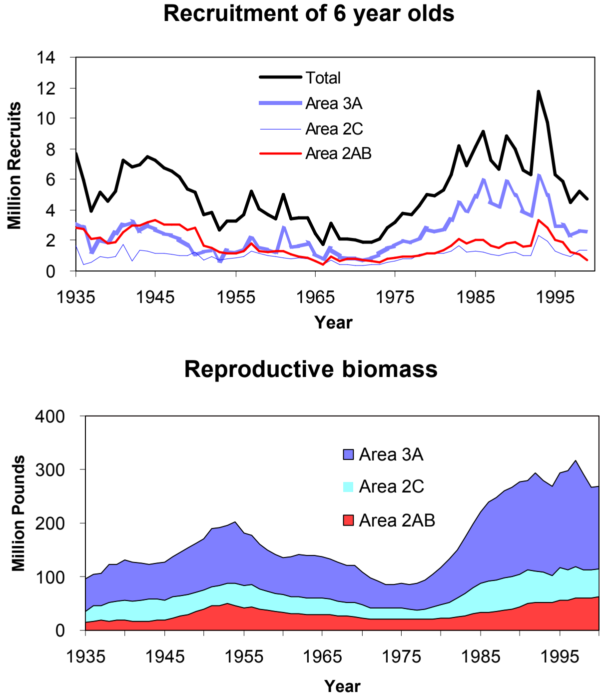


Fig. 2 Long-term trends in recruitment (measured as six-year olds) and spawning biomass of Pacific halibut from 1935 to 2000, for IPHC areas 2AB (British Columbia), 2C (Southeast Alaska), and 3A (central Gulf of Alaska).

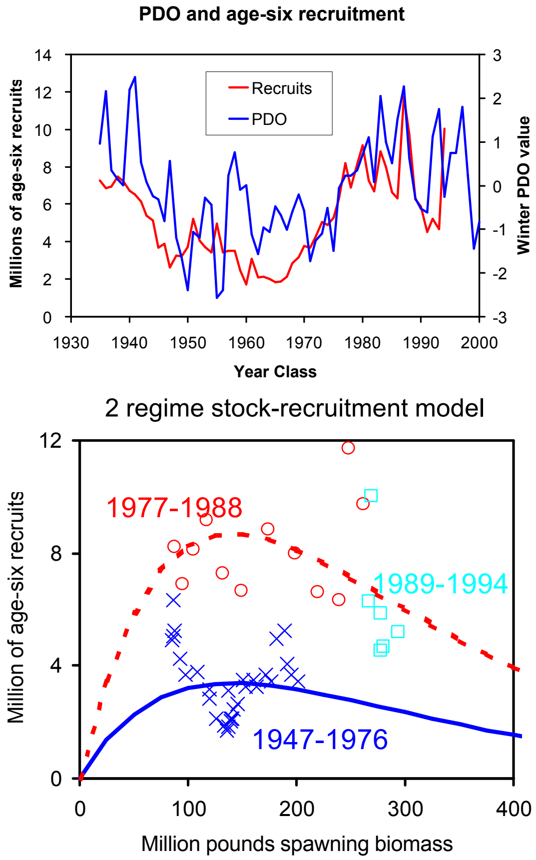
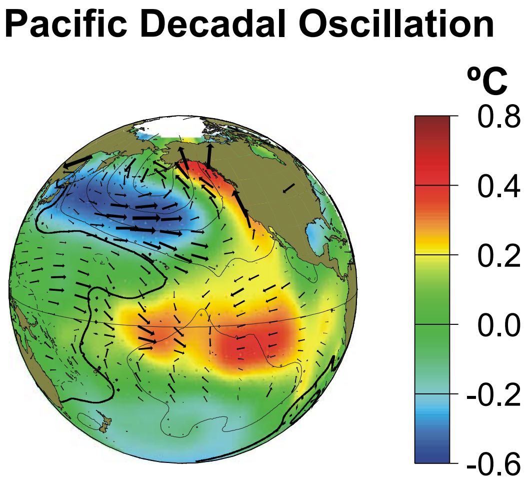


Fig. 3 Relationship between halibut spawning biomass and recruitment (top) and winter values of the Pacific Decadal Oscillation (PDO) and halibut recruitment (bottom).

Available time series

1. Age-6 Recruitment, 1935-1994, GOA and BC: these estimates are generated from a catch-age stock assessment model;
2. Spawning biomass, 1935-2001, GOA and BC: these estimates are generated from a catch-age stock assessment model;
3. Weight at age, incomplete from 1925-2000, GOA and BC: these estimates come from fish measured during annual surveys.



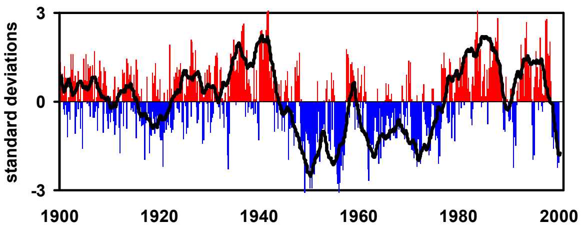


Fig. 4 The Pacific Decadal Oscillation, 1900-2000. The positive phase is illustrated, corresponding to positive values of the temporal index. The index most recently turned negative in October 1998, and has remained strongly negative through the end of 2000.

Biological and physical environment databases of the International Pacific Halibut Commission

Steven R. Hare
International Pacific Halibut Commission, P. O. Box 95009, Seattle, WA 98145-2009, U.S.A. E-mail: hare@iphc.washington.edu

Introduction

The International Pacific Halibut Commission (IPHC) collects a broad variety of data in support of its research and management mandates. Scientific data collection activities began in 1925 and have continued unabated to the present. Bering Sea activities commenced in 1930 and a great deal of larval and juvenile work has been conducted there. In 1997, as part of an expanded survey design, regular longline surveying of the Bering Sea continental shelf edge and slope was initiated. This plan calls for the same areas to be surveyed each year until 2001, at which time the sampling plan will be re-evaluated. This brief report summarizes the biological and physical environmental data collected by the IPHC.

Biological data

Three types of biological data are collected, or estimated, by the IPHC:

Commercial catch (fishery-dependent) data since 1935

The IPHC employs port samplers at 18 ports from St. Paul Island (Pribilofs) to Newport (Oregon). The port samplers collect both fishing log and biological data. From the fishing logs we gather fishing data, time and location as well as fishing effort. From this data we are able to continue our 60-year industry catch-per-unit-effort-index. From the landed catches we obtain size data and take otoliths to determine age composition.

Survey (since 1963) and research (since 1925, fishery-independent) data

The IPHC has conducted research aboard chartered commercial fishing vessels since 1925. The primary purpose of most charters has been to collect information pertaining to stock assessment and migration of Pacific halibut. Since 1925, the IPHC has completed approximately 271 separate charters: 99 using trawl gear and 172 using setline gear. Charter duration has varied between 1 week to 4 months consisting of 1 to 9 separate trips per charter. From the regular surveys we obtain data on the sex, size and age composition of the population. We also collect data on other aspects of the biology such as spawning condition, prior hook injuries and bycatch data on other species. Special research charters have been used to investigate questions relating to migration, effects of hook spacing and hook type catchability, bait loss and oil spill impact, among many others. In addition, the IPHC has placed observers aboard numerous commercial and government vessels gathering information on the size, age, and sex composition of halibut.

Population dynamics model output since 1974

The commercial and research data collected are input to a complex size, sex and age structured model we use for assessing the population dynamics of the Pacific halibut resource. The model produces estimates (from 1974 to the present) of exploitable biomass, exploitation rates, fishing mortality, annual surplus production and recruitment. Estimates of recruitment and exploitable biomass prior to 1974 are available from a VPA type analysis.

Physical environment data

While most of the IPHC sampling effort is directed toward the fishery, we also have a long history of interest in the oceanic environment. Bottom temperatures have been collected at all stations of the research survey since 1963. During the extensive egg, juvenile, and larval halibut work of the 1960s, detailed temperature and salinity data were collected. As part of a recently initiated halibut fisheries oceanography project, an ocean bottom properties database has been assembled. A number of uses are envisioned for this database including attempts to determine migration pathways of juvenile halibut, understand and model low frequency variability in growth rates, and model oceanic flow at depth along the ocean bottom.

Ocean bottom properties database

Data for the IPHC ocean bottom properties database were assembled from several sources, including the National Oceanic Data Center, National Marine Fisheries Service, Japanese Meteorological Agency, U.S. Foreign Observer Program, University of Alaska, and IPHC longline surveys. The data were quality controlled through comparison of means and variances in areas of overlap. All data were plotted and depths were checked against an independent bathymetry database (TerrainBase). At present, the database contains 107,000 records and has the following boundary conditions:

- *Areal coverage*: Alaska, British Columbia, and U.S. West Coast (to 30ºN) shelf & upper slope;
- *Depth*: observations must be within 15 m of the bottom and are restricted to areas with a bottom depth of 1,000 m or less;
- *Variables*: temperature, salinity, dissolved oxygen, nutrients (phosphate, nitrate, nitrite);
- *Time*: as complete a historical record as possible.

To illustrate the temporal and spatial distribution of data, plots of temperature (Fig. 5) and salinity (Fig. 6) were made for each decade. Most of the data were compiled in the months of May through September. For the study of halibut, this is encouraging since these are the months during which most growth takes place and during which most of the fishery occurs. The amount of usable data varies substantially by decade and variable. The temperature data are the most promising and it is anticipated that annual indices of ocean bottom temperatures by IPHC area from 1960-present can be constructed. For salinity, we may not be able to do better than 5-year averages. The long-term average fields for the months May to September and the years 1961-95 are shown in Figure 7. These average fields should be viewed as the conditions to which halibut have adapted over time. Sustained departures from these average conditions are then prime candidates for exploration as agents of change in halibut biology. Analysis of the temporal variability of ocean bottom temperature has begun and initial results are highly encouraging.

Availability of IPHC data

The IPHC has long strived to make its data available to interested parties. Much of the data are available in the three primary IPHC data series. These reports contain both raw and interpreted data as well as analysis:

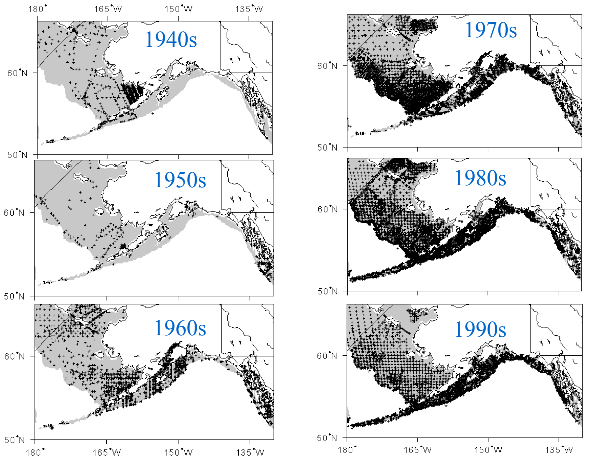


Fig. 5 Location of ocean bottom temperature data by decade.

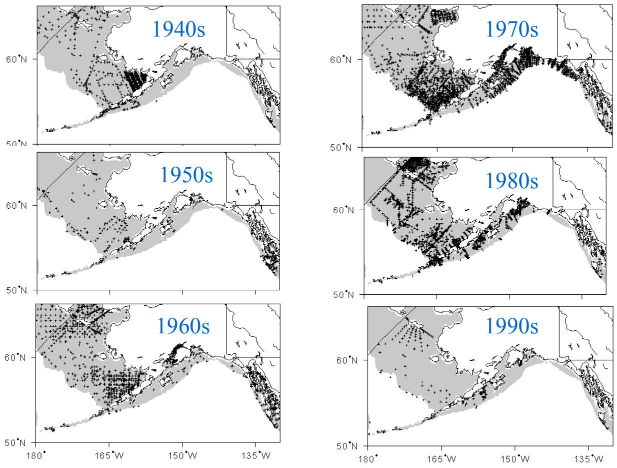


Fig. 6 Location of ocean bottom salinity data by decade.

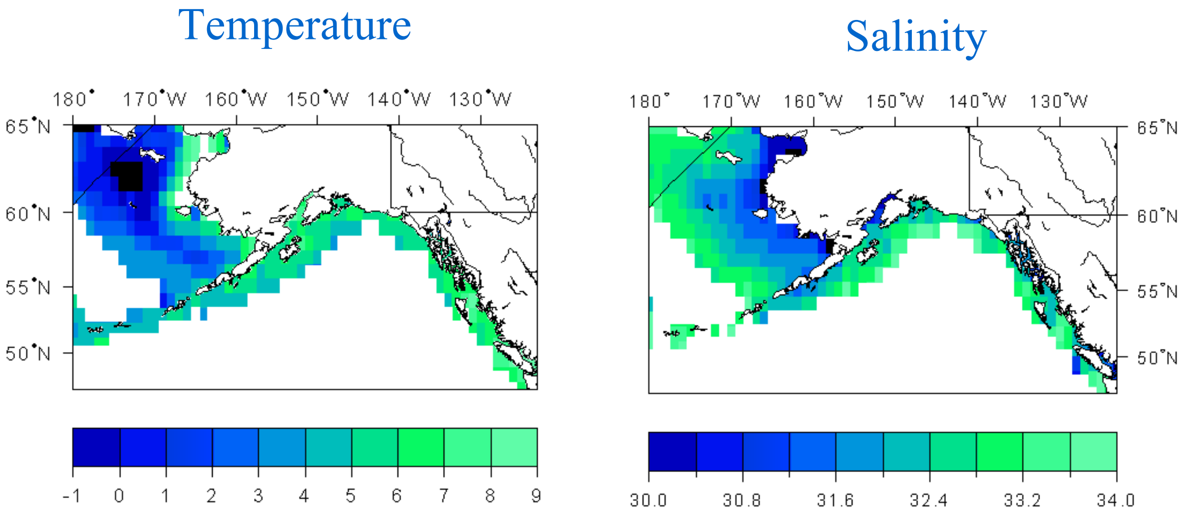


Fig. 7 Long-term (1961-1995) average fields for ocean bottom temperature and salinity for the months May to September.

- Scientific Reports, 1931-2000, most recent is Report No. 79;
- Technical Reports, 1969-2000, most recent is Report No. 42; and
- Annual Reports, 1969-2000, most recent is 2000.

One of the main methods of data distribution has been through personal communication and IPHC generally responds in a timely manner to such requests. Increasingly, IPHC is making data available over the World Wide Web. For example, our annual survey catch data is of great interest to halibut fishermen. We will shortly be making these data available interactively over the WWW. Much of the pre-1963 IPHC data is available only in hard copy (i.e., the IPHC Reports). We have initiated an effort to digitize these data and preserve them in electronic format.

IPHC contacts

WWW page: http://www.iphc.washington.edu
Dr. Bruce Leaman, Director
International Pacific Halibut Commission
P. O. Box 95009
Seattle, WA 98125-2009
Phone: (206) 634-1838

Fishery data of the Republic of Korea

Suam Kim
Department of Marine Biology, Pukyong National University, 599-1 Daeyeon 3-dong, Nam-gu, Pusan, Republic of Korea. 608-737 E-mail:suamkim@pknu.ac.kr

Catch statistics of major species

Warm and cold water masses are found permanently around the Korean peninsula: a branch of warm Kuroshio Current flows into the Yellow Sea and the southern part of the Japan/East Sea (JES), and cold water occupies the north part of the JES forming a Polar Front near the mid JES. Therefore, many warm and cold water species have been exploited traditionally in Korean waters. Catch statistics of about 40 commercially important fishes have been recorded since the 1920s, and some additional species were considered necessary and added later (Table 3). The Fishery Administration Authority of Korea has collected and published monthly and annual catch data for about 60 fish species.

Recently, the National Statistical Office of Korean Government began to archive the fishery data in electronic form. Monthly and annual catch statistics (fish, 58 species; squids and octopus, 7 species; shellfish, 19 species; shrimps and crabs, 12 species; and macro-algae, 12 species) since 1988 were digitized, and the electronic data can be found at “www.nso.go.kr”.

Biomass estimation

In Korean waters, many fish are transboundary specie: they span the national boundaries of Korea, North Korea, China, Japan, and Russia through their life cycles, which often results in the lack of fishery information. Because of scanty research facilities and complexity in ecosystems, intensive scientific surveys such as hydroacoustic and trawl surveys were not started until recently. Trawl/acoustic surveys for biomass estimation were conducted in the southwestern part of the Yellow Sea from the late 1990s. However, the spatial and seasonal coverage of the survey was not enough to reveal biomass and migration routes of the major stocks.

Cohort analysis for biomass estimation was applied to some species since the early 1990s. By using catch and ageing data since 1970s, biomasses of about 10 species were estimated (Table 3). However, as is a common problem in scientific survey, it has been often criticised that there was no integration of fishery data between countries for the transboundary species. Furthermore, there was no consideration of climate change on the small pelagic fish population.

Fish length measurement

Length composition of fish can be found in some literature (Table 3). However, not much published information is available though the National Fisheries Research and Development Institute (NFRDI) of Korea has collected annual mean length of some major species continuously.

Table 3 Fish catch, biomass estimation, and length frequency in Korean waters.

Common Name	Scientific Name	year (catch)	year (biomass)	year (length)
Flounders		26-00		
Bastard	(*Paralichthys olivaceus*)	26-00		
Tongue Fish		26-00		
Cod	*Gadus macrocephalus*	26-00		
Pollock	*Theragra chalcogramma*	26-00		
Common Sea Bream	*Pagrus major*	26-00	75, 79, 80, 85, 86 (VPA)	70, 75, 80, 85, 86
Black Sea Bream	*Acanthopagrus schlegeli*	44-00		
Others Sea Bream		26-00		

Table 3 (continued)

Common Name	Scientific Name	year (catch)	year (biomass)	year (length)
Pomfret	*Pampus argenteus*	26-00		
Brown Croaker	*Miichthys miiuy*	26-00		
Small yellow Croaker	*Larimichthys polyactis*	26-00	74-76, 80, 85, 86 (VPA)	70, 74, 75, 78, 80, 82-99
White Croaker	*Argyrosomus argentatus*	75-00	75-95 (VPA)	70, 75, 80, 85, 86
Large Yellow Croaker	*Larimichthys crocea*			85, 86
Other Croakers		52-00		
Corvenias		26-00		
Hairtail	*Trichiurus lepturus*	26-00	70-97 (VPA)	
Sandfish	*Arctoscopus japonicus*	26-00		
Common Sea Bass	*Lateolabrax japonicus*	26-00		
Bea Bass	*Epinephelus septemfasciatus*	31-00		
Redfish	*Doederleinia berycoides*	28-00		
Sharp Toothed Eel	*Muraenesox cinereus*	26-00	76-95 (VPA)	
Sea Eel	*Conger myriaster*	26-00		
Gobies		76-00		
Lizard Fishes	(*Saurida undosquamis*)	59-00		
Flat Head	*Platycephalus indicus*	26-00		
Rockfish	*Sebastes inermis*	26-00		
Puffers		26-00		
Anchovies	(*Engraulis japonicus*)	26-00		
Sardine	*Sardinops melanostictus*	27-00	71-94 (VPA)	75-94
Hickory Shad	*Konosirus punctatus*	26-00		
Herring	*Clupea pallasii*	26-00		
Round Herring	*Sardinella zunasi*	27-00		
Mackerel	(*Scomber japonicus*)	26-00	76-94 (VPA)	
Jack Mackerels	(*Trachurus japonicus*)	26-00	65-95 (VPA)	75, 80, 85, 86
Spanish Mackerels	(*Scomberomorus niphonius*)	26-00		84, 85, 86
Saury	*Cololabis saira*	26-00		75, 80, 85, 86
Half Baek	*Hyporhamphus sajori*	26-00		
Tuna	*Thunnus thynnus*	26-00		
Yellow Tail	*Seriola quinqueradiata*	26-00		
Salmon	*Oncorhynchus keta*	26-40, 91-00		
Trout		26-00		
Sea Smelt	*Sillago sihama*	74-00		
Monk Fish	*Lophiomus setigerus*	26-00		
Yellow goosefish	*Lophius litulon*	85-00		94-97
Filefish	*Stepanolepis cirrhifer*	75-00		
Filefish	*Navodon modestus*	75-00	80-86 (VPA)	80-86
Gurnards	(*Chelidonichthys spinosus*)	26-00		
Sand Lance	*Hypoptychus dybowskii*	26-00		
Mullets	(*Mugil cephalus cephalus*)	26-00		
Whitings		26-00		
Bigeyed Herring	*Ilisha elongata*	26-00		
Atka Fish	*Pleurogrammus azonus*	26-00		
Sharks		26-00		
Skates		26-00		
Skateray	*Raja kenojei*	91-00		
Squid	*Todarodes pacificus*	26-00		
Cuttle Fish	*Sepia esculenta*	31-00		
Shrimp Medium	*Panaeus orientalis*	44-00		
Tanner Crab	*Chionoecetos opilio*	65-00		
Blue Crab	*Portunus trituberculatus*	66-00		
Pink Shrimp	*Pandalus borealis*	80-00		

TINRO's time-series data on Russian fish and ecosystems

Victor V. Lapko
Pacific Scientific Research Fisheries Centre (TINRO-Centre), 4 Schevchenko Alley, Vladivostok, 690950, Russia. E-mail: interdept@tinro.wavenet.ru

Most data that are considered suitable for a contribution to a North Pacific Ecosystem Status Report from Russia were collected in the Russian EEZ on commercially valuable species. Only fisheries research institutes are capable of providing regular monitoring of the commercial stocks over large areas and during prolonged periods. The main goal of the monitoring is to evaluate the biological condition of the stocks, to observe their abundance dynamics and to determine allowable catches.

The fisheries resources of Russia are now composed of about 200 species, however only 30 species could be defined as basic. The most common are Pacific salmon, walleye pollock, Pacific herring, cod, flatfishes, saury, atka mackerel, squids, crabs, and till 1993 – Japanese sardine. During 1981–2000, these taxa constituted 90–94% of the total predictable catch, and these were the only taxa receiving the most regular and thorough monitoring and statistics reporting.

Observations were started beginning in the late 1970s – early 1980s, after the Exclusive Economic Zones (EEZ) were established. The reasons were self-evident – first of all, the Russian fisheries industry had to pay attention to the bioresources of its own EEZ, and began regular investigations on commercial species. Such work – to carry out monitoring of the major fisheries stocks, was entrusted to the institutes of TINRO's system. Also in the beginning of 1980s, the Laboratory of Applied Biocenology was established at TINRO-Centre. The Laboratory initiated and, up to now, has conducted an ecosystem study of fishery resources in the far-eastern waters of Russian EEZ. So it could be concluded that regular monitoring of the fisheries resources in the far-eastern waters of Russia was started in the early 1980s.

To date, TINRO-Centre has accomplished several hundred expeditions according to the program of stock observation on single commercially valuable species and populations. However those data appear slightly inappropriate for an Ecosystem Status Report because they have been collected mainly on single species or even population of species, for example, walleye pollock, cod, herring etc. Bycatch species were usually not recorded entirely or recorded very roughly (both species composition and abundance of the bycatch) in those surveys. Nevertheless, information collected in single-species surveys as well as fishery statistics have been used for summarizing and analysing the abundance of those species, status and time trends. In this respect the major target species and groups (pollock, herring, salmons, cod, crabs etc.) are well provided with prolonged time-series data that can be used for commenting on long-term species condition.

Otherwise, TINRO's ecosystem investigations were aimed at studying marine communities and foremost – fish communities, which involve a major commercial species. All species have been systematically recorded in such observations, providing the necessary information for monitoring on pelagic and demersal communities. The main method for collecting data was the trawl survey. Stations were arranged in transects and covered the area of interest. Integrating, averaging and extrapolating the point data throughout the observed area provided the necessary assessments of species composition and abundance. Accordingly, about 70 expeditions totaling about 15,000 stations and pelagic trawl tows have been carried out in the Pacific waters of Russian EEZ. These data could be used for preparing a North Pacific Ecosystem Status Report (Table 4). In addition, the western Kamchatka shelf is a region with a valuable commercial bottom fishery and hence is well-provided with regular data collected in trawl surveys. About 10 expeditions (approximately 2,000 trawl tows) have been accomplished in that area in 1981–2000 and these data can also be used for preparing the Report.

To collect nektonic and nektobenthic species, we applied both midwater and demersal rope trawls, trying to keep using the same types while carrying out the same surveys. The method and techniques of trawl towing differed slightly depending on the investigation, but the resulting calculations are very comparable with respect to swept area or volume.

The major gear for plankton sampling was Jedy's net with mouth diameter 0.1 m^2. Vertical hauls (total and in separate layers) were usually accomplished over a wide range of depths. The total number of plankton hauls slightly exceeds that of trawl tows because of round-the-clock plankton stations, which were regularly conducted almost in each expedition.

In TINRO's system, all the above-mentioned information is used for preparing the "Annual Prediction of the Commercial Stocks' Status and Establishing of Total Allowable Catches" for each exploited species.

Table 4 Time-series surveys conducted in pelagic layer in Pacific waters according to ecosystem studying program.

Region	Time range (month, year)	No. of surveys
Bering Sea (western part)	April – December (1986 – 2000)	21
Waters off Eastern Kamchatka	June – December (1986 – 1995)	6
Pacific waters off Kuril Islands	June – December (1986 – 2000)	21
Sea of Okhotsk	January – December (1984 – 2000)	24
Total	January – December (1984 – 2000)	72

Groundfish, crab, shrimp and other time-series of the Alaska Fisheries Science Center

Patricia Livingston and Anne B. Hollowed
Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, U.S.A. E-mail: Pat.Livingston@noaa.gov; Anne.Hollowed@noaa.gov

The Alaska Fisheries Science Center in Seattle, Washington, maintains several time-series of fish, crab, and shrimp abundance (Table 5). The Center also collects physical and biological data (e.g., temperature, stomach contents, weight and length at age, etc.) and produces stock assessments for groundfish populations (Table 5). Echointegration/ trawl surveys are used to assess species with a large off-bottom component such as walleye pollock and Pacific hake. Summer bottom trawl surveys in the eastern Bering Sea, Gulf of Alaska, Aleutian Islands and off the Washington-Oregon-California coasts have a primary purpose of quantifying groundfish biomass and size-at-age composition for setting allowable biological catch limits for fishery management. Limited winter survey efforts have recently begun to look at winter distribution of walleye pollock and Pacific cod in Steller sea lion foraging areas. The summer eastern Bering Sea time-series is also used for crab assessment purposes. Many non-commercial species and benthic invertebrates are captured in these surveys, so they can also be used to assess the abundance of some of these species. Time trends in abundance of non-commercial species can be compared with exploited species to understand possible links to climate variability (Figs. 8 and 9). Changes in spatial distribution or abundance of small pelagics such as capelin and eulachon or perhaps sharks, might be indexed by these surveys (see "www.afsc.noaa.gov/kodiak/osmeridebs.htm" for summer distribution of capelin and eulachon in the eastern Bering Sea 1982-1999, and p. 35-36 of "www.refm.noaa.gov/docs/Ecocon2000.pdf" for capelin abundance changes in inshore areas of the Gulf of Alaska 1972-1999, and p.62-67 for shark distribution changes in the Gulf of Alaska). Changes in abundance of species and diversity of trophic guilds might provide information to help separate fishing versus climate (Fig. 10). Life history characteristics and responses to climate variability are a focus.

Surveys also provide information used in fish stock assessment models. The statistical age-structured models developed at the Alaska Fisheries Science Center use the Baranov catch equation as the underlying population model, and incorporate diverse sources of information on species catch, abundance, age composition, and life history parameters to assess historical population abundance at age. These estimates can provide historical estimates of population biomass (Fig. 11) and recruitment. Relationships between these estimates and climate regime shifts have been examined in recent years (e.g., Hollowed *et al*. 1999; Hare and Mantua 2000). See "www.refm.noaa.gov/stocks/Default.htm" for more information on the Center's fish stock assessments. Historical groundfish estimates from stock assessments (total biomass, spawning biomass, recruitment, catch and weight-at-age data) can be accessed at "www.refm.noaa.gov/stocks/stocksum.htm". Groundfish stomach content data have been collected by the Alaska Fisheries Science Center from summer research surveys and during other times of the year from commercial fishing vessels utilizing fishery observers (see "www.refm.noaa.gov/reem/data/Default.htm" for more details). These data are incorporated into multispecies and ecosystem models.

A time-series of ocean surface current speed and direction have been compiled for the North Pacific from an ocean surface current model of the Alaska

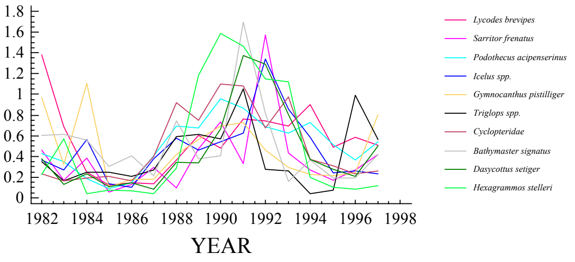


Fig. 8 Changes in population estimates for a variety of non-commercial species showing a similarity in trends. Species include sculpins, eelpouts, poachers, snailfish, ronquils, and greenlings (source: Gerry Hoff, AFSC).

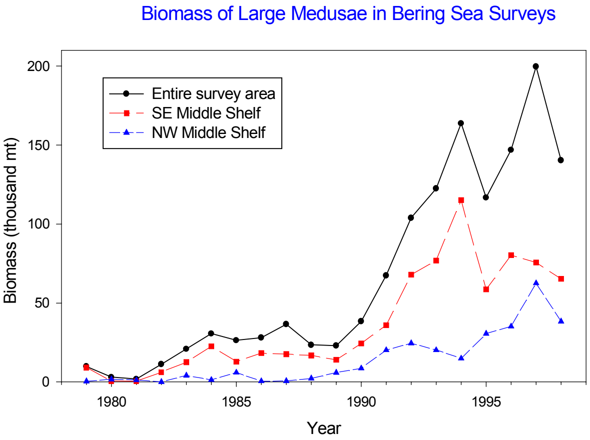


Fig. 9 Biomass of jellyfish medusae in the eastern Bering Sea from bottom trawl surveys, 1979-1998 (source: Ric Brodeur, NWFSC).

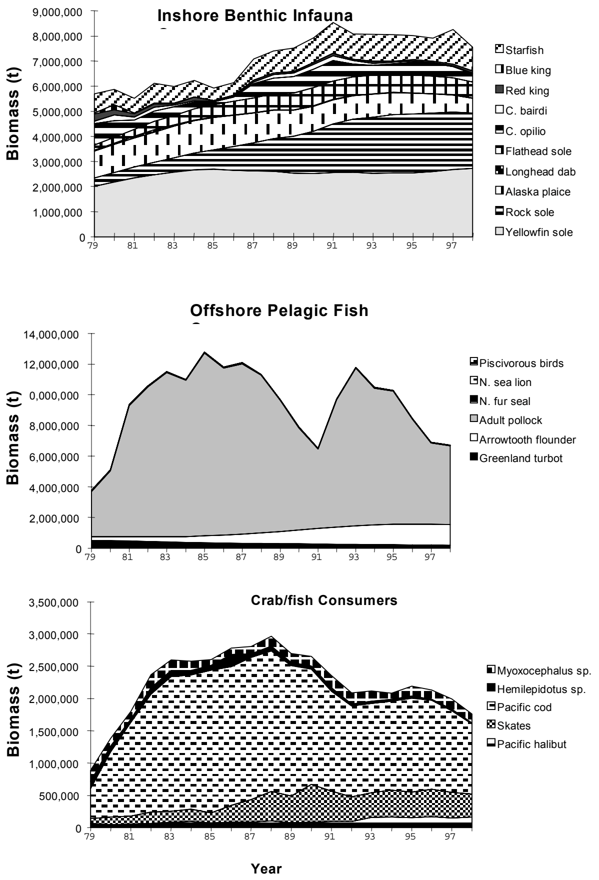


Fig. 10 Changes in biomass within trophic guilds in the eastern Bering Sea (source: Pat Livingston, AFSC).

Table 5 Time-series maintained by the Alaska Fisheries Science Center, Seattle, WA, U.S.A.

Time series	**Area**[1]	**Years**	**Sampling period**	**Main species**	**Gear**	**Physical data**	**Bottom depth range (m)**
Groundfish bottom trawl survey	GOA	84,87,90,93,96,99	June-August	Groundfish	Bottom trawl (roller gear)	Bottom and surface temp., XBT or MBT	10-500 (some 500-1000)
"	AI	80,83,86,91,94,97,00	"	Groundfish	"	"	10-900
"	EBS shelf Slope	75, 79-00 79,81,82,85,88,91, 00	"	Groundfish, crab	Bottom trawl	"	10-200 200-800
"	WOC	77,80,83,86,89,92,95,98	"	Groundfish	Bottom trawl	"	55-366
Hydroacoustic/trawl survey	EBS – shelf SE shelf Bogoslof I.	79,82,85,88,91,94,96,97,99,00 91,92,93,95,00,01 88-89, 91-00	June-Aug. Feb-Apr Feb.-Mar.	Walleye pollock	38kHz echosounder/midwater trawl	"	10-200 10-200 >200
"	GOA (Shelikof Strait)	81,83-85, 88-98,00	March	Walleye pollock	"	"	10-200
"	WOC	77,80,83,86,89,92,95,98	July-Sept	Pacific hake	"	"	Mostly 55-366
Longline survey	GOA AI EBS	1978-00 80-94,96,98,99 82-94,97,99	May-August	Sablefish	longline	"	200-1000
Inshore small mesh survey	GOA-	1953-54, 57-59,62-64,68, 1970-2000	Mostly June-Nov.	Shrimp and epibenthic fish	Small-mesh shrimp trawl (same gear since 1972)	"	20-250
Groundfish stomach content collection	EBS GOA AI WOC	Mostly 1984-2000 1990,93,96, 99, 2001 91,94,97,2000 87,88,89,91,92,95,98	Mostly June-Aug.	Groundfish	Multiple		Mostly 10-500
Groundfish stock assessments	EBS GOA AI	1979-present	Annual assessment cycle				
Fishery Observer data	EBS GOA AI	1977-present	All months	Groundfish	Multiple	Surface temp	Mostly 10-500
Chum salmon age and size at maturity	GOA	1972-present	Late Aug.	Chum salmon			
Ocean surface current model outputs	North Pacific	1901-present	All months			Surface current direction and velocity	
Pinniped and cetacean data	EBS GOA AI WOC			Pinnipeds and cetaceans			
Recruitment processes	EBS GOA	(see contribution by B. Megrey for more details)		Larval fish and walleye pollock			

[1] GOA = Gulf of Alaska; AI = Aleutian Islands; EBS = Eastern Bering Sea; WOC = Washington-Oregon-California

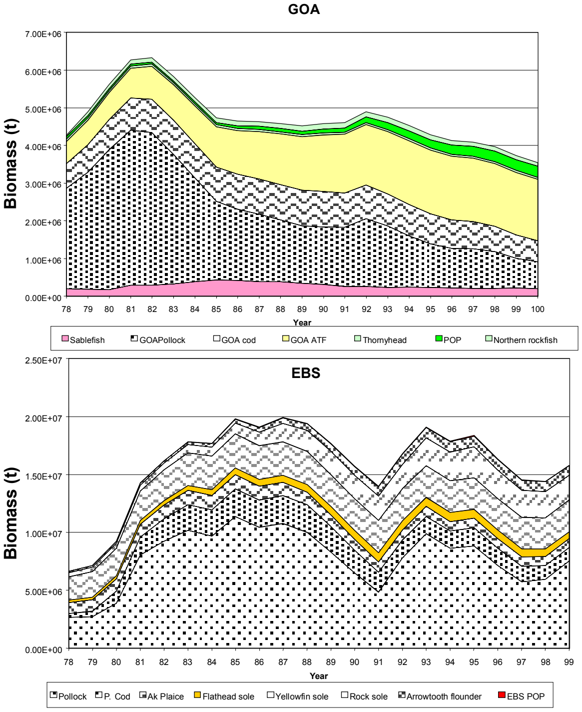


Fig. 11 Groundfish stock biomass estimates in the Gulf of Alaska (GOA) and eastern Bering Sea (EBS) derived from stock assessment models of the Alaska Fisheries Science Center.

Fisheries Science Center. A model description and the outputs can be viewed at "www.refm.noaa.gov/docs/oscurs/Default.htm".

The Alaska Fisheries Science Center's Ocean Carrying Capacity Program carries out work on North Pacific salmon ecology. It has begun a series of coastal cruises in the Bering Sea and Gulf of Alaska to look at salmon ecology, and has a historical time-series of chum salmon age and size of return ("www.afsc.noaa.gov/abl/OCC/occ.htm").

The North Pacific Groundfish Observer Program maintains a fishery observer database containing the catch and other biological and physical information recorded by fishery observers on commercial fishing vessels or at fish processing plants ("www.refm.noaa.gov/observers/Default.htm").

Marine mammal population data are maintained for Alaska pinniped information ("nmml.afsc.noaaov/AlaskaEcosystems/akprog.htm"), for Alaska cetacean assessments "nmml.afsc.noaa.gov/CetaceanAssessment/cetacean.htm", and for California Current pinniped and cetacean assessments ("nmml.afsc.noaa.gov/CaliforniaCurrent/calcurr.htm"). Marine mammal stock assessment reports can be viewed at "www.nmfs.noaa.gov/prot_res/PR2/Stock_Assessment_Program/ ars.html".

The Recruitment Processes program ("www.afsc.noaa.gov/race/recruit-fociprog.htm") has time-series relating to early life history stages of fish and physical and biological data to assist in understanding population processes (see Megrey in this volume for details).

Groundfish and pelagic time-series maintained by the Stock Assessment Division of Fisheries and Oceans, Canada

Gordon A. McFarlane
Fisheries and Ocean Canada, Pacific Biological Station, 3190 Hammond Bay Road, Nanaimo, B.C. Canada. V9R 5K6 E-mail: McfarlaneS@pac.dfo-mpo.gc.ca

The Groundfish Section at the Pacific Biological Station maintains several time-series of data related to groundfish fishery monitoring and fishery surveys (Table 6). The Section also collects physical and biological data (e.g., temperature, weight and length-at-age, etc.) and produces stock assessments for groundfish populations (Table 6).

Echo-integration/midwater trawl surveys are used to estimate Pacific hake abundance for the offshore and the Strait of Georgia stocks. The bottom trawl surveys in Hecate Strait and Queen Charlotte Sound are conducted to index the abundance of exploited species and to study multispecies groundfish assemblages. Ecosystem dynamics are studied using an annual midwater

Table 6 The physical and biological data used for stock assessment of groundfish and small pelagics.

Time series	**Area**[1]	**Years**	**Sampling period**	**Main species**	**Gear**	**Physical data**	**Bottom depth range (m)**	**Email Contact**
Groundfish bottom trawl survey	Hecate Strait, BC	84, 87, 89, 91, 93, 95, 96, 98, 2000	May-June	Groundfish	Bottom trawl (soft-bottom gear)	CTD (87-present)	20-150	fargoj@pac.dfo-mpo.gc.ca
Pacific ocean perch bottom trawl survey	Queen Charlotte Sound, BC	65-67, 69-71, 73, 76-77, 84, 94, 95	June-September	Pacific ocean perch	Bottom trawl (roller gear)	None	100-400	krishkab@pac.dfo-mpo.gc.ca
Hydroacoustic / trawl survey	Coastwide, BC	90-2000	August	Pacific Hake	38kHz echosounder/ midwater trawl	CTD	50-1000	saundersm@pac.dfo-mpo.gc.ca
La Perouse Ecosystem Project	Southwest Coast Vancouver Island, BC	85-2000	August	Herring/ Pacific Hake	38kHz echosounder/ midwater trawl	CTD	50-1000	mcfarlanes@pac.dfo-mpo.gc.ca
Hydroacoustic / trawl survey	Strait of Georgia, BC	80, 88, 93, 96, 97, 98, 2000	February-April	Pacific Hake	38kHz echosounder/ midwater trawl	CTD/ADCP (2000 only)	50-350	saundersm@pac.dfo-mpo.gc.ca
Sardine/ Midwater Trawl Survey	West Coast Vancouver Island, BC	1996-present	July	Sardine	38kHz echosounder/ midwater trawl	CTD	50-1000	mcfarlanes@pac.dfo-mpo.gc.ca
Groundfish stock assessments	BC	1979-present	Annual assessment cycle	Commecially important species				www.pac.dfo-mpo.gc.ca/sci/psarc/
Groundfish Fishery Observer data	Foreign Pacific Whiting Fishery, BC	1987-present	June-October	Pacific Hake	Midwater trawl		50-500	saundersm@pac.dfo-mpo.gc.ca
Groundfish Fishery Observer data	Domestic trawl (100% coverage), BC	1996-present	All year	All groundfish species	Trawl		20-1100	rutherfordka@pac.dfo-mpo.gc.ca
Groundfish Fishery Observer data	Domestic hook-and-line (5-10% coverage), BC	2000-present	All year	All groundfish species	Hook-and-line		20-1100	rutherfordka@pac.dfo-mpo.gc.ca

Table 6 (continued)

Time series	**Area**[1]	**Years**	**Sampling period**	**Main species**	**Gear**	**Physical data**	**Bottom depth range (m)**	**Email Contact**
Groundfish Fishery Sales slips	Domestic fishery (all gears), BC	1950-1996	All year	Commercially important species	All Gears		20-1100	bijsterveldl@pac.dfo-mpo.gc.ca
Groundfish Dockside monitoring	Trawl and Hook-and-line, BC	1996-present	All year	All landed catch	Trawl and hook-and-line		20-1100	rutherfordka@pac.dfo-mpo.gc.ca
Groundfish Fisher logs	Domestic trawl fishery, BC	1950-present	All year	Commercially important species	Trawl		20-1100	rutherfordka@pac.dfo-mpo.gc.ca
Groundfish Fisher logs	Domestic hook-and-line fishery, BC	1995-present	All year	Commercially important species	Hook-and-line		20-1100	rutherfordka@pac.dfo-mpo.gc.ca
Groundfish Fisher logs	Domestic sablefish trap fishery, BC	1980-present	All year	Sablefish	Trawl and hook-and-line		200-1100	saundersm@pac.dfo-mpo.gc.ca
Groundfish Specimen Sampling	From commercial and research catches, BC	1950-present	All year	Most commercially important groundfish species	All gear		20-1100	rutherfordka@pac.dfo-mpo.gc.ca
Herring Spawn survey	Coastwide, BC	1950-present	March-April	Herring	Dive and Aerial surveys		0-30	schweigertj@pac.dfo-mpo.gc.ca
Herring Assessments	BC	1950-present	Annual assessment cycle	Herring				www.pac.dfo-mpo.gc.ca/sci/psarc/
Herring Specimen Sampling	Coastwide, BC	1950-present	September-April	Herring	Seine and gillnet			schweigertj@pac.dfo-mpo.gc.ca
Herring Catch data	Coastwide, BC	1950-present	September-April	Herring	Seine and gillnet			schweigertj@pac.dfo-mpo.gc.ca

[1] BC = British Columbia Coast

trawl survey off the southwest coast of Vancouver Island.

The Section maintains the principal fishery monitoring databases of the commercial fishery. These include fisher and observer logs and dockside monitoring results of the trawl, trap and hook-and-line fisheries. The section also maintains a centralised biological database system with results of approximately 4,000,000 specimens that have been examined since 1950 from on-board and dockside sampling of research and commercial catches.

Stock assessments are conducted using a variety of analytical methods depending on the amount and types of information available. These include catch-at-age analyses tuned with abundance indices for Pacific hake, Pacific Ocean perch and some of the sole species or simple catch curve analyses for “data poor” stocks which include many rockfish species.

The Pelagics Section at the Pacific Biological Station maintains several data series related to stock assessment. These include a long time-series of information on the extent and intensity of herring egg deposition, estimates of the total catch removed by gear, area and year, and estimates of biological characteristics of each stock including length, weight, sex, maturity and age (Table 6). These data series are updated and analysed annually to produce estimates of current stock abundance and forecasts of abundance for the next fishing season.

Stock assessments are conducted using primarily two methods. The first is based on a synthesis of the annual surveys of egg deposition into an estimate of spawning biomass which is combined with catch-at-age data to estimate total mature biomass in each area for each season. The second method of stock assessment is based on a catch-at-age analysis tuned with the spawn deposition information.

The Section also maintains a database of tagging and tag recovery data from all areas of the coast dating back to the late 1930s. These data indicate the degree of fidelity of herring to particular areas as well as highlighting the tendency of herring to stray extensively from year to year.

Time series of 5 ocean/climate indices have been compiled (Aleutian Low Pressure Index-ALPI; Pacific Circulation Index-PCI; Atmospheric Forcing Index-AFI; Length of Day-LOD; and Fraser River Flows) to examine the relationship between ocean/ climate conditions and trends in abundance, recruitment and distribution of marine fishes. These indices are available at “www.pac.dfo-mpo.gc.ca./sci/sa-mfpd/”.

FOCI biological time-series available for use as ecosystem indicators from the Fisheries Oceanography Coordinated Investigation

Bernard A. Megrey
National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, U.S.A. E-mail: Bern.Megrey@noaa.gov

Note: The time-series described below are variable with respect to the number of years they describe. FOCI is in the process of updating these time-series to make them as current as possible.

Ichthyoplankton database

Data from ichthyoplankton research surveys from the west coast of the United States as well as the Gulf of Alaska and Bering Sea are available from 1972. These data, which concentrate on eggs and larvae of ecologically important marine fish species, were collected by the U.S. and other international participants, and are assembled into a scientific database maintained at the Alaska Fisheries Science Center. Included are species, stage, length (age), abundance and haul specifics (i.e., sample time, location, sampling method, etc.).

Biological oceanography database

Zooplankton and water nutrient information from research cruises are archived into a scientific database similar to the one described above. Data records date from the early 1980s. The recorded information includes species, stage, length, abundance, nutrient concentrations and haul specifics (i.e., sample time, location, sampling method, etc.).

Egg and larval pollock abundance indices

Egg and larval index values are calculated from data collected on Alaska Fisheries Science Center (AFSC) research cruises. Since cruises were conducted for a variety of purposes, station patterns and the number of stations sampled are not consistent between cruises (Dunn and Rugen 1989). To deal with these inconsistencies, index values were calculated for regions and times that are of historic importance to eggs and larvae and were sampled during most years. This was done to avoid extrapolating data to areas where no information was available. The egg time-series begins in 1978 and the larval series begins in 1979.

Because mortality can have a large effect during an index interval (one month in this case), abundance values were standardized to the mid-point of the index period. The egg mortality rate (z=0.186/day) was taken from Picquelle and Megrey (1993, 1991) and larval mortality rate (z=0.110/day) was taken from Yoklavich and Bailey (1990). The abundances for eggs and larvae in the index region were calculated by year using the Sette and Ahlstrom method (Richardson 1981). Mean catch per m^2 was calculated by weighting catch per 10 m^2 for each station by the polygonal area of the station. The grand mean of all stations within the index region was then multiplied by the total area of the index region to give the abundance index. Because early sampling for eggs was done to an insufficient depth to cover the whole vertical range of distribution, egg abundances were corrected for tows sampled to less than 250 m depth using the method described in Kendall and Kim (1989).

Age-0 and age-1 juvenile pollock abundance

Indices of juvenile pollock were derived from data generated from shrimp and juvenile pollock surveys conducted in the Shelikof Strait region. Data for age-0 pollock begin in 1975. Data for age-1 pollock begin in 1979. Spring and Bailey (1991) provided detailed descriptions of gear used to collect samples, geographic and temporal coverage of the surveys, gear-dependent mortality corrections, and all assumptions and data processing steps. Juvenile abundance values used in this study were corrected for gear and mortality affects.

Egg production estimates of pollock spawning biomass

Estimates of spawning biomass in Shelikof Strait derived from the application of egg production methods to results of egg surveys are available in 1981 and from 1985-1992. A complete description is given in Picquelle and Megrey (1991). These fishery-independent estimates of spawner biomass have been used to calibrate stock assessment models but can be useful in an ecosystem analysis context. The time-series will be updated as new egg surveys are conducted.

FOCI recruitment prediction

FOCI supplies annual recruitment forecasts for Gulf of Alaska estimates for Shelikof Strait walleye pollock based on a conceptual model which incorporates biological and physical factors that influence survival of early life history forms. The sections above explained the biological data that are incorporated into the recruitment forecast. The sections below describe the historical data used in this activity.

COADS SST, air temperature and sea level pressure

To account for the variability in fluid temperature affecting the ocean's mixed layer in Shelikof Strait, FOCI also considers air temperature, sea-surface temperature, and sea-level pressure from the Monthly Summaries Trimmed Group of the Comprehensive Ocean-Atmosphere Data Set (COADS) (Woodruff *et al.* 1987). These data, which begin in 1962, are monthly averages of marine observations subjected to quality control to remove outliers and binned into 2º latitude by 2º longitude boxes. Our subset comprised monthly averaged data from three locations: 55ºN, 159ºW; 57ºN, 155ºW; and 59ºN, 153ºW.

Advection

Advection through Sheilkof Strait, expressed as an index of continuous transport, is inferred from satellite-tracked drifters and is available beginning in 1980.

Freshwater runoff

The Alaska Coastal Current has a strong buoyancy-driven component created by freshwater runoff originating from ice melt, precipitation and coastal river discharge. Buoyancy-driven coastal flows are typical of subarctic regions where changes in salinity rather than temperature generate density gradients. Royer (1982) modeled the monthly freshwater runoff as a line source around the Gulf of Alaska by estimating the effects of insolation, local precipitation minus evaporation, and air temperature around the northern Gulf of Alaska. This series was modified (Parker 1989a, 1989b) to include freshwater additions from Cook Inlet and sources along Shelikof Strait. Values used in this study are indices that represent deviations from the mean winter (November-April) estimates of integrated coastal freshwater discharge into the Gulf of Alaska as provided by Parker (1989a, 1989b).

Wind mixing

Winds transfer mechanical energy between the atmosphere and the ocean. The main effects of wind on early life stages of larvae are transport by wind-driven currents and deepening of the mixed layer. Wind stress, proportional to the square of the wind speed, causes the former, and wind mixing, proportional to the cube of the wind speed, causes the latter. The relative importance of these energy-transfer mechanisms depends on wind and current directions and the structure of the oceanic mixed layer (Klein 1980). To account for the maximum effect of wind on early life stages of pollock larvae, we picked mixing, the highest mode. A study of survival of first-feeding larvae with respect to wind mixing in Shelikof Strait (Bailey and Macklin 1993) supports this choice. Twice daily, winds were computed from the gridded NMC sea level pressures by applying a geotriptic wind model tuned to the Shelikof Strait region (Macklin *et al.* 1993). The wind speeds were cubed and monthly averages determined for the study period. We retained monthly averages to avoid the possibility of missing the influence of small-scale wind events, which are episodic in nature. One NMC time-series was produced for wind mixing near the exit of Shelikof Strait (57ºN, 156ºW) and one for the Shumagin Islands (55ºN, 160ºW). An independent estimate of wind mixing was determined from COADS wind data. The COADS wind data comprised monthly averaged wind speed observations from three locations: 55ºN, 159ºW; 57ºN, 155ºW; and 59ºN, 153ºW. The time-series begins in 1962.

OSCURS model output

OSCURS (Ocean Surface Current Simulations) is an empirical ocean-wide model covering the subarctic Pacific region with a 1/4 mesh FNOC (U.S. Navy Fleet Numerical Oceanography Center) grid (about 90 km). Expanding the studies of Hubert and Laevastu (1965) and Larson and Laevastu (1972), the model combines long-term mean surface geostrophic currents (Ingraham and Miyahara 1989) with wind-generated surface-mixed-layer currents to form a resultant current vector at each grid point. Wind speed and direction are derived from daily FNOC sea-level pressure data to provide daily continuity from 1946 to 1990 following the methods of Larson (1975). Wind-induced ocean currents are then calculated from the empirical functions of the wind (Witting 1909; Huang 1979; Weber 1983). The Gulf of Alaska portion of the model was first tuned so that the model trajectories calculated for the period September 21 to December 31, 1978 (about 3 months), matched the trajectory of a satellite-tracked drifter (drogued at 20-m) from Reed (1980) for the same dates and starting locations (Ingraham and Miyahara 1989).

OSCURS data consist of an annual index (1946-1991) of the tendency for surface currents to flow southwestward out of the Gulf of Alaska, as derived from model trajectory patterns. The numerical value of the index used in this study is defined as the number of trajectories out of six, starting on February 1, that are along 55ºN between 137ºW and 152ºW, and move west of 154ºW by the end of April. This is the same index used by Ingraham *et al.* (1991) to show that large-scale interannual changes in surface currents in the Gulf of Alaska during February-April (1976-1989), were connected to changes in water properties below sill-depth in Shelikof Strait. The data are extended annually back to 1946.

NEPPI

Much of the variability in the physical environment of the Gulf of Alaska is due to large-scale atmospheric phenomena (Schumacher and Kendall 1991). The Aleutian Low dominates the variability of the atmospheric circulation over the Gulf of Alaska and plays a crucial role in the hydrological cycle (Neibauer 1988). NEPPI (Northeast Pacific Pressure Index (Emery and Hamilton 1985)), is a scalar index of the large-scale, sea-level pressure gradient across the northeast Pacific Ocean from (40ºN, 120ºW) near Reno, Nevada, to (50ºN, 170ºW) south of Amukta Pass in the Aleutian Islands. NEPPI, which varies with the intensity of the atmospheric circulation and the track of storms over the northeast Pacific Ocean, provides a measure of the strength, frequency, and location of the Aleutian Low. NEPPI correlates strongly with northeastern Pacific sea-surface temperatures and adjusted coastal sea levels (Emery and Hamilton 1985), with coastal volume transport in the Shelikof Strait region (Roach and Schumacher 1991), and with Gulf of Alaska circulation (Ingraham *et al.* 1991). We computed a monthly mean NEPPI from twice daily, gridded (381 km at 60ºN) sea-level pressures produced by the U.S. National Meteorological Center (NMC), and archived and averaged by the Department of Atmospheric Sciences, University of Washington, Seattle, WA. Linear interpolation of gridded pressures yielded sea level pressures at (40ºN, 120ºW) and (50ºN, 170ºW). The time-series begins in 1962.

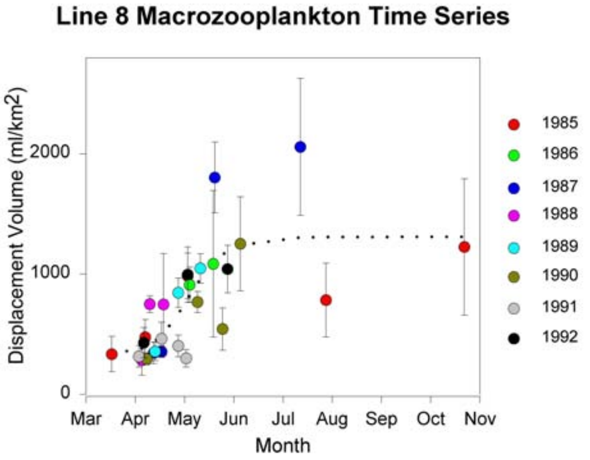


Fig. 12 Displacement zooplankton volume data from line 8.

Zooplankton, chlorophyll and nutrients in the Gulf of Alaska and Bering Sea

Gulf of Alaska

NOAA's Fisheries Oceanography Coordinated Investigations monitoring program of the Gulf of Alaska has dramatically declined in the recent past. Our cardinal sampling line (Line 8, 7 stations across Shelikof Strait between Cape Kekurnoi and Kodiak Island) was routinely sampled for nutrients, chlorophyll, icthyo- and zooplankton several times each year from March – June. Monitoring began in 1985, but not all sample types were collected in all years. Currently Line 8 is sampled for nutrients, chlorophyll, and zooplankton only once or twice a year (May), and broad-scale surveys for ichthyoplankton are conducted approximately twice a year. Every other year a process-oriented springtime cruise is conducted in Shelikof Strait to investigate a physical or biological process that contributes to recruitment variability of walleye pollock.

Figure 12 is an example of how zooplankton displacement volume data from Line 8 have been used to examine inter-annual variability despite seasonal trends in the data. For this exercise we examined the departures from a logistic population growth curve fit to the data. Note that we have not yet added data from recent years to the graph, although we do have these data.

Bering Sea

A consistent monitoring program from FOCI did not emerge until very recently. Fall surveys for age-0 pollock around the Pribilof Islands (Lines A – D) were begun in 1994. These surveys included hydrography, nutrients, chlorophyll, zooplankton, and juvenile fish along the 4 sampling transects. The project that initiated these collections is not funded to continue sample collection past fall 1999. The Southeast Bering Sea Carrying Capacity (SEBSCC) Monitoring and Indices program began in 1997, and field collections will end in FY00. In this program, nutrients, chlorophyll and zooplankton are collected winter, spring and fall at the shelf break, and around moorings in the Outer and Middle Shelf Domains (Fig. 13). Sample collection around Unimak Pass is less frequent. Biological and chemical data from this project are currently being synthesized with physical environmental data to produce indices of ecosystem "health" for use in predicting survival potential of juvenile walleye pollock. We are also looking for extra-mural support to continue our monitoring.

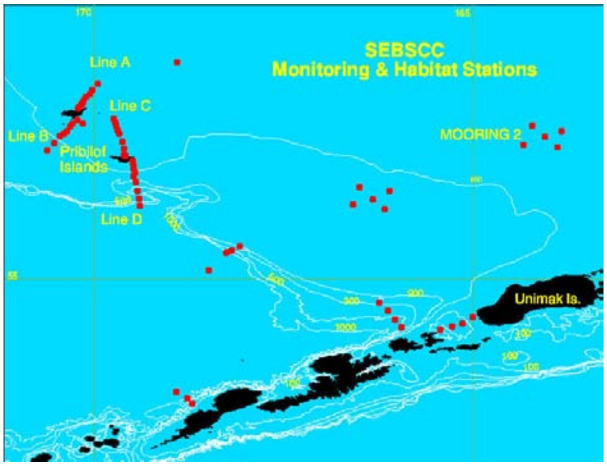


Fig. 13 Survey area in Bering Sea.

References

Bailey, K.M., and Macklin, S.A. 1993. Coherent patterns of larval walleye pollock (*Theragra chalcogramma*) survival and wind mixing events in Shelikof Strait, Gulf of Alaska. Mar. Ecol. Prog. Ser.

Cayan, D.R., McLain, D.R., and Nichols, W.D. 1991. Monthly climate time series data for the Pacific Ocean and western America's. United States Geological Survey Report OFR 91-92.

Dunn, J.R., and Rugen, W.C. 1989. A catalog of Northwest and Alaska Fisheries Science Center ichthyoplankton cruises 1965-1988. NWAFC Proc. Rep. 89-04, Northwest and Alaska Fish. Ctr., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98115-0070, 66p.

Emery, W.J., and Hamilton. 1985. Atmospheric forcing of interannual variability in the northeast Pacific Ocean: connections with El Niño. J. Geophys. Res. 90: 857-868.

Huang, N.E. 1979. On the surface drift currents in the ocean. J. Fluid Mech. 91: 191-208.

Hubert, W.E., and Laevastu, T. 1965. Synoptic analysis and forecasting of surface currents. U.S. Navy Fleet Numerical Weather Facility, Monterey, CA. Tech. Note 9, 47p.

Ingraham, W.J., Jr., Reed, R.K., Schumacher, J.D., and Macklin, S.A. 1991. Interannual variability of circulation in the Gulf of Alaska in relation to water properties and fisheries resources. EOS, Trans. Am. Geophys. Union 72: 257-264.

Ingraham, W.J., Jr., and Miyahara, R.K. 1989. Tuning of OSCURS numerical model to ocean surface current measurements in the Gulf of Alaska. NOAA Tech. Memo. NMFS F/NWC-168, 67p.

Kendall, A.W., Jr., and Kim, S. 1989. Buoyancy of walleye pollock (*Theragra chalcogramma*) eggs in relation to water properties and movement in Shelikof Strait, Gulf of Alaska. *In* Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. *Edited by* R.J. Beamish and G.A. McFarlane. Can. Spec. Publ. Fish. Aquat. Sci. 108: 169-180.

Klein, P. 1980. A simulation of the effects of air-sea transfer variability on the structure of the marine upper layers. J. Phys. Oceanog. 10: 1824-1841.

Larson, S., and Laevastu, T. 1972. Numerical analysis of ocean surface currents *In* Studi in onore di Giuseppina Aliverti, Instituto Universitario Navale di Napoli, Napoli pp. 55-74.

Larson, S.E. 1975. A 26-year time series of monthly mean winds over the oceans, Part 1, a statistical verification of computed surface winds over the North Pacific and North

Atlantic. U.S. Navy Environmental Prediction Research Facility, Monterey, CA. Envpredr-scwfac Tech. Paper No. 8-75.

Macklin, S.A., Stabeno, P.J., and Schumacher, J.D. 1993. A comparison of gradient and observed over-the-water winds along a mountainous coast. J. Geophys. Res. 98: 16555-16569.

Niebauer, H.J. 1988. Effects of El Niño-Southern Oscillation and North Pacific weather patterns on interannual variability in the subarctic Bering Sea. J. Geophys. Res. 93: 5051-5068.

Parker, K.S. 1989a. Influence of oceanographic and meteorological processes on the recruitment of Pacific halibut, *Hippoglossus stenolepis*, in the Gulf of Alaska. Ph.D. dissertation, Univ. Washington, Seattle, WA 154p.

Parker, K.S. 1989b. Influence of oceanographic and meteorological processes on the recruitment of Pacific halibut, *Hippoglossus stenolepis*, in the Gulf of Alaska. *In* Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. *Edited by* R.J. Beamish and G.A. McFarlane. Can. Spec. Pub. Fish. Aquat. Sci. 108: 221-237.

Picquelle, S.J., and Megrey, B.A. 1993. A preliminary spawning biomass estimate of walleye pollock, *Theragra chalcogramma*, in the Shelikof Strait, Alaska, based on the annual egg production method. *In* Proceedings from the symposium on the advances in estimating the biomass of marine fish stocks using ichthyoplankton, during the 15th annual Early Life History Section of the American Fisheries Society. *Edited by* J.R. Hunter and N.C.H. Lo. Bull. Mar. Sci. 53: 230-252.

Picquelle, S.J., and Megrey, B.A. 1991. A method of estimating spawning biomass from egg surveys with an application to walleye pollock, *Theragra chalcogramma*, in the Shelikof Strait, Alaska. AFSC Processed Report 91-21.

Reed, R.K. 1980. Direct measurements of recirculation in the Alaskan Stream. J. Phys. Oceanogr. 10: 976-978.

Richardson, S.L. 1981. Spawning biomass and early life of northern anchovy, *Engraulis mordax*, in the northern subpopulation off Oregon and Washington. Fish. Bull. 78: 855-876.

Roach, A.T., and Schumacher, J.D. 1991. Observations of seasonal and interseasonal variability in Shelikof Strait, Alaska. Proc. Seventh Symposium on Coastal and Ocean Management, Coastal Zone 91: 3304-3317.

Royer, T.C. 1982. Coastal fresh water discharge in the Northeast Pacific. J. Geophys. Res. 87: 2017-2021.

Schumacher, J.D., and Kendall, A.W., Jr. 1991. Some interactions between young walleye pollock and their environment in the western Gulf of Alaska. CalCOFI Rep. 32: 22-40.

Spring, S., and Bailey, K. 1991. Distribution and abundance of juvenile pollock from historical shrimp trawl surveys in the western Gulf of Alaska. Alaska Fisheries Science Center Processed Report 91-18. NOAA/NMFS, Seattle, WA 98115, 66p.

Weber, J.E. 1983. Steady wind- and wave-induced currents in the open ocean. J. Phys. Oceanogr. 13: 524-530.

Witting, R. 1909. Zur Kenntnie den vom Winde Erzeigtem Oberflächenstromes. Ann. Hydrogr. Marit. Met. 73, 193p.

Woodruff, S.D., Slutz, R.J., Jenne, R.L., and Steurer, P.M. 1987. A comprehensive ocean-atmosphere data set. Bull. Amer. Met. Soc. 68: 1239-1250.

Yoklavich, M.M., and Bailey, K.M. 1990. Hatching period, growth, and survival of young walleye pollock *Theragra chalcogramma* as determined from otolith analysis. Mar. Ecol. Prog. Ser. 64: 13-22.

The California Cooperative Oceanic Fisheries Investigations ichthyoplankton time-series

H. Geoffrey Moser
National Marine Fisheries Service, Southwest Fisheries Science Center, P.O. Box 271, La Jolla, CA 92038, U.S.A. E-mail: Geoff.Moser@noaa.gov

The California Cooperative Oceanic Fisheries Investigations (CalCOFI) is a partnership of the Southwest Fisheries Science Center (SWFSC) of the National Marine Fisheries Service (NMFS), the Scripps Institution of Oceanography (SIO), and the California Department of Fish and Game (CDFG). This program was initiated in 1949, under the sponsorship of the Marine Research Committee of the State of California, to study the population changes of the Pacific sardine (*Sardinops sagax*) and the environmental factors that may play a role in these fluctuations. The three organizations conduct cooperative sea surveys, hold quarterly meetings, and sponsor an annual conference, with symposia. CalCOFI publishes *CalCOFI Reports*, a peer reviewed journal, and an atlas series. The *CalCOFI Atlas* series summarizes a wide variety of data from the CalCOFI surveys in the oceanographic (10 atlases), zooplankton (13 atlases), and ichthyoplankton (11 atlases) fields (see workshop report by David Checkley for additional information on the history and conceptual basis of CalCOFI).

Sea surveys

The boundaries, station placement, and sampling frequency for the CalCOFI surveys were based on the results of joint biological-oceanographic cruises conducted by Elton Sette (NMFS) and Harald Sverdrup (SIO) during 1939–1941. Originally, CalCOFI cruises were designed to collect sardine eggs and larvae and associated hydrographic data over the entire areal and seasonal spawning range of the species. From 1951 to 1960 the surveys were annual with cruises conducted monthly over the greater CalCOFI sampling area (Fig. 14) extending from northern California to Cabo San Lucas, Mexico. The survey area was occupied quarterly during 1961–1965, and in 1966 the surveys became triennial with monthly cruises. In 1985, the survey pattern

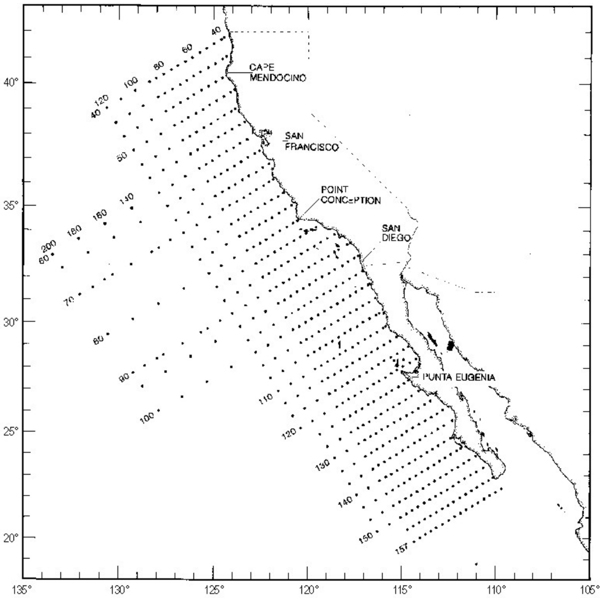


Fig. 14 The basic CalCOFI station pattern occupied, in part, by cruises during 1951-1984.

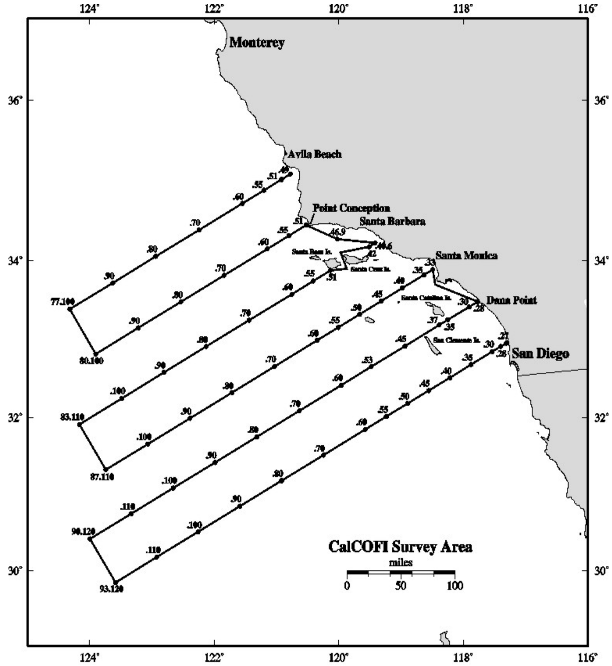


Fig. 15 Station plan for CaCOFI survey cruises from 1984 to the present.

was limited to 66 standard stations in the Southern California Bight region (Fig. 15), with surveys conducted each year on a quarterly basis (see Hewitt 1988; Moser *et al.* 1993, 1994; Ohman and Smith 1995; and Checkley in this workshop for summaries of CalCOFI sampling history).

The basic plankton tow methodology has been consistent throughout the time-series, double-oblique tows with a cable pay-out rate of 50 m per minute and retrieval rate of 20 m per minute at a constant wire angle. Tows from 1951 through 1968 employed a 1-m ring net towed to a depth of 140 m. Beginning in 1969, the nominal tow depth was increased to 210 m and the 71-cm bongo net (McGowan and Brown 1966) replaced the ring net from the last cruise in 1977 to the present. Silk mesh (0.55 mm opening), used from 1951 to 1968, was replaced by nylon mesh (0.505 mm opening) in 1969. Beginning in 1978, surface tows were taken at each station with a Manta net (Brown and Cheng 1981), consisting of a rectangular mouth 15.5 cm deep and 86 cm wide attached to a frame that supports square lateral extensions covered with plywood and urethane foam. These extensions stabilize the net when it is towed and keep the top of the net at the sea surface. The net material is 0.505 mm nylon mesh.

Sample processing

Prior to sorting fish eggs and larvae, we determine zooplankton displacement volume for each sample (methods described in Kramer *et al.* 1972). Then, eggs and larvae of Pacific sardine, northern anchovy and Pacific saury, and larvae of Pacific hake are removed and body lengths of sardine, anchovy, and hake larvae are measured to the nearest 0.5 mm. Identification of ichthyoplankton species beyond those separated during the sorting process is done by a separate group of specialists. Since 1951, fish larvae in CalCOFI samples have been identified to species or to the lowest taxon that knowledge permitted. The number of identifiable taxa increased with the improvement of taxonomic knowledge and competency. Historical identifications were evaluated thoroughly during the development of the CalCOFI ichthyoplankton computer data base in 1984–1988, and historical advances in the identification process were standardized at approximately decadal intervals. Our ability to identify larvae in the California Current region improved greatly during 1988–1995, as a result of taxonomic research that culminated in a taxonomic monograph on the ontogenetic stages of fishes of this region (Moser 1996). This resulted in a ~60% increase in the number of identifiable taxa beginning with samples collected in 1985.

After samples are processed from a cruise, the specimens are stored and archived, by station, in a permanent ichthyoplankton collection which is curated on a regular basis. These collections are available for re-examination when taxonomic advances permit identification of previously unknown eggs and larvae. The collection has become an important asset in establishing time-series of the larvae of important species that were not identifiable during the early years of the CalCOFI surveys.

Ichthyoplankton time-series

The major features of the CalCOFI ichthyoplankton time-series are listed in Table 7. Ichthyoplankton, plankton displacement volumes and station data for all cruises from 1951 to 1998

Table 7 Summary of major features of the CalCOFI ichthyoplankton time-series.

Years		1951– 2001
Area surveyed		California Current Region
Number of cruises		306
Number of tows		
	1-m ring net	28.8 K
	Bongo net	13.9 K
	Manta net	8.5 K
	CalVET net*	13.9 K
	Total	65.1 K
Total fish larvae		4.8 M
Total fish eggs		12.7 M
Data base		Oracle
Operating system		In house UNIX
Web page		In development

A 0.25 m diameter net used in fish egg production surveys; the tow is vertical (70 m/min retrieval rate).

Table 8 List of ichthyoplankton data reports for CalCOFI surveys from 1951 to 1998. Citations for each report are included in the References section of this report.

Survey Year	Senior Author	Publication Year
1951	Ambrose *et al.*	1987a
1952	Sandknop *et al.*	1987a
1953	Stevens *et al.*	1987a
1954	Sumida *et al.*	1987a
1955	Ambrose *et al.*	1987b
1956	Stevens *et al.*	1987b
1957	Sumida *et al.*	1987b
1958	Sandknop *et al.*	1987b
1959	Stevens *et al.*	1987c
1960	Ambrose *et al.*	1987c
1961	Sandknop *et al.*	1988a
1962	Sumida *et al.*	1988a
1963	Ambrose *et al.*	1988a
1964	Sandknop *et al.*	1988b
1965	Stevens *et al.*	1988a
1966	Sumida *et al.*	1988b
1967	Ambrose *et al.*	1988b
1968	Sandknop *et al.*	1988c
1969	Stevens *et al.*	1988b
1972	Sumida *et al.*	1988c
1975	Ambrose *et al.*	1988c
1978	Sandknop *et al.*	1988d
1981	Ambrose *et al.*	1988d
1984	Stevens *et al.*	1990
1985	Ambrose *et al.*	1999a
1986	Charter *et al.*	1999a
1987	Sandknop *et al.*	1999a
1988	Watson *et al.*	1999a
1989	Ambrose *et al.*	1999b
1990	Charter *et al.*	1999b
1991	Sandknop *et al.*	1999b
1992	Watson *et al.*	1999b
1993	Ambrose *et al.*	1999c
1994	Charter *et al.*	1999c
1995	Sandknop *et al.*	1999c
1996	Watson *et al.*	1999c
1997	Ambrose *et al.*	1999d
1998	Charter *et al.*	1999d

are listed in a series of 38 data reports (Table 8). *CalCOFI Atlases* 31 and 32 presented distributional summaries for all taxa taken on surveys that covered the greater CalCOFI sampling area extending from northern California to Cabo San Lucas, Mexico, during 1951–1984 (Moser *et al.* 1993, 1994). *CalCOFI Atlas* 34 (in press) summarizes the distribution and abundance of 160 ichthyoplankton taxa or categories collected in plankton net tows on CalCOFI survey cruises from 1951 to 1998 in the Southern California Bight (SCB) region, the area encompassed by CalCOFI surveys since 1985. This atlas presents areal and temporal (seasonal, annual and decadal) changes in occurrence and abundance of larval fish taxa in a format that permits the reader to interpret, in general terms, the effects that fisheries and ocean climate may have had on larval fish populations in the SCB during 1951–1998. CalCOFI surveys are the basis for research on the population biology of the major coastal pelagic (Pacific sardine, northern anchovy, Pacific mackerel, Pacific hake and jack mackerel) and demersal (e.g., rockfishes) fishes of the California Current System. The CalCOFI database provides a fishery-independent measure of abundance trends that is essential in the monitoring of biomass changes of these important commercial stocks, and is important in the development of management plans for their fisheries.

IMECOCAL (Investigaciones Mexicanas de la Corriente California)

Beginning in 1997, Mexican research partners of CalCOFI at CICESE in Ensenada and CICIMAR in La Paz began conducting biological-oceanographic survey cruises off Baja California, occupying stations that had not been sampled by CalCOFI surveys since 1984. Generally, four cruises have been conducted each year since September-October, 1997, using CalCOFI sampling gear and techniques. The resurgence of surveys off Baja California is an important step in improving our knowledge and monitoring capability of oceanographic and ecological processes in the southern region of the California Current. The ability to monitor important trans-boundary fish populations has been improved greatly, and has increased our potential to manage and conserve such valuable species as Pacific sardine, northern anchovy and Pacific mackerel. IMECOCAL and CalCOFI scientists have cooperated in all phases of the two programs, to maximize the benefits from our surveys. The web site for IMECOCAL is http://imecocal.cicese.mx.

References

Ambrose, D.A., Charter, R.L., Moser, H.G., and Santos Methot, C.R. 1987a. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1951. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-79. 196p.

Ambrose, D.A., Charter, R.L., Moser, H.G., and Santos Methot, C.R. 1987b. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1955. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-83. 185p.

Ambrose, D.A., Charter, R.L., Moser, H.G., and Santos Methot, C.R. 1987c. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1960. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-88. 253p.

Ambrose, D.A., Charter, R.L., Moser, H.G., and Earhart, B.S. 1988a. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1963. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-94. 209p.

Ambrose, D.A., Charter, R.L., Moser, H.G., and Earhart, B.S. 1988b. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1967. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-98. 103p.

Ambrose, D.A., Charter, R.L., Moser, H.G., and Earhart, B.S. 1988c. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1975. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-110. 221p.

Ambrose, D.A., Charter, R.L., Moser, H.G., and Earhart, B.S. 1988d. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1981. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-112. 170p.

Ambrose, D.A., Charter, R.L., and Moser, H.G. 1999a. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1985. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-266. 79p.

Ambrose, D.A., Charter, R.L., and Moser, H.G. 1999b. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1989. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-270. 87p.

Ambrose, D.A., Charter, R.L., and Moser, H.G. 1999c. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1993. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-274. 88p.

Ambrose, D.A., Charter, R.L., and Moser, H.G. 1999d. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1997. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-278. 86p.

Brown, D.M., and Cheng, L. 1981. New net for sampling the ocean surface. Mar. Ecol. Prog. Ser.5: 224–227.

Charter, S.R., Charter, R.L., and Moser, H.G. 1999a. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1986. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-267. 79p.

Charter, S.R., Charter, R.L., and Moser, H.G. 1999b. Ichthyoplankton and station data for Calfornia Cooperative Oceanic Fisheries Investigations survey cruises in 1990. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-271. 86p.

Charter, S.R., Charter, R.L., and Moser, H.G. 1999c. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1994. U. S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-275. 89p.

Charter, S.R., Charter, R.L., and Moser, H.G. 1999d. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1998. U. S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-279. 104p.

Hewitt, R.P. 1988. Historical review of the oceanographic approach to fishery research. Calif. Coop. Oceanic Fish. Invest. Rep. 29:27-41.

Kramer, D., Kalin, M., Stevens, E.G., Thrailkill, J.R., and Zweifel, J.R. 1972. Collecting and processing data on fish eggs and larvae in the California Current Region. NOAA Tech. Rep. NMFS Circ. 370. 38p.

McGowan, J.S. and Brown, D.M. 1966. A new opening-closing paired zooplankton net. Scripps Inst. Oceanogr. Ref. 66-23. 23 pp.

Moser, H.G. (ed.). 1996. The early stages of fishes in the California Current region. CalCOFI Atlas 33. 1505p.

Moser, H.G., Charter, R.L., Smith, P.E., Ambrose, D.A., Charter, S.R., Meyer, C.R., Sandknop, E.M., and Watson, W. 1993. Distributional atlas of fish larvae and eggs in the California Current region: taxa with 1000 or more total larvae, 1951 through 1984. CalCOFI Atlas 31. 233p.

Moser, H.G., Charter, R.L., Smith, P.L., Ambrose, D.A., Charter, S.R., Meyer, C.A., Sandknop, E.M., and Watson, W. 1994. Distributional atlas of fish larvae in the California Current region: taxa with less than 1000 total larvae, 1951 through 1984. CalCOFI Atlas 32. 181p.

Ohman, M.D. and Smith, P.E. 1995. A comparison of zooplankton sampling methods in the CalCOFI time series. Calif. Coop. Oceanic Fish. Invest. Rep. 36: 153-158.

Sandknop, E.M., Charter, R.L., Moser, H.G., and Ryan, J.D. 1987a. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1952. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-80. 207p.

Sandknop, E.M., Charter, R.L., Moser, H.G., and Ryan, J.D. 1987b. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1958. U.S. Dep. Commer. NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-86. 248p.

Sandknop, E.M., Charter, R.L., Moser, H.G., Meyer, C.A., and Hays, A.E. 1988a. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1961. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-92. 167p.

Sandknop, E.M., Charter, R.L., Moser, H.G., Meyer, C.A., and Hays, A.E. 1988b. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1964. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-95. 222p.

Sandknop, E.M., Charter, R.L., Moser, H.G., Meyer, C.A., and Hays, A.E. 1988c. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1968. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-99. 112p.

Sandknop, E.M., Charter, R.L., Moser, H.G., Meyer, C.A., and Hays, A.E. 1988d. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1978. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-111. 216p.

Sandknop, E.M., Charter, R.L., and Moser, H.G. 1999a. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1987. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-268. 91p.

Sandknop, E.M., Charter, R.L., and Moser, H.G. 1999b. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1991. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-272. 90p.

Sandknop, E.M., Charter, R.L., and Moser, H.G. 1999c. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1995. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-276. 84p.

Smith, P.E. and Richardson, S.L. 1977. Standard techniques for pelagic fish egg and larva surveys. FAO Fish. Tech. Pap. 175. 100p.

Stevens, E.G., Charter, R.L., Moser, H.G., and Busby, M.S. 1987a. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1953. U.S. Dep. Commer., NOAA

Tech. Memo., NOAA-TM-NMFS-SWFC-81. 186p.

Stevens, E.G., Charter, R.L., Moser, H.G., and Busby, M.S. 1987b. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1956. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-84. 189p.

Stevens, E.G., Charter, R.L., Moser, H.G., and Busby, M.S. 1987c. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1959. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-87. 273p.

Stevens, E.G., Charter, R.L., Moser, H.G., and Zins, L.R. 1988a. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1965. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-96. 220p.

Stevens, E.G., Charter, R.L., Moser, H.G., and Zins, L.R. 1988b. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1969. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-100. 265p.

Stevens, E.G., Charter, R.L., Moser, H.G., and Meyer, C.A. 1990. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1984. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-141. 157p.

Sumida, B.Y., Charter, R.L., Moser, H.G., and Snow, D.L. 1987a. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1954. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-82. 207p.

Sumida, B.Y., Charter, R.L., Moser, H.G., and Snow, D.L. 1987b. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1957. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-85. 225p.

Sumida, B.Y., Charter, R.L., Moser, H.G., and Snow, D.L. 1988a. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1962. U.S. Dep. Commer., NOAA Tech. Memo, NOAA-TM-NMFS-SWFC-93. 179p.

Sumida, B.Y., Charter, R.L., Moser, H.G., and Snow, D.L. 1988b. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1966. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-97. 287p.

Sumida, B.Y., Charter, R.L., Moser, H.G., and Snow, D.L. 1988c. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1972. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-109. 219p.

Watson, W., Charter, R.L., and Moser, H.G. 1999a. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1988. U. S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-269. 88p.

Watson, W., Charter, R.L., and Moser, H.G. 1999b. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1992. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-273. 90p.

Watson, W., Charter, R.L., and Moser, H.G. 1999c. Ichthyoplankton and station data for California Cooperative Oceanic Fisheries Investigations survey cruises in 1996. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-277. 91p.

Long-term monitoring of subarctic North Pacific ecosystems by the T/S *Oshoro Maru* and *Hokusei Maru* (Hokkaido University): The present and the future

Yasunori Sakurai
Division of Marine Environment and Resources, Graduate School of Fisheries Science, Hokkaido University, Minato-cho, Hakodate, Hokkaido, Japan. 041-8611 E-mail: sakurai@fish.hokudai.ac.jp

Since the late-1970s, the T/S *Oshoro Maru* and *Hokusei Maru* of Hokkaido University have been conducting summer monitoring surveys of the oceanography and ecology of the northern North Pacific by sampling micronekton and zooplankton, deploying research driftnets and taking hydrographic observations. This monitoring has been repeated yearly from June to early August in the North Pacific along 155°E, 170°E, 175°30'E, 180°, 165°W, 145°W, and in the southeastern Bering Sea. The data from each cruise are published annually in the Faculty of Fisheries' "*Data Record of Oceanographic Observations and Exploratory Fishing*".

The long-term monitoring of the subarctic North Pacific ecosystems was conducted as part of the cadet training program of the Faculty of Fisheries, Hokkaido University. Unfortunately, this program will end in March 2002, and the T/S *Hokusei Maru* will be decommissioned at this time. After April 2002, the T/S *Oshoro Maru* (1,383 tons) and R/V *Ushio Maru* (175 tons) will be used to continue some sampling in the North Pacific while training undergraduate and graduate students in the area of Oceanography and Fisheries Science. Hokkaido University scientists remain hopeful that the monitoring in the North Pacific and the cooperative research programs in the PICES region will be able to continue (Bower 2001), because our main scientific concern is to determine how physical forces are linked with the marine ecosystem dynamics in the North Pacific at regional and basin scales. Also, our long-range goal is to forecast how changes in ocean climate will alter the productivity of keystone species in the boreal ocean, including walleye pollock, salmon and pelagic migratory fishes and squids from the subtropics, and to develop acoustic, sampling and observation systems to assess and forecast stock fluctuations.

Research on community structure and dynamics over large areas of the northern North Pacific is needed to understand the present and future ecological responses to changes in climate. To address these goals, Hokkaido University scientists will establish and maintain partnerships between physical, biological and modeling scientists, and continue international cooperative research programs related to the International-GLOBEC and PICES programs, such as "Response of keystone species in marine ecosystems to multi-decadal changes in the subarctic circulation" and "Comparison of Ecosystem dynamics in the northeast and northwest Pacific", aboard the T/S *Oshoro Maru* and R/V *Ushio Maru.*

Scientific findings by the drift gillnet survey

Hokkaido University has a large data set collected over long time period from a large area of subarctic North Pacific. This review shows some results on the interannual variability in distribution and abundance of pelagic species obtained from summer cruises of the T/S *Oshoro Maru* and *Hokusei Maru* during the past two decades. The transition domain area shifts seasonally from 35ºN in winter to 45ºN in summer. The Subarctic Boundary denoted by the vertical ascent of the 33.8 or 34.0 psu of salinity to the surface (Favorite *et al.* 1976). In spring, this boundary forms an environmental barrier creating a subarctic ecosystem. In summer, warming of the shallow water mass extends to the northern subarctic region.

Figures 16 and 17 show interannual variation of CPUE and species composition by gillnet survey at transects along 170°E, 175°E and 180° during summer cruises of the T/S *Oshoro Maru* and *Hokusei Maru*, from late-1970s to late-1990s. These surveys used research gillnets which were composed of tans (50-m lengths) of different mesh size, often from 19 or 25 mm (knot to knot in stretched length) to 204 mm. Marine animals were collected in drift gillnets set overnight from the surface down to about 7 m.

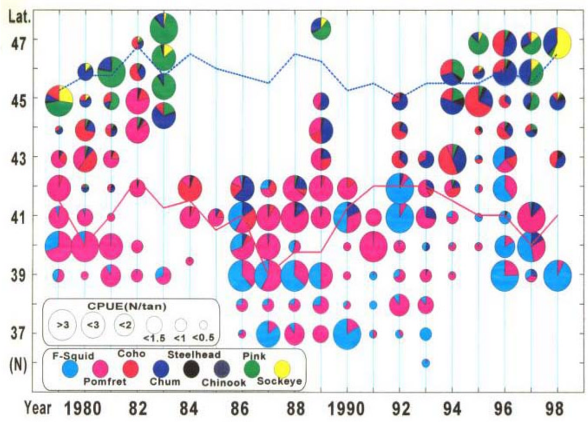


Fig. 16 Interannual variation of CPUE (kg/tan/day) and composition of species by gillnet surveys along 180° during summer cruises of T/S *Oshoro Maru*, 1979-1998. Blue line: Subarctic Front, red line: Subarctic Boundary (modified from Takagi and Onhisi 1996).

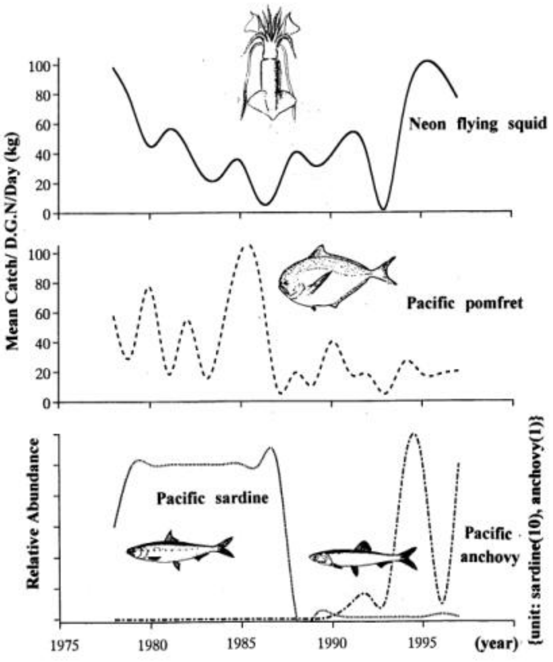


Fig. 17 Interannual variation of CPUE (kg/tan) and relative abundance of pelagic migrant species by gillnet surveys along 170°E and 175°E during summer cruises of T/S *Hokusei maru,* 1978-1997.

Along 180° (37-48°N), the position of the southern boundary (Subarctic Boundary) of the transition domain fluctuated between 39°N and 42°N within a period of ten years, but the position of the northern boundary (Subarctic Front) remained constant (Fig. 16). Sockeye, pink and chinook salmon were distributed mainly in cold water (<8°C) such as the Subarctic Current. Steelhead, chum and coho salmon were distributed in water of subarctic domain (<12°C), where they slightly overlapped in distribution of Pacific pomfret and flying squid. Neon flying squid and Pacific pomfret migrated north across the Subarctic Boundary during the summer. By the late-1980s, the abundance of both species decreased (Fig. 17). Since the late-1990s, neon flying squid abundance has increased, while Pacific pomfret abundance remains low, which might be a reflection of difference in their life-span. These stock fluctuations may be due to changing ocean conditions, such as those caused by El Niño, and impacts of fishing, such as the intensive driftnet fishing that occurred before 1992 (Yatsu *et al.* 2000). Also, Figure 17 shows the expansion of the distribution of Pacific sardine and anchovy from coastal water around Japan to the subarctic ocean, which is strongly related to their stock fluctuation after 1970s.

References

Bower, J.R. 2001. The *Oshoro Maru*: a short history of Hokkaido University's workhorse in the North Pacific. PICES Press 9: 25-28.

Favorite, F., Dodimead, A.J., and Nasu, K. 1976. Oceanography of the subarctic Pacific region, 1960-71. Bull. Int. North Pacific Fish. Comm. 33: 1-187.

Takagi, S., and Onishi, H. 1996. Interannual variability in distribution and abundance of pelagic nekton and oceanographic condition in the Central North Pacific in early summer, 1979-1995. Proc. 1996 Salmon Workshop, 10-26.

Yatsu, A., Watanabe, T., Mori, J., Nagasawa, *et al.* 2000. Interannual variability in stock abundance of the neon flying squid, *Ommastrephes bartramii*, in the North Pacific Ocean during 1979-1998: impact of driftnet fishing and oceanographic conditions. Fisheries Oceanography, 9: 163-170.

Time-series information in the Yellow Sea and Bohai Sea

Qisheng Tang and Xianshi Jin
Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, 106 Nanjing Road, Qingdao, Shandong, People's Republic of China. 266071 E-mail: ysfri@public.qd.sd.cn

The time-series data collected by the Yellow Sea Fisheries Research Institute (YSFRI) mainly focused on the Yellow Sea and Bohai Sea (Table 9). The surveys were conducted only by bottom trawl at different years since the mid-1980s, with the purpose of assessing relative abundance and shift of dominant species. The stations of these bottom trawl surveys were all predetermined (Fig. 18). The data include temperature, salinity, nutrients, plankton, invertebrate, species composition of trawl, length, weight, stomach contents of fish, etc.

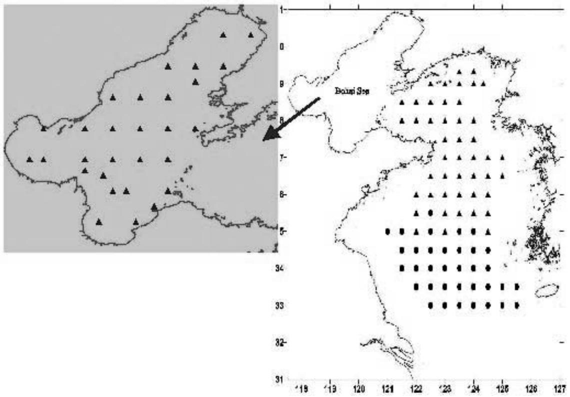


Fig. 18 Survey stations (source: YSFRI).

Table 9 List of bottom trawl surveys in the Bohai Sea and Yellow Sea (source: YSFRI).

Year	Bohai Sea	Yellow Sea	Method
1959-60	Monthly	Monthly	Bottom trawl
1982-83	Monthly		”””””
1985-86		Seasonally	Acoustic/bottom trawl
1992-93	Seasonally		Bottom trawl
1985-1996,1999-2001		Winter	Acoustic/trawl
1998-99	Seasonally		Bottom trawl
1998-2000		Seasonally	Acoustic/trawl

The variations of species composition in the two seas are given in Figures 19-21. The distribution of species and environmental factors in the Bohai Sea in 1982 and 1992 can be found in the *Atlas of the Ecological Environmenta and Living Resources in the Bohai Sea* edited by Qisheng Tang *et al.* (1997). A new atlas on the Yellow Sea will be published.

The hydroacoustic/trawl surveys have been used to assess the stock biomass in the Yellow Sea and sometimes in the East China Sea, for such species as Japanese anchovy (*Engraulis japonicus*), largehead hairtail (*Trichiurus haumela*) and sardine (*Sardinops melanosticta*). Particularly the results from the time-series of winter acoustic surveys carried out in the Yellow Sea since 1985 up to now have been used for fishery management (Fig. 21). Based on these surveys, the recruitment information on economically important species (e.g., Japanese anchovy, Pacific herring (*Clupea pallasi*) and Spanish mackerel (*Scomberomorus niphonius*) may be obtained (Figs. 22 and 23). Information from landings is also crucial for the explanation of changes of species composition in the ecosystem (Fig. 24).

During the stock assessment surveys, environmental parameters were also collected at the same time (Figs. 25 and 26). Those parameters are useful for studying ecosystem changes and may influence the ecosystem and biodiversity in the sea (e.g., see Figure 27 for Pacific herring).

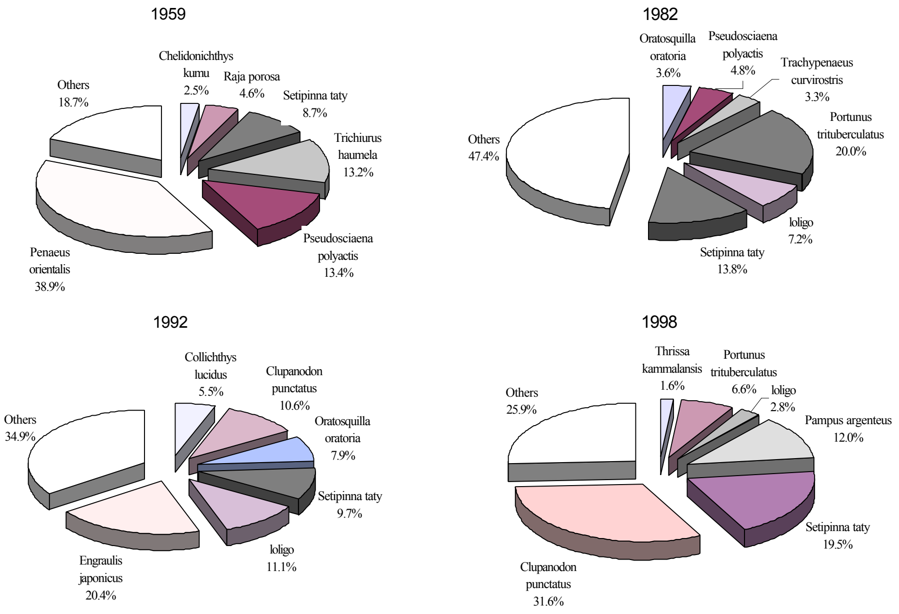


Fig. 19 Variations of dominant species composition in the Bohai Sea in autumn (source: YSFRI).

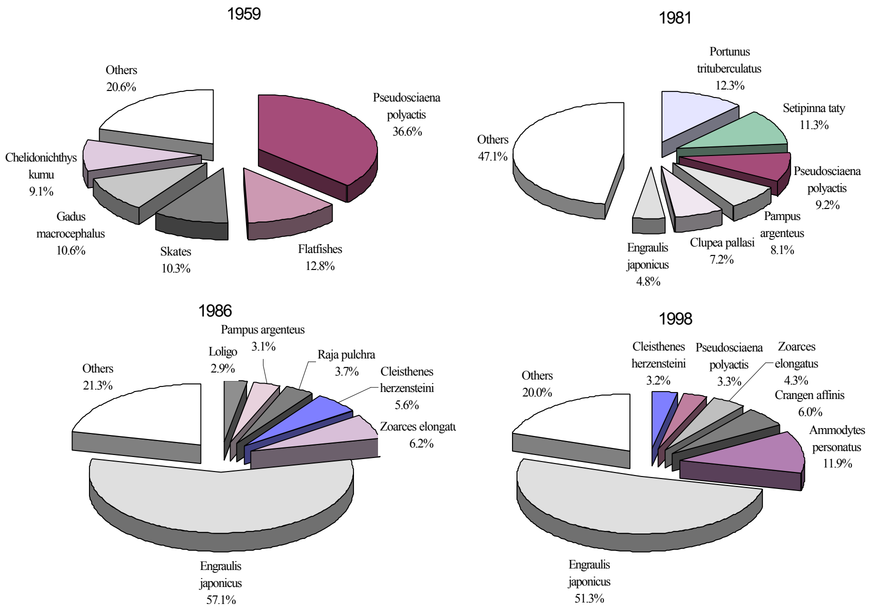


Fig. 20 Variations of dominant species composition in the Yellow Sea in spring (source: YSFRI).

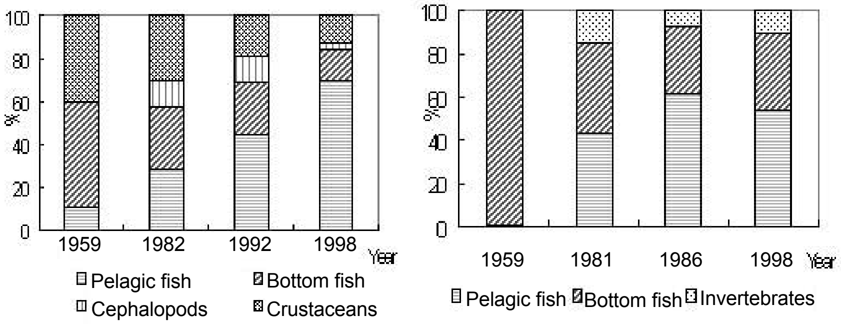


Fig. 21 Changes of species ecotype composition in Bohai Sea (left) and Yellow Sea (right) in May, from 1959 to 1998 (source: Jin 2000).

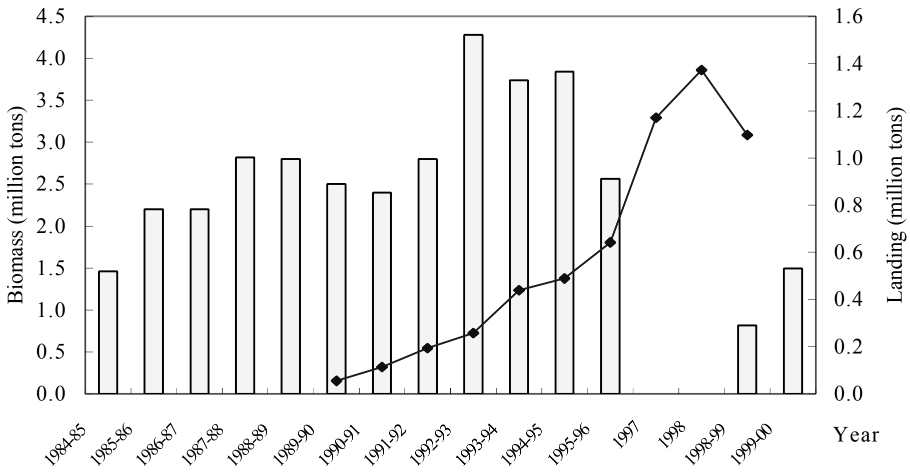


Fig. 22 The yearly variations of Japanese anchovy biomass (bars) and landings (line) (source: YSFRI).

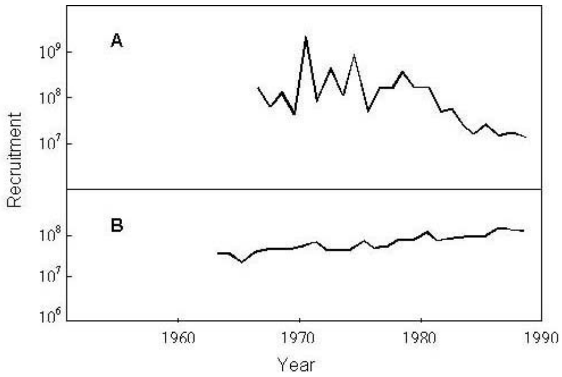


Fig. 23 Recruitment of Pacific herring (A) and Spanish mackerel (B) in the Yellow Sea (source: Tang 1993).

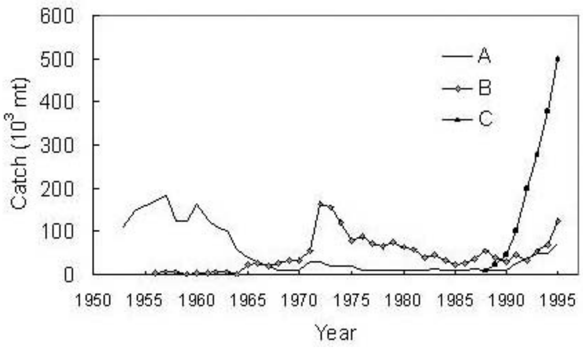


Fig. 24 Annual catch of dominant species: small yellow croaker and hairtail (A), Pacific herring and Japanese mackerel (B), and anchovy and half-fin anchovy (C) (source: Tang 1993, 1998).

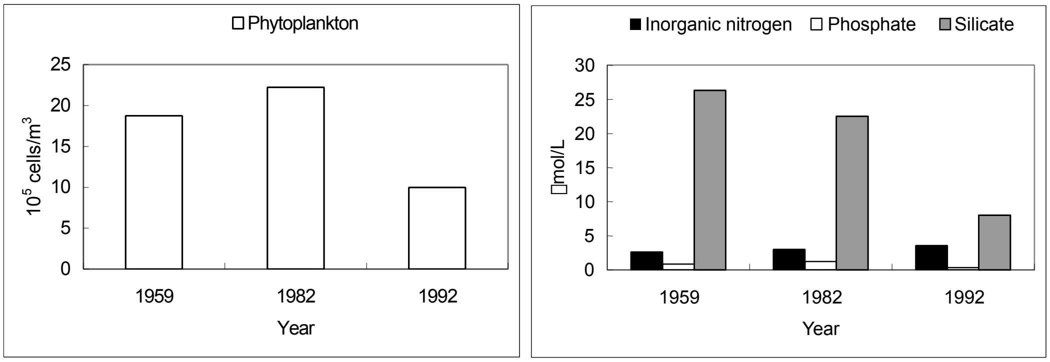


Fig. 25 Changes of phytoplankton and nutrients in the Bohai Sea (source: YSFRI).

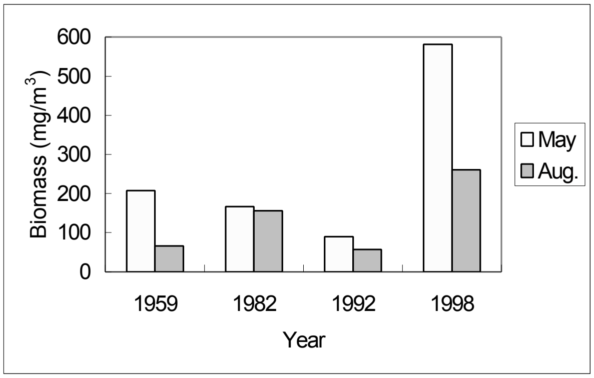


Fig. 26 Changes of zooplankton biomass in the Bohai Sea (source: YSFRI).

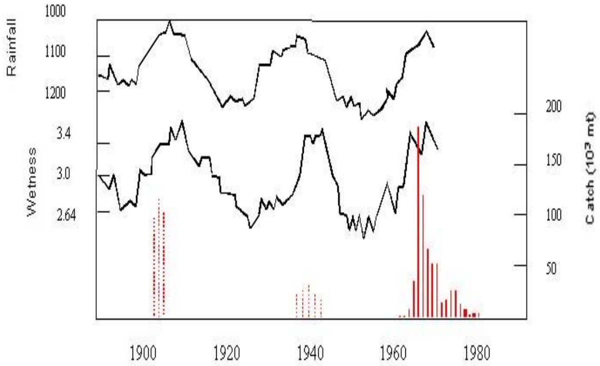


Fig. 27 Relationship between the fluctuations in herring abundance in the Yellow Sea and the 36-yr cycle of wetness oscillation in eastern China (source: Tang 1981, 1995).

Trajectories of catch and stock abundance of dominant small pelagic fishes and common squid with some related environmental indices around Japan

Akihiko Yatsu[1], Hiroshi Nishida[1], Minoru Ishida[1], Akira Tomosada[1], Takahiro Kinoshita[2] and Tokio Wada[3]

[1] National Research Institute of Fisheries Science, 2-12 Fukuura, Kanazawa-ku, Yokohama, Japan. 256-8648 E-mail: yatsua@nrifs.affrc.go.jp

[2] Hokkaido National Fisheries Research Institute

[3] Fisheries Agency of Japan

Small pelagics are ideal subjects for studying ocean-climate variability (Hunter and Alheit 1995). In the northwestern Pacific, 2 - 6 million tons of small pelagic fishes have been harvested annually since the 1950s by the Japanese commercial fisheries, with quasi-decadal alternations in dominant species known as species replacement: chub mackerel, *Scomber japonicus*, in the 1970s, Japanese sardine, *Sardinopus melanostictus*, in the 1980s, Pacific saury, *Cololabis saira*, anchovy, *Engraulis japonicus*, and Japanese common squid, *Todarodes pacificus*, in the early 1990s (Fig. 28). These small pelagics have a short life span (<10 yr) and migrate between spawning grounds in southern Japan including the East China Sea, and feeding grounds in the northwestern Pacific and the Japan Sea and Okhotsk Sea. Herring is confined to subarctic waters of Japan, mainly around Hokkaido. Time-series of catch, recruitment and biomass of these small pelagics in the Japanese waters together with related environmental factors are presented below (Table 10; Figs. 29-34).

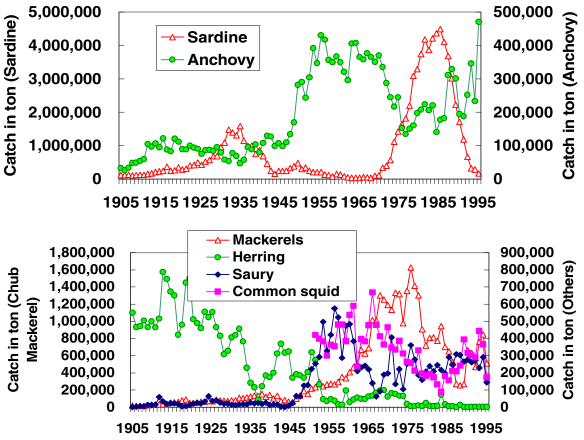


Fig. 28 Catch histories of small pelagic fishes by Japan.

Table 10 Summary of time-series for dominant small pelagic fishes and common squid and related environmental indices around Japan.

Time series	Fig.	Start year	Sampling interval	Time of year	Sampling location	Sampling gear, data source
Commercial catch statistics	28	1905	Annual	All seasons combined	Japanese fishing grounds	Purse seine, jigging, etc.
Sardine biomass & egg production	30	1951	Annual	All seasons combined	Japanese EEZ Pacific side	VPA, plankton net, Wada and Jacobson (1998)
Chub mackerel abundance	31	1961	Annual	All seasons combined	Japanese EEZ Pacific side	VPA, Honma *et al.* (1987)
Common squid biomass	32	1964	Annual	All seasons combined	Japanese EEZ Pacific side	Production model with regime shift
Juvenile fish abundance	33	1996	Annual	May-June	35-39N, 140-170E	Midwater trawl, Nishida *et al.* (2000)
Sardine, anchovy, mackerels annual egg production	34	1978	Monthly	All seasons	Japanese EEZ Pacific side	Ishida (unpubl.)
Kuroshio path type	35, 36	1965	Monthly	All seasons	Central Japan	Japan Coast Guard Hydrographic Dept.
Kuroshio path length	32	1965	Monthly	All seasons	Central Japan	Ditto, Tomosada (unpubl.)
Oyashio index	30	1975	Annual	Feb-Mar.	Northern Japan	Ebisawa and Kinoshita (1998)

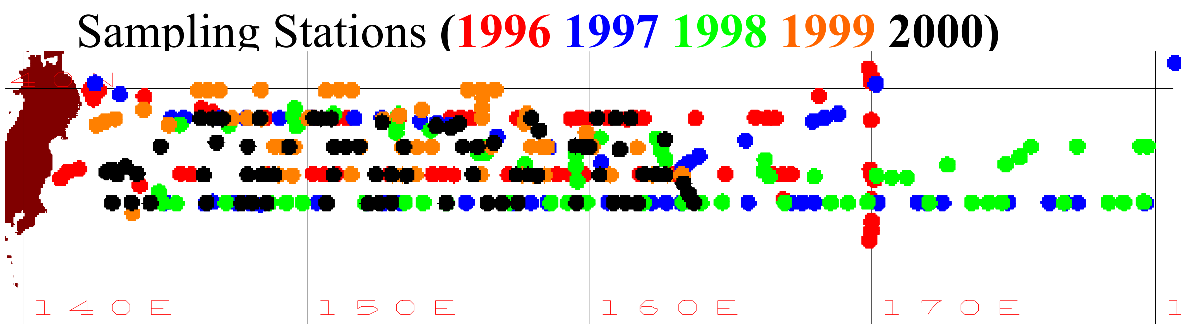


Fig. 29 Midwater-trawl survey towed locations from 1996-2000.

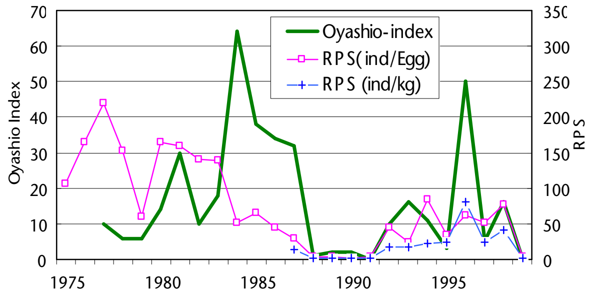


Fig. 30 Spawning stock abundance (SSB), egg production, recruitment and reproductive success of the Japanese sardine along the Pacific coast of Japan and Oyashio index.

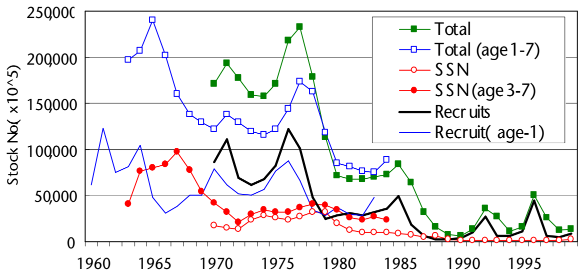


Fig. 31 Total stock numbers, spawning stock numbers (SSN), and recruitment of the chub mackerel along the Pacific coast of Japan (1960-1984: Honma *et al.* (1987)).

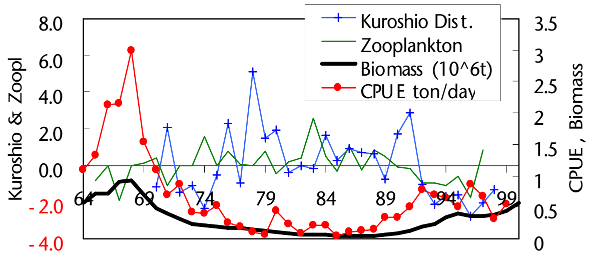


Fig. 32 Kuroshio path distance (March) anomaly, zooplankton abundance anomaly in the central North Pacific, and biomass and CPUE of the Japanese common squid along the Pacific coast of Japan.

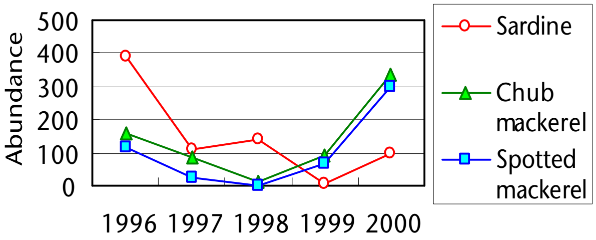


Fig. 33 Abundance indices of the Japanese sardine, chub mackerel and spotted mackerel from midwater trawl survey in the Kuroshio-Oyahiso Transition Zone.

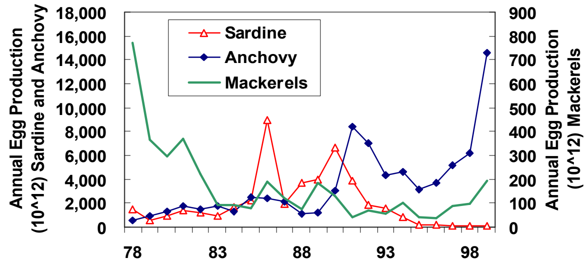


Fig. 34 Annual egg production of small pelagic fishes along the Pacific coast of Japan.

The commercial catch statistics have been published annually by the Ministry of Agriculture, Forestry and Fisheries. Biomass, recruitment and other stock information are based on the routine stock assessments of small pelagic fishes harvested by Japan. Midwater trawl survey has been carried out by NRIFS since 1996 in the Kuroshio-Oyashio Transition Zone in order to examine recruitment. Recruitment abundance indices for sardine and mackerels are calculated from catch in numbers standardized by the sea surface water temperature and tow numbers. The abundance indices are in reasonable agreement with age-0 fish stock numbers estimated from VPA. The decline of sardine populations in the late 1980s was caused by recruitment failures corresponding to Oyashio index and SST anomalies in the Kuroshio Extention (Ebisawa and Kinoshita 1988; Noto and Yasuda 1999). Annual egg production has been estimated from the extensive plankton net surveys throughout the season in the Pacific coast of Japan for sardine, anchovy and mackerels (*Scomber japonicus* and *S. australacicus* combined).

Oyashio index is the area of 10 C SST south of 37 N. The decline of chub mackerel stock can be partly explained by the low reproductive success in the late 1970s and 1980s, when Kuroshio path type was dominated by “A-type” (Figs. 35 and 36) and the famous regime shifts occurred (Hare and Mantua 2000).

The common squid biomass (derived from production model) and catch also showed both low and high frequency variability, of which the former one seemed inversely correlated to the Kuroshio path distance between the longitudes 131 E and 142 E, and also to the zooplankton abundance in the Central North Pacific taken from Hare and Mantua (2000).

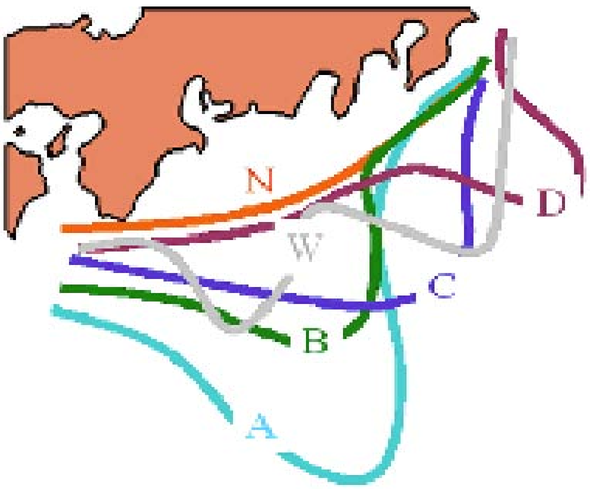
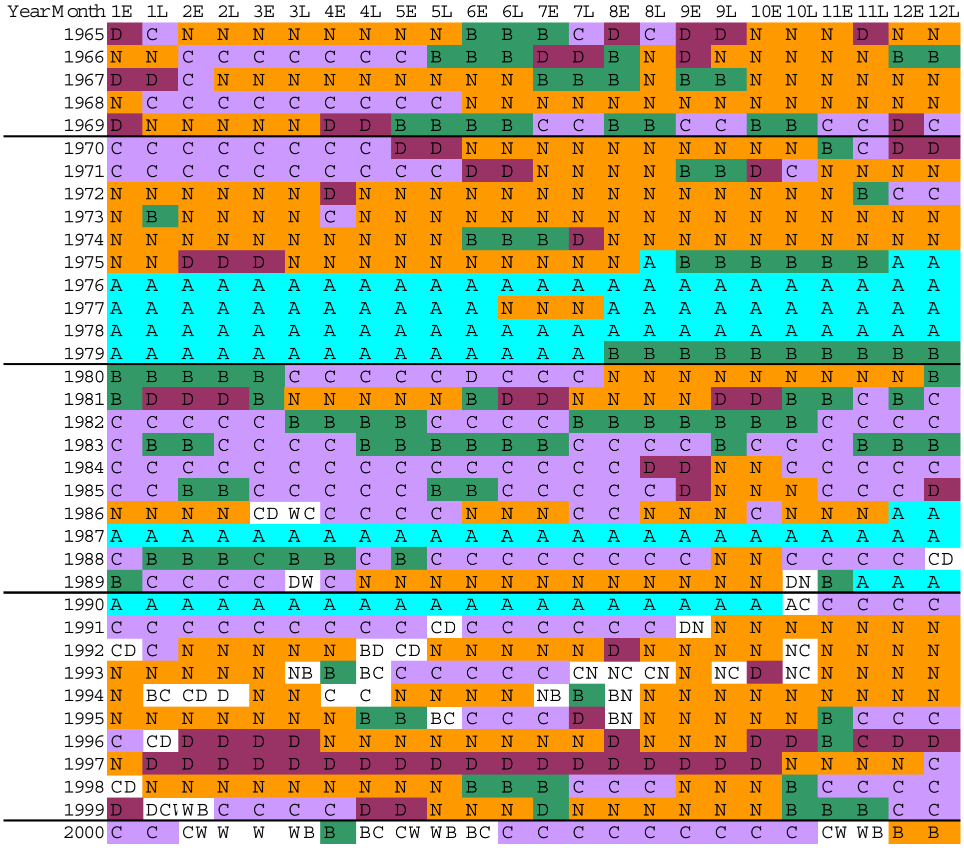


Fig. 35 Kuroshio path types.



YearMonth	1E	1L	2E	2L	3E	3L	4E	4L	5E	5L	6E	6L	7E	7L	8E	8L	9E	9L	10E	10L	11E	11L	12E	12L
1965	D	C	N	N	N	N	N	N	N	N	B	B	B	C	D	C	D	D	N	N	N	D	N	N
1966	N	N	C	C	C	C	C	C	C	B	B	B	D	D	B	N	D	N	N	N	N	N	B	B
1967	D	D	C	N	N	N	N	N	N	N	N	N	B	B	B	N	B	B	N	N	N	N	N	N
1968	N	C	C	C	C	C	C	C	C	C	N	N	N	N	N	N	N	N	N	N	N	N	N	N
1969	D	N	N	N	N	N	D	D	B	B	B	B	C	C	B	B	C	C	B	B	C	C	D	C
1970	C	C	C	C	C	C	C	C	D	D	N	N	N	N	N	N	N	N	N	N	B	C	D	D
1971	C	C	C	C	C	C	C	C	C	C	D	D	N	N	N	N	B	B	D	C	N	N	N	N
1972	N	N	N	N	N	N	D	N	N	N	N	N	N	N	N	N	N	N	N	N	N	B	C	C
1973	N	B	N	N	N	N	C	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
1974	N	N	N	N	N	N	N	N	N	N	B	B	B	D	N	N	N	N	N	N	N	N	N	N
1975	N	N	D	D	D	N	N	N	N	N	N	N	N	N	N	A	B	B	B	B	B	B	A	A
1976	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1977	A	A	A	A	A	A	A	A	A	A	A	N	N	N	A	A	A	A	A	A	A	A	A	A
1978	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1979	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B
1980	B	B	B	B	B	C	C	C	C	C	D	C	C	C	N	N	N	N	N	N	N	N	N	B
1981	B	D	D	D	B	N	N	N	N	N	B	D	D	N	N	N	N	D	D	B	B	C	B	C
1982	C	C	C	C	C	B	B	B	B	C	C	C	C	B	B	B	B	B	B	B	C	C	C	C
1983	C	B	B	C	C	C	C	B	B	B	B	B	B	C	C	C	C	B	C	C	C	B	B	B
1984	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	D	D	N	N	C	C	C	C	C
1985	C	C	B	B	C	C	C	C	C	B	B	C	C	C	C	C	D	N	N	N	C	C	C	D
1986	N	N	N	N	CD	WC	C	C	C	C	N	N	N	C	C	N	N	N	C	N	N	N	A	A
1987	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1988	C	B	B	B	C	B	B	C	B	C	C	C	C	C	C	C	C	N	N	C	C	C	C	CD
1989	B	C	C	C	C	DW	C	N	N	N	N	N	N	N	N	N	N	N	N	DN	B	A	A	A
1990	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	AC	C	C	C	C
1991	C	C	C	C	C	C	C	C	C	CD	C	C	C	C	C	C	DN	N	N	N	N	N	N	N
1992	CD	C	N	N	N	N	N	BD	CD	N	N	N	N	N	D	N	N	N	N	NC	N	N	N	N
1993	N	N	N	N	N	NB	B	BC	C	C	C	C	C	CN	NC	CN	N	NC	D	NC	N	N	N	N
1994	N	BC	CD	D	N	N	C	C	N	N	N	N	NB	B	BN	N	N	N	N	N	N	N	N	N
1995	N	N	N	N	N	N	N	B	B	BC	C	C	C	D	BN	N	N	N	N	N	B	C	C	C
1996	C	CD	D	D	D	D	N	N	N	N	N	N	N	N	D	N	N	N	D	D	B	C	D	D
1997	N	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	N	N	N	N	C
1998	CD	N	N	N	N	N	N	N	N	N	B	B	B	C	C	C	N	N	N	B	C	C	C	C
1999	D	DC	WB	C	C	C	C	D	D	N	N	N	D	N	N	N	N	N	N	B	B	B	C	C
2000	C	C	CW	W	W	WB	B	BC	CW	WB	BC	C	C	C	C	C	C	C	C	C	CW	WB	B	B

Fig. 36 Half-month statistics of the Kuroshio path type.

References

Ebisawa, Y., and Kinoshita, T. 1998. Relationship of surface water temperature in Boso-Sanriku area sea and recruitment per spawning biomass of the Japanese sardine. Bull. Ibaragi Fish. Exp. Sta., 36: 49-55 (In Japanese).

Hare, S.R., and Mantua, N.J. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Prog. Oceanogr., 47: 103-145.

Honma, M., Sato, Y., and Usami, S. 1987. Estimation of the population size of Pacific mackerel by the cohort analysis. Bull. Tokai Reg. Fish. Res. Lab., 121: 1-11. (In Japanese).

Hunter, J., and Aleit, J. 1995. International GLOBEC small pelagic fishes and climate change program. Report of the first planning meeting, La Paz, Mexico, June 20-24, 1994. GLOBEC Rept., 8: 1-72.

Noto, M., and Yasuda, I. 1999. Population decline of the Japanese sardine, *Sardinops melanostictus*, in relation to sea surface temperature in the Kuroshio Extension. Can. J. Fish. Aquat. Sci. 56: 973-983.

Wada, T., and Jacobson, L.D. 1998. Regimes and stock-recruitment relationships in Japanese sardine (*Sardinops melanostictus*), 1951-1995. Can. J. Fish. Aquat. Sci., 55:2455-2463.

GROUP 4: HIGHLY MIGRATORY FISHES, SEABIRDS AND MARINE MAMMALS

Seabirds reflect changes in ocean climate

Douglas F. Bertram
Canadian Wildlife Service & Simon Fraser University, Institute of Ocean Sciences, P.O. Box 6000, Sidney, B.C., Canada. V8L 4B2 E-mail: bertramd@pac.dfo-mpo.gc.ca

Seabirds spend most of their lives on the ocean but come to shore to raise their young. Most seabirds breed on island colonies. When birds are on the colony it is relatively easy for scientists to obtain rigorous quantitative information on their diet, reproduction and survival. The response of seabirds to variation in ocean climate will likely reflect species-specific traits that include body size, cost of foraging, potential foraging range, ability to dive, amount of 'spare' time in the daily budget, and ability to switch diet (Furness and Tasker 2000). The following example outlines some research on Triangle Island, British Columbia, Canada, examining time-series data on breeding seabirds during a period of extreme variation in ocean temperatures.

Background and natural history

British Columbia has major proportions of the world's populations of Cassin's Auklet and Rhinoceros Auklet, which breed on a few large colonies. Triangle Island (50°52'N, 129°05'W), an Ecological Reserve and internationally Important Bird Area (IBA), is the outermost of the Scott Island Group off the northern tip of Vancouver Island (Fig. 1). The island supports the world's largest population of Cassin's Auklet (*Ptychoramphus aleuticus*; 1.1 million breeders) and a large population of Rhinoceros Auklet (*Cerorhinca monocerata*; 82,000 breeders) in addition to significant populations of Tufted Puffin (*Fratercula cirrhata*; 52,000 breeders) and Common Murre (*Uria aalge*; 8,200 breeders) (Rodway 1991). The Cassin's Auklet is a small (190 g) planktivorous, burrow-nesting seabird which visits the colony only at night. Nestlings leave the burrow (fledge) between 40-60 d old. The Rhinoceros Auklet (*Cerorhinca monocerata*) is a 550 g piscivorous, burrow-nesting species that only visits the colony at night. Nestlings are cared for from 45-60 d until fledging. The Tufted Puffin is a 750 g, piscivorous, burrow nester which visits the colony at multiple times throughout the day. Nestlings fledge at 40-50 d. The breeding population for Triangle Island is estimated to be 26,000 pairs (Rodway 1991). The Common Murre is a large (950 g), piscivorous, cliff nesting, diurnal species. Nestling development is semi-precocial and the chicks leave the colony with their fathers at age 20-25 d to complete the majority of development at sea.

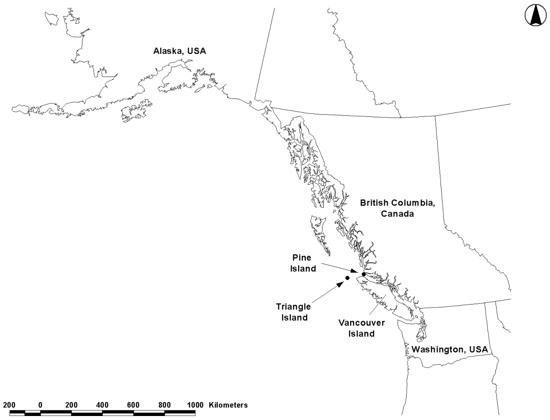


Fig. 1 Location of the seabird colony, Triangle Island, and Pine Island light station in British Columbia, Canada.

From 1989 – 1999, the Cassin's Auklet population size on Triangle Island has declined and breeding success was very poor in several years. To the south on the Farallon Islands in California, a 65% population decline of Cassin's Auklet from 1972-1997 has been linked to a long-term decline in zooplankton in the California Current marine ecosystem (which stretches from California to Northern Vancouver Island). A decline in the world's largest population of Cassin's Auklet on Triangle Island may also be related to the long-term zooplankton changes in the California Current. However, in northern British Columbia, the Cassin's Auklets on Frederick Island (53°56'N, 133°11'W) show no sign of population decline and the birds have had consistently good breeding success in the 1990s, in marked contrast to the Triangle Island population. Populations of the fish eating Rhinoceros Aukelts and Tufted Puffin are stable (1984-1999) and there is no indication of changes in the murre population on Triangle Island.

Time-series information

Seabirds are long-lived species so the research and monitoring must be conducted over appropriate durations to understand how populations change over time. The Pacific Seabird Group (led by Dr. Scott Hatch) in collaboration with the US Geological Survey is working to assemble an interactive database of time-series information for seabirds that is slated to be made available on the web. The database includes contributions from the PICES member nations (Canada, Japan, Russia and U.S.A.) as well as Mexico. An online data entry system is currently being developed so that researchers can easily update their time-series. The database contains information on population size, productivity, components of productivity, survival, reproductive chronology and food habits. Some of the time-series available from Triangle Island are described below, to illustrate the value of seabird time-series information for understanding changes in marine ecosystems (see Bertram *et al.* 2001 for details).

Triangle Island, the largest seabird colony in British Columbia, has the most extensive time-series data sets for the region, spanning three decades. Since 1994, researchers from Canadian Wildlife Service (CWS) and Simon Fraser University have been visiting the colony annually to collect information on breeding propensity, timing of breeding, hatch success, nestling growth and development, nestling diet, fledging success, adult survival and population trends. (Valuable data can be obtained at this site from surveys shorter than 24 hr. The research focuses on the planktivorous Cassin's Auklet and the piscivorous Rhinoceros Auklet, Tufted Puffin and Common Murre.

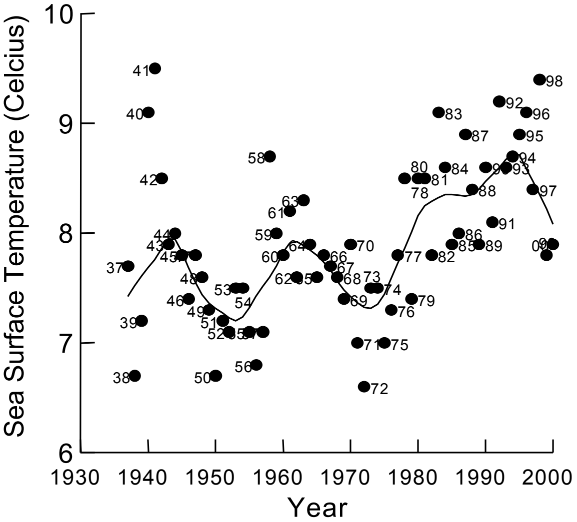


Fig. 2 Average sea surface temperature in April at Pine Is. light station, B.C., Canada.

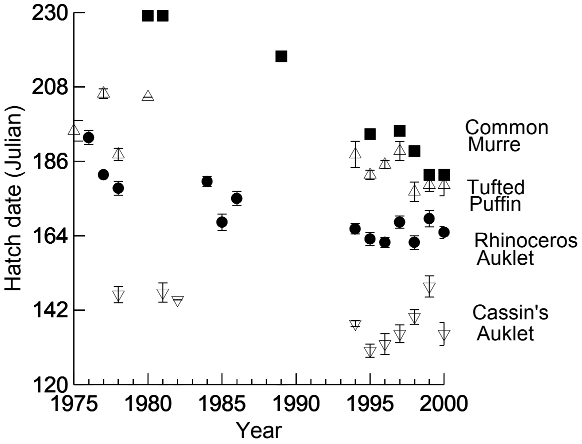


Fig. 3 Timing of breeding for seabirds on Triangle Island, B.C., Canada. Values are mean hatch dates (with 95% confidence intervals) for Cassin's Auklet Rhinoceros Auklet and Tufted Puffin. Values for Common Murre are dates when nestlings were first observed.

On the B.C. coast, the 1990s was the warmest decade of the century with some of the highest SSTs on record (Fig. 2). For the piscivores (Rhinoceros Auklet, Tufted Puffin and Common Murre), the timing of breeding in the 1990s and

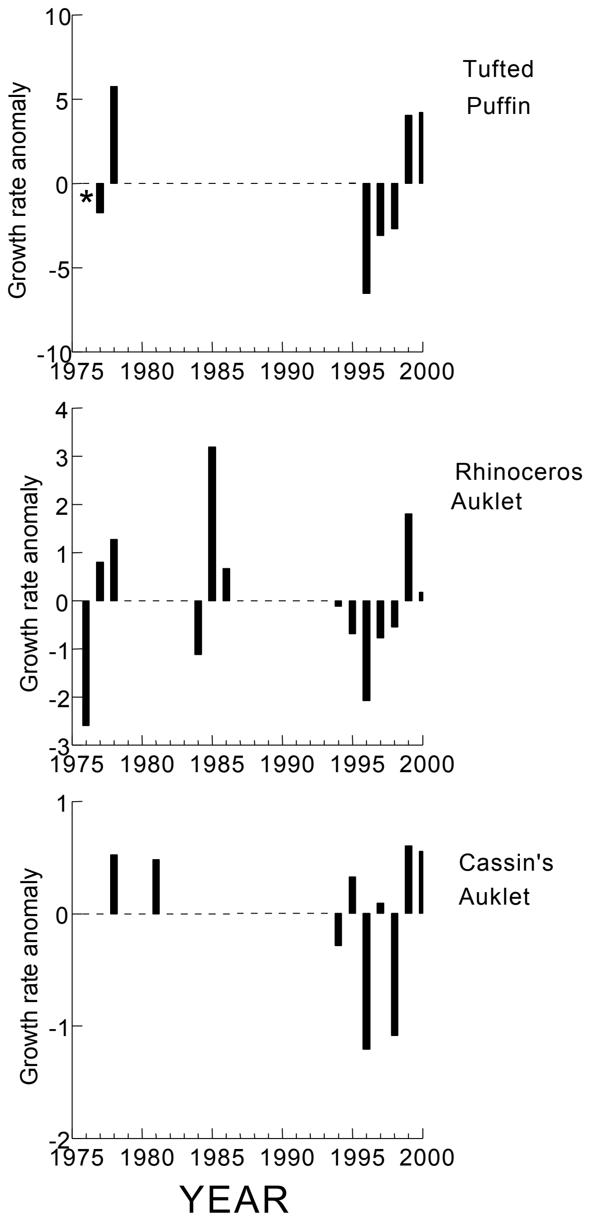


Fig. 4 Nestling growth rate anomalies (g/d) for Tufted Puffin, Rhinoceros Auklet and Cassin's Auklet on Triangle Island, B.C., Canada. Note that in 1976 breeding failure was observed for the Tufted Puffins because most eggs failed to hatch (marked by star).

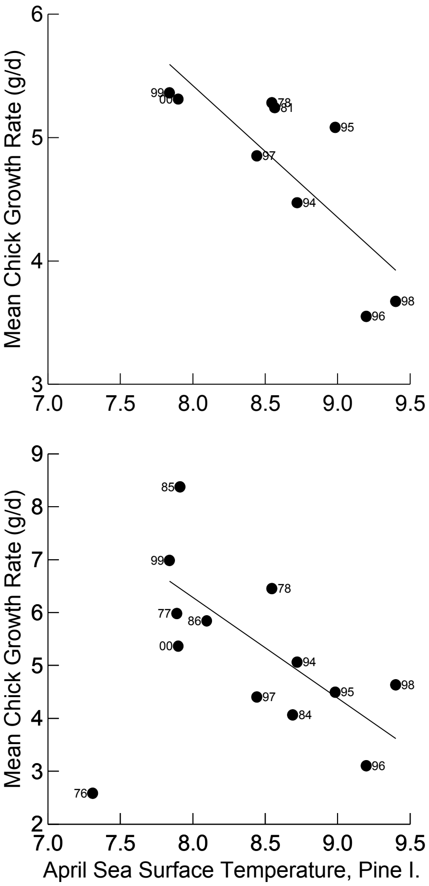


Fig. 5 Consequences of interannual variation in spring SST for Cassin's Auklet and Rhinoceros Auklet reproductive performance on Triangle Island, B.C., Canada. Growth rates of nestling Cassin's Auklet and Rhinoceros Auklets are generally lower when spring is early and sea surface temperatures are warm. Mortality from starvation is much more frequent when chick growth rates are low. The slopes of the lines are statistically significant for both the Cassin's Auklet ($y = 13.97 - 1.07x$; $F_{1,7} = 12.5$; $P = 0.009$) and the Rhinoceros Auklet (excluding 1976, $y = 21.53 - 1.91x$; $F_{1,10} = 11.2$; $P = 0.007$). Shown are mean annual population estimates of nestling growth rate in relation to the average SST in April at Pine Island light station.

2000 was significantly earlier than during the 1970s and 1980s (Fig. 3). For the planktivorous Cassin's Auklet, timing of breeding in the 1990s encompassed the entire range of values previously observed (Fig. 3). Nestling growth rates for Cassin's Auklet, Rhinoceros Auklet and Tufted Puffin tended to show poorer performance in the 1990s than in previous decades (Fig. 4). Between 1989 and 1999, the world's largest population of Cassin's Auklet on Triangle Island declined significantly (Bertram *et al.* 2000, CWS unpubl.). Note, too, that in the California Current ecosystem a 65% population decline of the planktivous Cassin's Auklet on the Farallon Islands from 1972-

1997 (Nur *et al*. 1998) has been linked (Ainley *et al*. 1996) to a significant long-term decline in zooplankton production in the California Current system (Roemmich and McGowan 1995).

For Cassin's Auklet and Rhinoceros Auklet, warm waters in spring are associated with poor nestling growth (Fig. 5). The poor performance of the Cassin's Auklet during warm spring years likely reflects a temporal mismatch between the timing of availability of their main prey (*Neocalanus cristatus*) and the timing of breeding (Bertram *et al*. 2001). In warm spring years (e.g., 1996 and 1998) the zooplankton peak is early and poor nestling growth and large scale nestling mortality are observed for Cassin's Auklet. The mechanism linking poor nestling growth and warm SST is less clear for the piscivorous Rhinoceros Auklet, but may be related to temperature dependent recruitment to fish prey populations such as Pacific sand lance (*Ammodytes hexapterus*).

The focus here has been on a colony-based example data but time-series data on birds at sea can also reveal significant patterns related to climate variability. For example, declines in populations of seabirds wintering in the California Current ecosystem have been associated with the large-scale decline of zooplankton in that ecosystem (Veit *et al*. 1996).

References

Ainley, D.G., Spear, L.B., and Allen, S.B. 1996. Variation in the diet of Cassin's Auklet reveals spatial, seasonal, and decadal occurrence patterns of euphausiids off California, USA. Mar. Ecol. Prog. Ser. 137: 1-10.

Bertram, D.F., Jones, I.L., Cooch, E., Knechtel, H., and Cooke, F. 2000. Survival rates of Cassin's and Rhinoceros Auklets at Triangle Island, British Columbia. Condor 102: 155-162.

Bertram, D.F., Mackas, D.L., and McKinnell, S.M. 2001. The seasonal cycle revisited: interannual variation and ecosystem consequences. Prog. Oceanogr. 49(1-4): 283-308.

Furness, R.W., and Tasker, M.L. 2000. Seabird-fishery interactions: quantifying the sensitivity of seabirds to reductions in sandeel abundance, an identification of key areas for sensitive species in the North Sea. Mar. Ecol. Prog. Ser. 202: 253-264.

Nur, N., Sydeman, W.J., Hester, M., and Pyle, P. 1998. Survival in Cassin's Auklets on Southeast Farallon Island: Temporal patterns, population viability, and the cost of double brooding. Pacific Seabirds 25: 38.

Rodway, M.S. 1991. Status and conservation of breeding seabirds in British Columbia. International Council for Bird Preservation Technical Publication No. 11, pp. 43-102.

Roemmich, D., and McGowan, J. 1995. Climate warming and the decline of zooplankton in the California Current. Science 267: 1324-1326.

Veit, R.R., Pyle, P., and McGowan, J.A. 1996. Ocean warming and long-term change in pelagic bird abundance within the California Current system. Mar. Ecol. Prog. Ser. 139: 11-18.

Assessment of feeding impact by higher trophic predators

Hidehiro Kato

Cetacean Population Biology Section, National Research Institute of Far Seas Fisheries, 5-7-1 Orido, Shimizu, Shizuoka, Japan. 424-8633 E-mail: katohide@enyo.affrc.go.jp

Okamura (2000) tried to develop an ECOPATH/ECOSIM model of the western North Pacific to elucidate the role of marine mammals and marine birds in the ecosystem. His attention was focused on two sub-regions: the Western Tropical Zone (WTZ) and the Kuroshio/Oyashio Region (KR/OY) in the PICES area in which food consumption by sea birds and marine mammals was assessed by PICES Working Group 11. These two sub-regions were selected based on data availability and academic interests of many Japanese fisheries scientists. In the case where toothed whales were removed from components in the western North Pacific model to give a high fishing rate, the biomasses of large squids and miscellaneous fishes in the ecosystem have increased two-fold at the end of the simulation but those of mesopelagics decreased by half. On the other hand, in the case where baleen whales, pinnipeds and sea birds were removed simultaneously from the ecosystem to give a high fishing rate, the remarkable change of biomass for various species was not observed. Furthermore, the author had made sensitivity test on the difference of the diet composition for respective whale groups. The change of the diet composition of the baleen whales had no big effect on the biomass trajectory, seemingly due to the small biomass of the baleen whales in this area. The change of the diet composition of the toothed whales had big visible effect on biomass change for every group in the ecosystem. These results suggest the importance of the toothed whales in the ecosystem. Okamura and his colleagues are now trying to construct the revised western North Pacific ECOPATH/ECOSIM model that incorporates more detailed information about biomass and diet composition for fishes.

Reference

Okamura, H. 2000. Consideration for modeling to incorporate prey consumption by marine birds and mammals (W6-183). Extended abstract for the PICES Ninth Annual Meeting.

Data summary: Impact of climate variability on observation and prediction of ecosystem and biodiversity changes in the North Pacific

Phillip R. Mundy[1], Cherri Womac[1] and Carrie Holba[2]

[1] Exxon Valdez Oil Spill Restoration Office, #401-645 G Street, Anchorage, AK 99501-3451, U.S.A. E-mail: phil_mundy@oilspill.state.ak.us; cherri_womac@oilspill.state.ak.us

[2] Alaska Resources Library and Information Service, Anchorage, AK 99501-3451, U.S.A. E-mail: carrie@arlis.org

The Exxon Valdez Trustee Council (EVOS) funds data collection, analysis and modeling by scientists at government, university and private institutions. The data for each project are submitted in the form of final reports, however, publication in peer-reviewed journals is strongly encouraged. Original data are held by the authors, and may be replicated in the final report. Formats are paper, MS-Word, Adobe Acrobat (pdf), and original software provided by authors.

Types of data

Observations and analyses from marine areas of the northern Gulf of Alaska include those of birds, fishes, shellfishes and mammals, physical, chemical, biological, geological and atmospheric data. The following parameters are considered: abundances, age structure, distributions, physiology, growth, survival, energetics, trophic level, contaminant burdens, multiple life cycle stages, macro- and micro-invertebrates and vertebrates and marine plants, air and water temperature, salinity, currents, wind, and bathymetry.

Prominent higher trophic level species are: pink salmon (embryos, adults), mussels, clams, sea otters, harbor seals, kittiwakes, murres, pigeon guillemot, and harlequin duck.

Time-series

Data collected by EVOS do not presently exceed 11 years (1989–present), however, for some oceanographic and biological variables, analyses include comparisons of EVOS data to historical data sets. Since observations are available on hundreds of species and several types of physical phenomena for varying lengths of time, locating time-series of interest requires the following:

1. Searching the file “EVOS Final Report List & Abstracts.doc” by keywords for the project title and number of interest;

2. Locating the "Project data field" following the abstract for projects of interest;
3. Locating data by consulting the Adobe Acrobat version of the Final Report at "http://dtlcrepository.downtownlegal.com/ARLIS/PDF/" or from the peer-reviewed publication to be found by searching the bibliography "EVOS TC Supported publications 020901.pdx";
4. Data not available from the Final Report or journal may be obtained from the author and agency, or often from the U.S. National Technical Information Service (NTIS), as indicated in the file "EVOS Final Report List & Abstracts.doc".

Models

1. Numerical simulation of the seasonal ocean circulation patterns and thermohaline structure of Prince William Sound based on the Princeton 3-D ocean circulation model (Wang and Mooers 1996; Wang *et al*. 1999).
2. A mass-balanced ECOPATH model of trophic flows in Prince William Sound: decompartmentalizing ecosystem knowledge (Okey and Pauly 1999).
3. Plankton dynamics: observed and modeled responses to physical factors in Prince William Sound, Alaska (Eslinger *et al*. in press).
4. Herring over-wintering survival model in Prince William Sound (Brown *et al*. unpubl.).

Metadata

1. EVOS GEM GOA database: descriptions and geographic coordinates of 280 active and historic data gathering projects in the Gulf of Alaska and adjacent waters by all U.S. and some Canadian entities. Satellite observing programs are included. Format: Summaries Excel and FileMaker Pro.
2. GIS: geographic locations with abstract of project's metadata for those with multiple sampling sites. Format: ArcView shape files.

Electronic bibliographies

1. TC Bibliography (file name: EVOS TC Supported publications 020901.pdx): work supported by EVOS includes 404 peer-reviewed journal citations, theses and dissertations, some with abstracts for marine biology, geophysics and numerical and statistical models. Search engine is provided. Format: ProCite (*.pdx).
2. GEM Cites Bibliography (file name: EVOS Gemcites 030101.pdx): 1,011 peer reviewed works and authoritative agency data reports cited in the GEM synthesis document or current synthesis articles on marine biology, geophysics, astrophysics, and numerical and statistical models. Search engine is provided. Format: ProCite (*.pdx).
3. EVOS Final Report List & Abstracts.doc – starts with a list of all Final Reports by number, author, title, agency and NTIS number if applicable. Searchable by key words or phrases. Format: MS-Word 2000 (*.doc).
4. EVOS Final Reports reviewed and accepted as of September 30, 2000, are available electronically in Adobe Acrobat (*.pdf) on two CD's and on web at "http://dtlcrepository.downtownlegal.com/ARLIS/PDF/".

Yellowfin, bigeye, skipjack, bluefin, and albacore tunas in the Eastern Pacific Ocean

Robert Olson
Inter-American Tropical Tuna Commission, 8604 La Jolla Shores Drive, La Jolla, CA 92037, U.S.A.
E-mail: rolson@iattc.ucsd.edu

The time-series described are for the eastern Pacific Ocean (EPO), currently defined as the area bounded by the coastline of North, Central, and South America, 40ºN, 150ºW, and 40ºS. The

IATTC (Inter-American Tropical Tuna Commission) staff maintains records for most of the vessels which fish at the surface for yellowfin tuna (*Thunnus albacares*), skipjack tuna (*Katsuwonus pelamis*), bigeye tuna (*Thunnus obesus*), or Pacific bluefin tuna (*T. orientalis*) in the EPO. Records are not maintained for sport-fishing vessels and small craft, such as canoes and launches.

The IATTC maintains field offices in Manta and Playas, Ecuador; Ensenada and Mazatlán, Mexico; Panama, Republic of Panama; Mayaguez, Puerto Rico; U.S.A.; and Cumaná, Venezuela. The scientists and technicians stationed at these offices collect landings data, abstract the logbooks of tuna vessels to obtain catch and effort data, measure fish and collect other biological data. Most of the data analyses are conducted by the permanent, internationally-recruited research and support staff at the IATTC's headquarters in La Jolla, California, U.S.A. The time-series presented in this report are summarized in Table 1.

Table 1 Data time-series summarized in this report. PS = purse seine, LL = longline, BB = baitboat.

Time Series	Figure number	Beginning year	Gear	EPO Sampling Locations	Estimate interval	Type of analysis
Yellowfin recruitment	Figure 7	1975[1]	PS-3 set types LL, BB	Figure 6 (1984-1998)	Quarterly	Length-based Age-structured Pop. yn. Model (A-SCALA)
Yellowfin biomass	Figure 8	1975[1]	PS-3 set types LL, BB	Figure 6 (1984-1998)	Quarterly	Length-based Age-structured Pop. Dyn. Model (A-SCALA)
Yellowfin average weight	Figures 9 & 10	1975[1]	PS-3 set types LL, BB	Figure 6 (1984-1998)	Quarterly	Length-based Age-structured Pop. Dyn. Model (A-SCALA)
Bigeye recruitment	Figure 12	1975[1]	PS-3 set types LL, BB	Figure 11 (1994-1998)	Quarterly	Length-based Age-structured Pop. Dyn. Model (A-SCALA)
Bigeye biomass	Figure 13	1975[1]	PS-3 set types LL, BB	Figure 11 (1994-1998)	Quarterly	Length-based Age-structured Pop. Dyn. Model (A-SCALA)
Bigeye average weight	Figure 14	1975[1]	PS-3 set types LL, BB	Figure 11 (1994-1998)	Quarterly	Length-based Age-structured Pop. Dyn. Model (A-SCALA)
Skipjack[2]	–	–	PS-2 set types BB	Figure 15 (1984-1998)	–	–
Bluefin CPUEs	Figures 18 & 19	1960	EPO: PS WPO: trolling, PS, traps, gillnets, LL	Figure 16 (1970-1989) Figure 17 (1972-1976)	Yearly	Habitat index, Regression Trees
Albacore[3]	–	–	LL, trolling, BB	Figures 19, 20 (1999; 1952-1976)	–	–

[1] Prior to 1975 the purse-seine fishery had not yet expanded its operations offshore.

[2] The IATTC is working during 2001 on improved analyses of skipjack tuna using the same length-based age-structured model approach used for yellowfin and bigeye tunas in the EPO. Therefore, time-series estimates of recruitment, biomass, and average weights are not presented in this report.

[3] Time-series of recruitment, biomass, and average weights are not available for albacore in the North Pacific Ocean.

Yellowfin tuna

The average annual distributions of the logged catches of yellowfin tuna by purse seiners in the EPO during 1984-1998 are shown in Figure 6. Most of these catches are from tropical and subtropical regions of the EPO. The annual distributions of catches have changed over the historical evolution of the fishery and are described by Bayliff (2001a). Prior to the mid-1950s, the eastern Pacific fishery for yellowfin took place mostly within 250 miles of the mainland, principally by baitboats. In the early 1960s, purse-seining became the predominant fishing method. During the mid-1960s the purse-seine fishery began to expand its operations further offshore, and by the mid-1970s vessels were fishing as far west as 150ºW. During 1975 through 1998, the majority of yellowfin catch was taken by purse-seine sets on yellowfin associated with dolphins and by purse-seine sets on yellowfin in unassociated schools (Maunder and Watters 2001).

The most recent stock assessment of yellowfin tuna in the EPO is presented by Maunder and Watters (2001). An age-structured population dynamics model and information contained in catch, effort, and size-composition data are used to assess the status of the yellowfin tuna stock in the EPO. The stock assessment model, termed an age-structured statistical catch-at-length analysis (A-SCALA), is based on the method described by Fournier *et al.* (1998). The assessment model uses quarterly time steps to describe the population dynamics. The A-SCALA method recognizes that there is temporal variation in recruitment, that the environment may influence both recruitment and the efficiencies of different fishing gears, and that different fishing methods usually catch fish of different ages. The model is described in detail by Maunder and Watters (2000).

It is assumed that yellowfin tuna can be recruited to the fishable population during every quarter of the year. The most-recent stock assessment of yellowfin makes no strong assumptions about the relationship between adult biomass (or abundance) and recruitment. The estimated time series of yellowfin recruitment is shown in Figure 7 (Maunder and Watters 2001). The estimates are scaled so that the average recruitment is equal to 1.0, which is 39,257,074 fish per quarter. The recruitment of yellowfin tuna to the fisheries in the EPO is variable, and appears to be related to sea-surface temperatures (SSTs). The levels of recruitment to the fishery, at the age of 6 months,

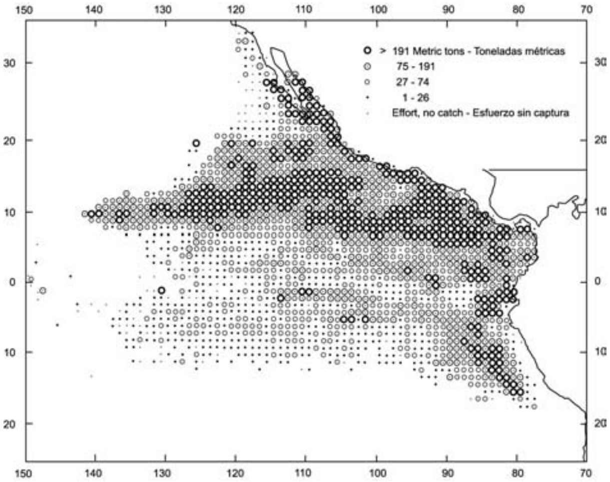


Fig. 6 Average annual catches of yellowfin tuna in the EPO during 1984-1998 for all purse-seine trips for which usable logbook data were obtained (from Bayliff 2001a).

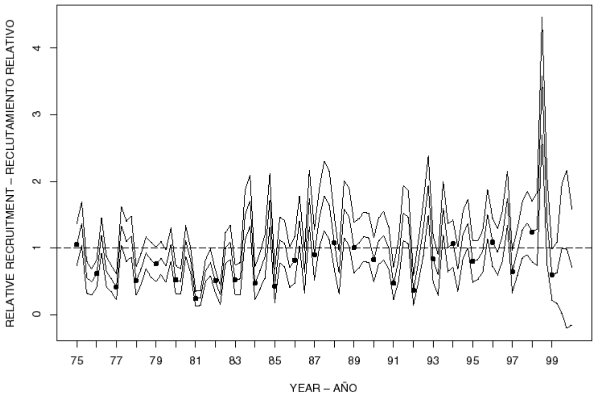


Fig. 7 Estimated recruitment of yellowfin tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the thin lines indicate the approximate 95-percent confidence intervals around those estimates. The labels on the time axis are drawn at the start of each year, but, since the assessment model represents time on a quarterly basis, there are four estimates of recruitment for each year (from Maunder and Watters 2001).

are positively correlated with the SST anomalies at the time of spawning 6 months earlier. However, SST does not explain all the variation in recruitment, and it is possible that other oceanographic variables influence the recruitment. The IATTC staff intends to consider other environmental indices as candidates for explaining the variation in recruitment.

One hypothesis is that the yellowfin population has experienced two different recruitment regimes (1975-1984 and 1985-1999), the second being higher than the first. These two regimes in recruitment are also correlated with regimes in the SSTs. This change in recruitment levels produces a similar change in biomass (Fig. 8). The analysis indicates that a very strong cohort entered the fishery in 1998 and that this cohort increased the spawning biomass ratio (the ratio of spawning biomass during a period of harvest to the spawning biomass which might accumulate in the absence of fishing, SBR) and catches during 1999. There is also an indication that most recent recruitments are low, which may lead to lower SBRs and catches. The lower SSTs may also indicate that the most recent recruitments will prove to be lower. However, these estimates of low recruitment are based on limited information, and are therefore very uncertain.

The trends in the biomass of yellowfin (fish that are at least one and a half years old) in the EPO are shown in Figure 8 (Maunder and Watters 2001). During 1975-1983 the biomass of yellowfin decreased from about 315,500 to 151,000 mt, caused by high levels of catch and less-than-average recruitment (assuming an overall average and not two regimes). It then increased rapidly during 1983-1985, and reached about 351,000 mt in 1985. This increase in biomass was caused by an increase in average recruitment (Fig. 7) and an increase in the average size of the fish caught. Since 1985 the biomass has been relatively constant. Increased fishing pressure prevented the biomass from increasing further during the 1986-1990 period.

The spawning biomass is defined as the total weight of mature female yellowfin. The estimated trend in spawning biomass is shown in Figure 8. The spawning biomass has generally followed a trend similar to that for biomass, described in the previous paragraph.

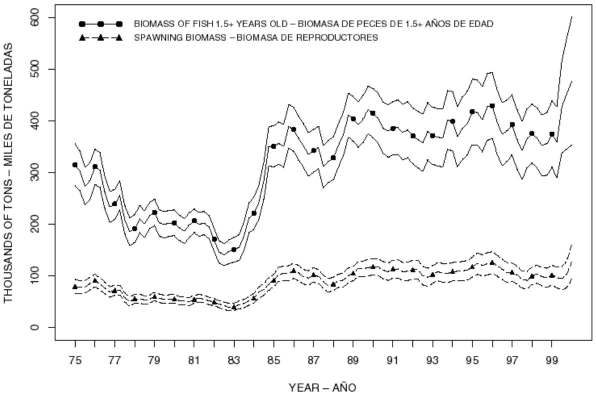


Fig. 8 Estimated biomass and spawning biomass of yellowfin tuna in the EPO. The bold lines illustrate the maximum likelihood estimates of the biomass, and the thin lines the approximate 95-percent confidence intervals around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year (from Maunder and Watters 2001).

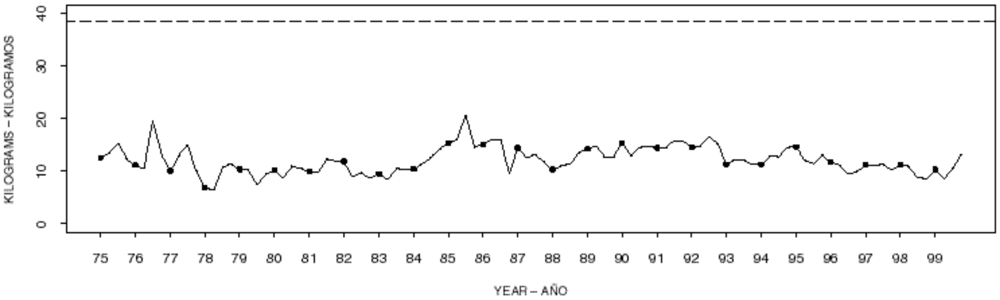


Fig. 9 Estimates of overall average weights of yellowfin tuna in the EPO. The critical weight is drawn as the horizontal dashed line (from Maunder and Watters 2001).

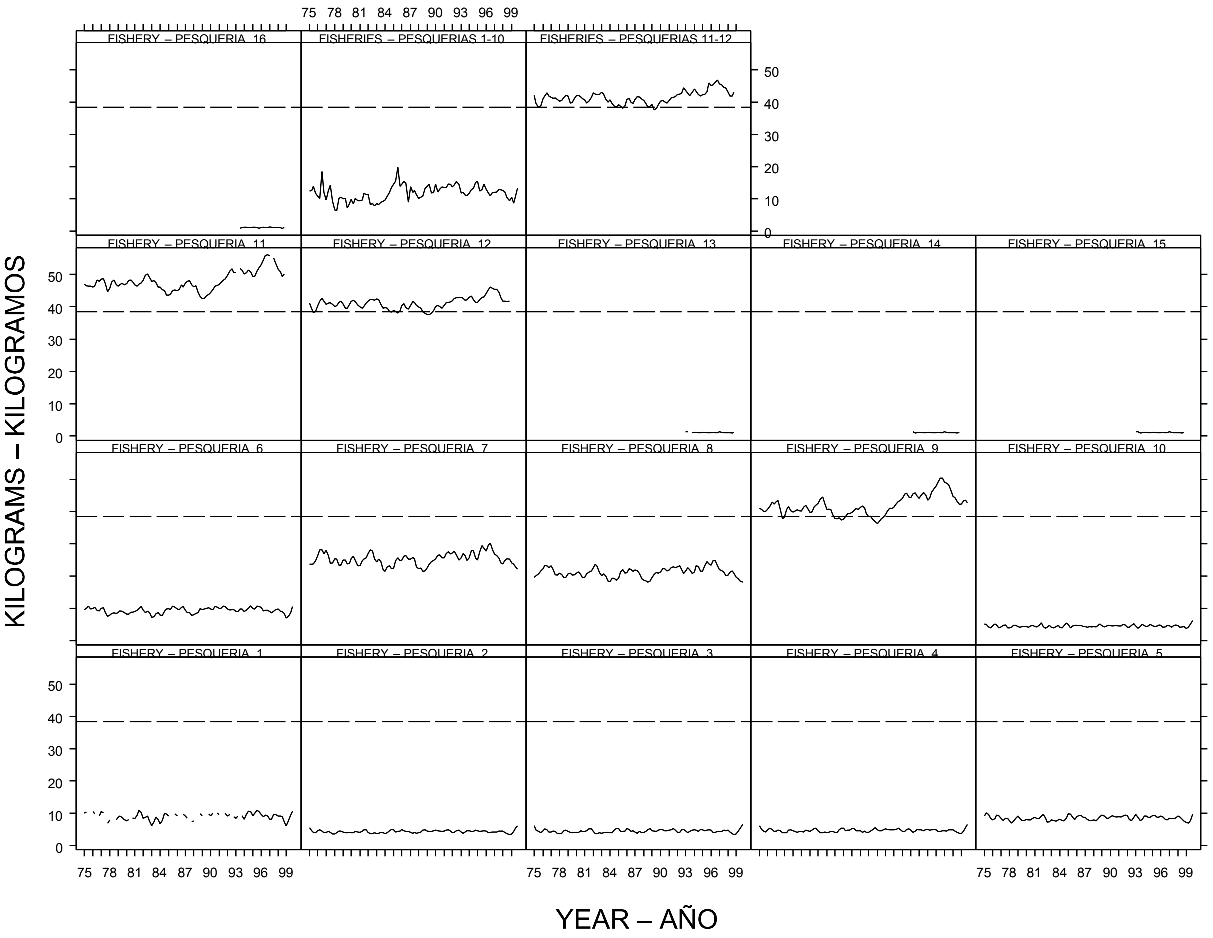


Fig. 10 Estimated average weights of yellowfin tuna caught by the fisheries of the EPO. The time-series for "Fisheries 1-10" is an average of Fisheries 1 through 10, and the time-series for "Fisheries 8-9" is an average of Fisheries 8 and 9. The dashed line identifies the critical weight (from Maunder and Watters 2001).

The overall average weights of the yellowfin tuna caught in the EPO predicted by Maunder and Watters (2001) have been consistently around 10 kg for most of the period from 1975 to 1999 (Fig. 9), but have differed considerably among fisheries (Fig. 10). Sixteen fisheries were defined for the stock assessment of yellowfin tuna. These fisheries were defined on the basis of gear type (purse seine, baitboat, and longline), purse-seine set type (sets on floating objects, unassociated schools, and dolphins), and IATTC length-frequency sampling area or latitude. The average weight of yellowfin caught by the different gears varies widely, but remains fairly consistent over time within each fishery (Fig. 10). The lowest average weights (about 1 kg) are produced by the discard fisheries (Fisheries 13-16), followed by the baitboat fishery (Fishery 10; about 4-5 kg), the floating-object fisheries (about 4-5 kg for Fisheries 2-4 and 10 kg for Fishery 1), the unassociated fisheries (Fisheries 5 and 6; about 8-10 kg), the northern and coastal dolphin-associated fisheries (Fisheries 7 and 8; about 20-30 kg), and the southern dolphin-associated fishery and the longline fisheries (Fisheries 9, 11, and 12; each about 40-50 kg).

Bigeye tuna

The average annual distributions of the logged catches of bigeye tuna by purse seiners in the EPO during 1994-1998 are shown in Figure 11. Most of these catches are from tropical and subtropical regions of the EPO, and there are substantial catches from south of the equator.

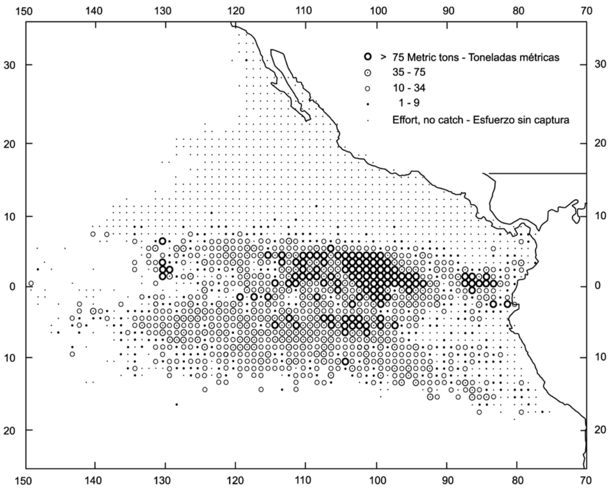


Fig. 11 Average annual catches of bigeye tuna in the EPO during 1994-1998 for all purse-seine trips for which usable logbook data were obtained (from Bayliff 2001a).

The most recent stock assessment of bigeye tuna in the EPO is presented by Maunder and Watters (2001). There have been important changes in the amount of fishing mortality exerted by the fisheries that catch bigeye tuna in the EPO. On average, the fishing mortality on bigeye less than about 14 quarters old was negligible until about 1994. Since 1993, the expansion of fisheries that catch bigeye in association with floating objects and the widespread use of fish-aggregating devices (FADs) has, on average, caused the fishing mortality on these young fish to increase. Purse-seine sets on floating objects select mostly young bigeye that are about 5 to 16 quarters old. It is assumed that bigeye from about 2 to 5 quarters old are discarded while the catch taken around floating objects is sorted on board the vessels. Purse-seine sets on unassociated schools of tuna select bigeye that span a wide range of ages, and since 1990, fish that were about 7 to 20 quarters old were most selected by this mode of fishing. In the area north of 15°N, the longline fleet selects bigeye that are about 10 to 26 quarters old; south of this parallel, bigeye become relatively vulnerable to longline fishing after they are about 17 quarters old. The southern longline fishery typically selects bigeye that are older than those selected by any of the other fisheries operating in the EPO. The catchability of bigeye by purse-seine vessels has changed over time, and these changes have been caused mostly by random events that affect the relationship between fishing effort and fishing mortality.

An age-structured population dynamics model and information contained in catch, effort, and size-composition data are used to assess the status of the bigeye tuna stock in the EPO (Watters and Maunder 2001). The stock assessment model, termed A-SCALA, is described briefly in the section on yellowfin tuna (above) and in detail by Maunder and Watters (2000).

It is assumed that bigeye tuna can be recruited to the fishable population during every quarter of the year. The most-recent stock assessment of bigeye makes no assumptions about the relationship between adult biomass (or abundance) and recruitment. The estimated time-series of bigeye recruitment is shown in Figure 12 (Watters and Maunder 2001). The estimates are scaled so that the average recruitment is equal to 1.0, which is 6,605,204 fish. Recruitment of bigeye tuna to the fisheries in the EPO is variable, and the mechanisms that explain variation in recruitment cannot currently be identified. The abundance of bigeye recruited to the fisheries in the EPO appears to be unrelated to SST anomalies at the time when these fish were assumed to have hatched. It is, however, possible that other oceanographic variables influence the recruitment, and the IATTC staff intends to consider other environmental indices as candidates for explaining the variation in recruitment. This will include offsetting the environmental index by one quarter (rather than two), to see whether recruitment is related to the environmental conditions during the early-juvenile phase (rather than the larval phase). Over the range of spawning biomasses estimated by the A-SCALA method, the abundance of bigeye recruited to the fishery also appears to be unrelated to the biomass of adult females present at the time of hatching.

Extremely large numbers of bigeye tuna are estimated to have been recruited to the fisheries in the EPO during 1997 and the first quarter of 1998. These recruitments were about 1.7 to 3.5 times the estimated level of average recruitment. Recruitment was estimated to be above average during most of 1995-1997, but below average during most of 1983-1991 and since the second quarter of 1998.

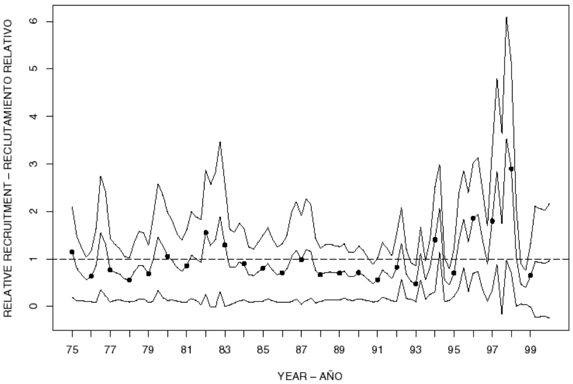


Fig. 12 Estimated recruitment of bigeye tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the thin lines indicate the approximate 95-percent confidence intervals around those estimates. The labels on the time axis are drawn at the start of each year, but, since the assessment model represents time on a quarterly basis, there are four estimates of recruitment for each year (from Watters and Maunder 2001).

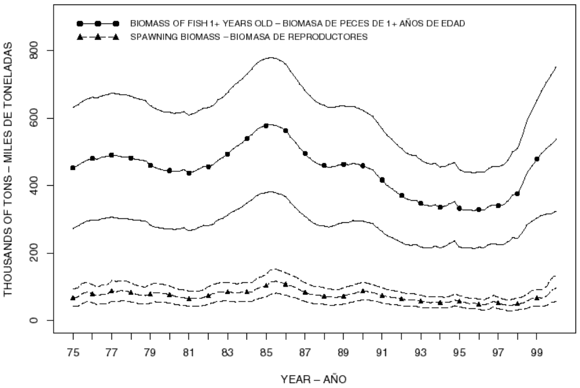


Fig. 13 Estimated biomass and spawning biomass (females that are at least 3 years old) of bigeye tuna in the EPO. The bold lines illustrate the maximum likelihood estimates of the biomass, and the thin lines the approximate 95 percent-confidence intervals around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year (from Watters and Maunder 2001).

Trends in the biomass of bigeye tuna in the EPO are shown in Figure 13 (Watters and Maunder 2001). During 1975-1980, the biomass of bigeye that were 1+ year-old is estimated to have been relatively stable, at a level of about 468,000 mt. The biomass of this age group increased steadily during 1981-1984, and reached a historic high of about 581,000 mt during the second quarter of 1985. It then decreased, and reached a historic low of about 326,000 mt during the fourth quarter of 1995. Following this, the assessment model indicates a steady increase in the biomass of 1+ year-olds, to a level of about 538,000 mt by the beginning of 2000.

The estimated trend in spawning biomass is shown in Figure 13. The spawners are assumed to be females that are at least 3 years old. The spawning biomass has generally followed a trend similar to that for the biomass of 1+ year-olds, but there are slight differences in the timing of the highest and lowest estimates of spawning biomass because the spawners are relatively old.

Given the amount of uncertainty in both the estimates of biomass and the estimates of recruitment, it is difficult to determine whether, in the EPO, trends in the biomass of bigeye have been influenced more by variation in fishing mortality or by variation in recruitment. Nevertheless, the simulation exercises by Watters and Maunder (2001) make it apparent that fishing has reduced the total biomass of bigeye present in the EPO.

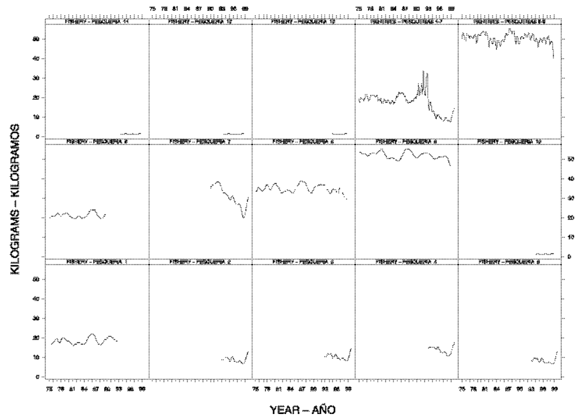


Fig. 14 Estimated average weights of bigeye tuna caught by the fisheries of the EPO. The time-series for "Fisheries 1-7" is an average of Fisheries 1 through 7, and the time-series for "Fisheries 8-9" is an average of Fisheries 8 and 9 (from Watters and Maunder 2001).

There have been important changes in the overall average weights of bigeye tuna caught by the surface fleet in the EPO predicted by Watters and Maunder (2001), due to changes in fishing mortality by different gears and purse-seine set types. These changes are illustrated in Figure 14. Thirteen fisheries were defined for the stock assessment of bigeye tuna. These fisheries were defined on the basis of gear type (purse seine, baitboat, and longline), purse-seine set type (sets on floating objects, unassociated schools, and dolphins), time period, and IATTC length-frequency sampling area or latitude. Prior to 1993, the average weight of bigeye caught in association with floating objects was about 18 kg (Fig. 14, Fishery 1). During 1993-1998, the average weight of bigeye caught in purse-seine sets on floating objects declined, but larger fish were caught by these fisheries during 1999 (Fig. 14, Fisheries 2-5). Prior to 1990, the average weight of bigeye caught in unassociated schools was stable at about 21 kg (Fig. 14, Fishery 6), but, since 1990, the average weight of bigeye in the catch taken in unassociated schools has varied between about 20 and 35 kg, with an average of about 31 kg (Fig. 14, Fishery 7). The average weight of bigeye caught in unassociated schools increased during 1999. The average weight of bigeye caught by the combined surface fleet, not including the discard fisheries, during 1975-1999 was about 18 kg (Fig. 14, Fisheries 1-7). The assessment model currently treats the increase in average weight of bigeye caught by the surface fleet during 1999 as evidence of low recruitment from the latter half of 1998 through 1999 (Fig. 12), but it is also possible that the surface fleet has become capable of catching greater proportions of larger bigeye. The average weights of bigeye tuna taken by longliners operating in the EPO have remained relatively stable at around 50 kg (Fig. 14, Fisheries 8 and 9).

Skipjack tuna

The status of skipjack tuna in the EPO is summarized by Anonymous (2001b). Skipjack are fished in the EPO by purse seiners (in schools associated with floating objects and in unassociated schools) and by baitboats. The average annual distributions of the logged catches of skipjack tuna by purse seiners in the EPO during 1984-1998 are shown in Figure 15. Most of the catches are made between northern Baja California and southern Peru, but the catches are relatively low off southern Mexico. The fishery extends westward to about 140°W in equatorial waters. Skipjack tagged in the EPO have been recaptured in the central and western Pacific Ocean, but no skipjack tagged in the central or western Pacific Ocean have been recaptured in the EPO.

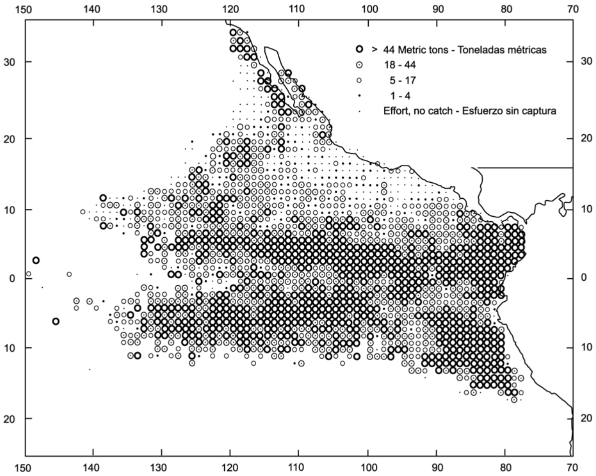


Fig. 15 Average annual catches of skipjack tuna in the EPO during 1984-1998 for all purse-seine trips for which usable logbook data were obtained (from Bayliff 2001a).

The catches per unit of effort of skipjack by commercial fishing gear in the EPO are positively correlated with the sea-surface temperatures in the central Pacific 18 months previously (Anonymous 2001b). The catches of skipjack by surface gear tend to be reduced during El Niño episodes, however, and it is hypothesized that during such times the depth of the thermocline increases, so that the fish spend less time at the surface than during anti-El Niño years.

There are two principal hypotheses for the stock structure of skipjack in the Pacific Ocean (Anonymous 2001b). The separate-subpopulation hypothesis states that there are two or more genetically-distinct subpopulations of skipjack in the Pacific Ocean, and the clinal hypothesis states that separate subpopulations of skipjack do not exist in the Pacific Ocean, but that there is isolation by distance, i.e. the probability of any two fish interbreeding is an inverse function of their distance from one another. The available data do not favor either the separate-subpopulation or the clinal hypothesis. It is reasonably certain that skipjack are underfished in the EPO (Anonymous 2001b). This situation could change, however, so it is important to learn more about this species and its relationships with the environment.

Time series of skipjack recruitment, biomass, and average weights are not presented here because the IATTC is working during 2001 on improved analyses of skipjack tuna data using the same length-based, age-structured model approach used for yellowfin and bigeye tunas in the EPO. Indices of abundance, however, are presented in Anonymous (2000a: Figure 51).

Pacific bluefin tuna

The status of Pacific bluefin tuna in the Pacific Ocean is summarized by Bayliff (2001b). Most of the catches of bluefin in the EPO are taken by purse seiners. The annual distributions of purse-seine catches of bluefin in the EPO during 1970-1989 are shown in Figure 16 (from Bayliff 1994). Nearly all of the purse-seine catch is made west of Baja California and California, within about 100 nautical miles of the coast, between about 23°N and 33°N. Lesser amounts of bluefin are caught by recreational, gillnet, and longline gear. Bluefin have been caught during every month of the year, but most of the fish are taken from May to October.

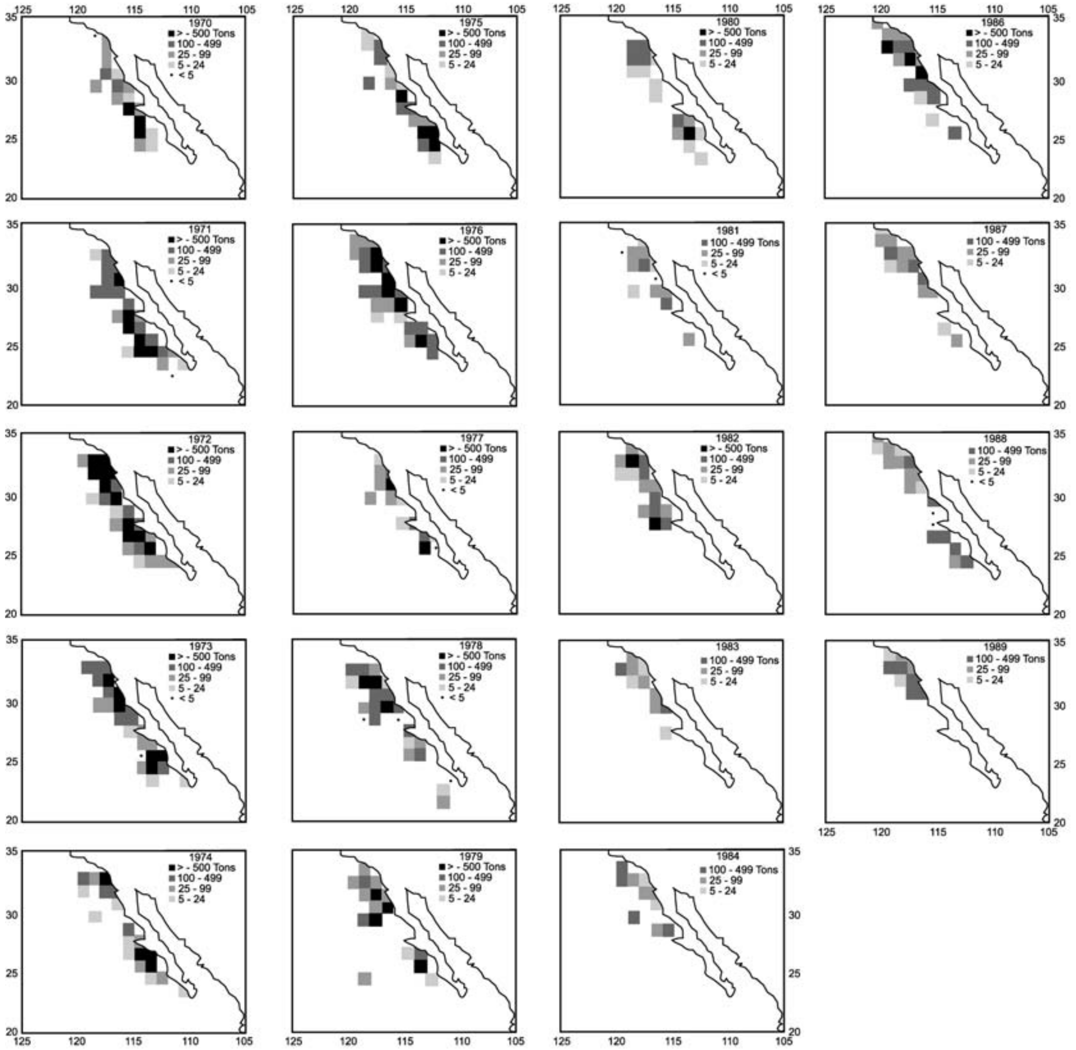


Fig. 16 Annual distributions of Pacific bluefin tuna catches in the eastern Pacific Ocean, 1970-1989 (from Bayliff 1994).

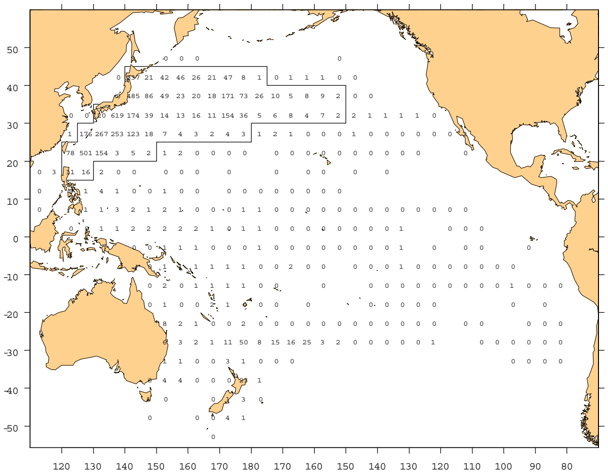


Fig. 17 5° latitude by 5° longitude quadrangles in which PBT were captured by the Japanese longline fleet during January 1952 – December 1997 (from Watters 1999). The numbers indicate the total number of PBT (100s) removed from each quadrangle during this period (zeros indicate catches of less than 51 fish). The quadrangles inside the polygon extending from Japan to 150°W constitute the core area defined by Tomlinson (1996).

Bluefin are exploited by various gears in the western Pacific Ocean (WPO) from Taiwan to Hokkaido (Bayliff 2001b). Age-0 fish about 15 to 30 cm in length are caught by trolling during July-October south of Shikoku Island and south of Shizuoka Prefecture. During November-April age-0 fish about 35 to 60 cm in length are taken by trolling south and west of Kyushu Island. Age-1 and older fish are caught by purse seining, mostly during May-September between about 30-42°N and 140-152°E. Bluefin of various sizes are also caught by traps, gillnets, and other gear, especially in the Sea of Japan. Bluefin are also caught near the southeastern coast of Japan by longlining.

The high-seas longline fisheries are directed mainly at tropical tunas, albacore, and billfishes, but some Pacific bluefin are caught by these fisheries. Catch distributions of bluefin by Japanese longliners during 1952-1997 in the Pacific Ocean are shown in Figure 17 (from Watters 1999). Small amounts of Pacific bluefin are also caught by Japanese pole-and-line vessels on the high seas.

Bluefin are most often found in the EPO in waters where the sea-surface temperatures (SSTs) are between 17 and 23°C (Bayliff 2001b). Fish 15 to 31 cm in length are found in the WPO in waters where the SSTs are between 24 and 29°C. Conditions in the WPO probably influence the portions of the juvenile fish there that move to the EPO, and also the timing of these movements. Likewise, conditions in the EPO probably influence the timing of the return of the juvenile fish to the WPO.

Various indices of abundance of Pacific bluefin in the EPO have been calculated, but none of these is entirely satisfactory. The IATTC has calculated "habitat" indices for the EPO routinely for several years. Since Bell (1963) had demonstrated that bluefin are most often found in waters where the SSTs are between 17 and 23°C, Bayliff (1996) considered the 1-degree areas north of 23°N and west of California and Baja California in which the SSTs were in that range during May through October to be "bluefin habitat." He then divided the catches of bluefin in those 1-degree areas during each year by the corresponding numbers of unstandardized days of fishing effort to obtain CPUEs of bluefin (Fig. 18). Indices of abundance of bluefin for the WPO were prepared by Watters (1999) of the IATTC and by scientists from other nations. Watters' time-series of abundance indices for the "core area" (Fig. 17) in the WPO for the Japanese longline fishery are shown in Figure 19.

The National Research Institute of Far Seas Fisheries, Japan, has been tagging Pacific bluefin tuna with archival tags to study the relationships between their movements and the physical environment (Anonymous 1999, Anonymous 2000b). Tsuji *et al.* (1999) reported the first recapture of a Pacific bluefin tuna that made a trans-Pacific migration while carrying an archival tag.

There was general agreement at a working group meeting on bluefin in December 2000, to start the process of developing a Pacific-wide assessment of bluefin tuna using the same length-based age-structured model approach used for yellowfin and bigeye tunas in the EPO (Anonymous 2000b).

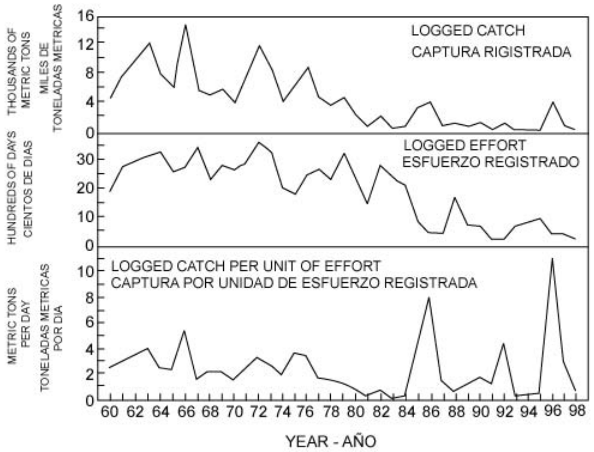


Fig. 18 Catch, effort, and catch-per-unit of effort data for the surface fishery for bluefin in the EPO, as determined by the habitat index method. The data for 1998 are preliminary (from Bayliff 2001b).

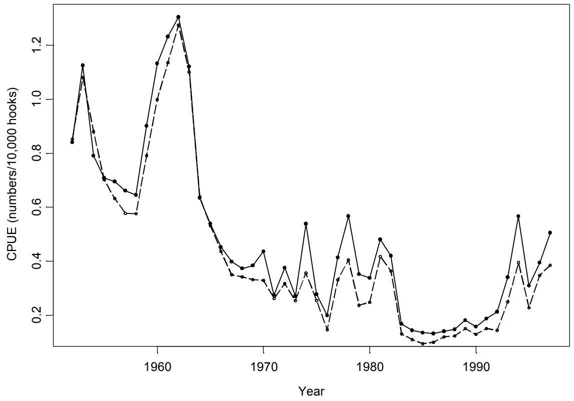


Fig. 19 Time-series of regional abundance indices for the entire PBT core area. The trend with a dashed line and open circles is the time series estimated from the safe abundance indices. The trend with a solid line and filled circles is the time series estimated from pooling the safe and the extrapolated abundance indices (see Watters 1999 for details).

Albacore tuna

The status of albacore tuna in the Pacific Ocean is summarized by Anonymous (2001a). There are two stocks of albacore in the Pacific Ocean, one occurring in the northern hemisphere and the other in the southern hemisphere. In the North Pacific, the adults live mostly in the Kuroshio Current, the North Pacific Transition Zone, and the California Current, but spawning occurs in tropical and subtropical waters.

Albacore are caught by longliners in most of the North Pacific, but not often between about 10°N and 5°S, by trollers in the eastern and central North Pacific, and by baitboats in the western North Pacific (Anonymous 2001a). Albacore are caught by fisheries from several nations, including Canada, Japan, Republic of Korea, Mexico, People's Republic of China, Taiwan, U.S.A, and others. During the 1980s and 1990s, the catches have ranged between about 45,000 and 75,000 metric tons in the North Pacific.

There appear to be two subgroups of albacore in the North Pacific Ocean. The fish of the northern subgroup occur mostly north of 40°N when they are in the eastern Pacific Ocean. There is considerable exchange of fish of this subgroup between the troll fishery of the eastern Pacific Ocean and the baitboat and longline fisheries of the western Pacific Ocean. The fish of the southern subgroup occur mostly south of 40°N in the eastern Pacific, and relatively few of them are caught in the western Pacific. Fish that were tagged in offshore waters of the eastern Pacific and recaptured in the coastal fishery of the eastern Pacific exhibited different movements, depending on the latitude of release. Most of the recaptures of those released north of 35°N were made north of 40°N, and most of the recaptures of those released south of 35°N were made south of 40°N.

Childers and Miller (2000) presented the distribution of catches per day's fishing for albacore caught by U.S. troll vessels in 1999 in the North Pacific (Fig. 20). Childers and Miller also presented maps of albacore catch distributions in relation to SSTs in the North Pacific. Anonymous (2001a) presented distributions of catches per hook of albacore by Japanese longliners averaged over 1952-1976 (Fig. 21).

Time-series of recruitment, biomass, and average weights have not been prepared by the IATTC for albacore in the North Pacific Ocean. A time-series of length-frequency histograms of albacore caught by U.S. troll vessels in the North Pacific are presented in a series of reports by Childers and Miller (the latest is Childers and Miller 2000).

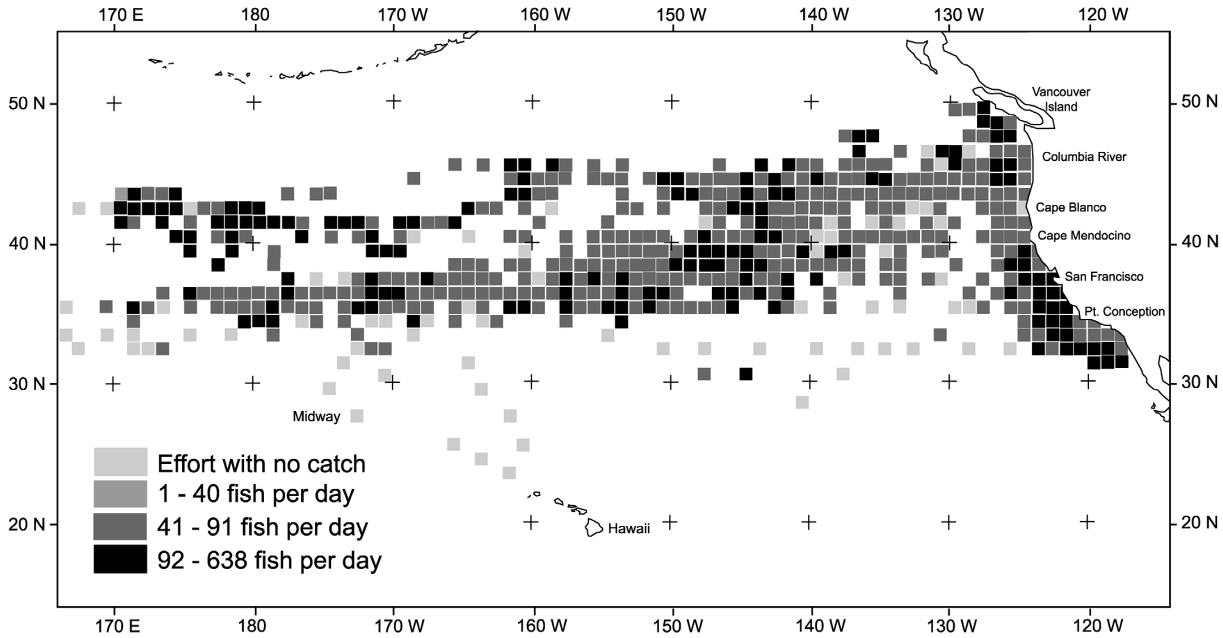


Fig. 20 Distribution of albacore CPUEs by U.S. troll vessels in the North Pacific Ocean during 1999 (from Childers and Miller 2000).

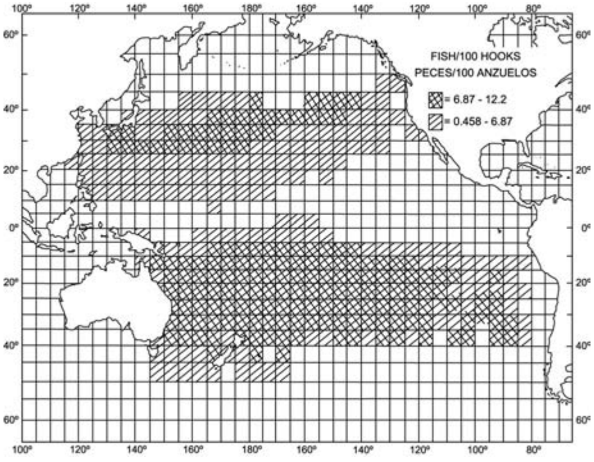


Fig. 21 Distribution of catches per hook of albacore by Japanese longliners averaged over the 1952-1976 period (from Anonymous 2001a).

Ecosystem model and climate forcing

The staff of the IATTC has been developing a modeling approach to evaluate the ecological implications of alternative fishing strategies in the pelagic tropical (EPO). Additional development and evaluation of the EPO ecosystem model was accomplished by a working group funded by the National Center for Ecological Analysis and Synthesis (NCEAS) in Santa Barbara, California. One of the products of the working group was an evaluation of the implications of climate forcing on ecosystem dynamics of the tropical EPO. One of the ways that the physical environment affects ecosystem dynamics is by inducing variation in primary production at the base of the food web. The tropical EPO is strongly influenced by El Niño and La Niña events. Over a large portion of the tropical EPO, the chlorophyll concentrations are reduced during El Niño and increased during La Niña. To simulate ENSO-scale variations in producer biomass in the ecosystem model, the working group constructed an empirical model that relates SST anomalies to surface chlorophyll concentrations. They used time-series of SST anomalies to specify trajectories of producer biomass, and simulated the ecosystem effects of ENSO-scale pulses and cycles and a time-series of producer biomass predicted from a greenhouse-warming scenario for the 21st century. A manuscript describing the analysis has been submitted to *Fisheries Oceanography*, and is in review at the present time. The abstract of the manuscript (Olson *et al*. submitted) follows:

Evaluating the top-down effects of fishing on marine ecosystem dynamics requires an

understanding of the role of bottom-up physical processes. We used a recently-developed ecosystem model for the pelagic eastern tropical Pacific Ocean (ETP) to explore how El-Niño-Southern-Oscillation (ENSO)-scale variability might affect the animals at middle and upper trophic levels. We forced the model with ENSO-scale variations in primary-producer biomass that were estimated from an empirical relationship between observed sea-surface temperature (SST) anomalies and surface chlorophyll concentrations. We used time series of SST anomalies to specify trajectories of producer biomass, and simulated the ecosystem effects of 1) single, positive (La Niña-like) and negative (El Niño-like) pulses in producer biomass, 2) regular warm-cold cycles in producer biomass, and 3) a time series of producer biomass predicted from a greenhouse-warming scenario for the 21st century. Pulses in producer biomass in the model ecosystem affected components at middle trophic levels (forage fishes and cephalopods) more than the apex predators. Bottom-up forces acted as a wave propagating through the ecosystem at various time lags. Regular warm-cold cycles with low periodicity had the greatest impact, increasing the relative biomasses and biomass variability of organisms at middle trophic levels and decreasing those of organisms at higher trophic levels. The biomasses of all ecosystem components decreased during the long-term trend of the greenhouse-warming scenario, and only components with relatively high production/biomass ratios were sensitive to the high-frequency ENSO signal. Comparing simulations with and without fishing mortality allowed us to identify which ecosystem components are primarily top-down controlled by fishing and which are primarily bottom-up controlled by resource dynamics.

References

Anonymous. 1999. Report of the Sixth Joint NRIFSF-IATTC Workshop on Pacific Bluefin Tuna. Dec 8-9, 1999. Shimizu, Japan.

Anonymous. 2000a. Annual Report of the Inter-American Tropical Tuna Commission, 1998. IATTC, La Jolla. 357p.

Anonymous. 2000b. Report of the Interim Scientific Committee Bluefin Tuna Working Group. Nov 30-Dec 1, 2000. Shimizu, Japan.

Anonymous. 2001a. Status of albacore tuna in the Pacific Ocean. IATTC, Stock Assessment Rep. 1: 255-283.

Anonymous. 2001b. Status of skipjack tuna in the eastern Pacific Ocean. IATTC, Stock Assessment Rep. 1: 87-108.

Bayliff, W.H. 1994. A review of the biology and fisheries for northern bluefin tuna, *Thunnus thynnus*, in the Pacific Ocean. FAO Fish. Tech. Pap. 336: 244-295.

Bayliff, W.H. 1996. Indices of abundance of northern bluefin tuna, *Thunnus thynnus*, in the eastern Pacific Ocean. FAO Fish. Tech. Pap. 365: 460-475.

Bayliff, W.H. 2001a. Organization, functions, and achievements of the Inter-American Tropical Tuna Commission. IATTC, Spec. Rep. 13: 1-122.

Bayliff, W.H. 2001b. Status of bluefin tuna in the Pacific Ocean. IATTC, Stock Assessment Rep. 1: 211-254.

Bell, R.R. 1963. Synopsis of biological data on California bluefin tuna *Thunnus saliens* Jordan and Evermann 1926. FAO Fish. Rep. 6: 380-421.

Childers, J., and Miller, F.R. 2000. Summary of the 1999 U.S. North and South Pacific albacore troll fisheries. NMFS-SWFSC Admin. ReportLJ-00-06. 42p.

Fournier, D.A., Hampton, J., and Sibert, J.R. 1998. MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga*. Can. J. Fish. Aquat. Sci. 55: 2105-2116.

Maunder, M., and Watters, G. 2000. A-SCALA: an age-structured statistical catch-at-length analysis for assessing tuna stocks in the eastern Pacific Ocean. Draft manuscript presented to the Scientific Working Group of the Inter-American Tropical Tuna Commission .

Maunder, M.N., and Watters, G.M. 2001. Status of yellowfin tuna in the eastern Pacific Ocean. IATTC, Stock Assessment Rep. 1: 5-86.

Olson, R. J., Watters, G.W., Francis, R.C., Fiedler, P.C., Polovina, J.J., Reilly, S.B., Aydin, K.Y., Boggs, C.H., Essington, T.E., Walters, C.J., and Kitchell, J.F. 2001. Climate forcing and ecosystem dynamics in the eastern tropical Pacific Ocean. Fish. Oceanogr.(submitted)

Tomlinson, P.K. 1996. Movement of large bluefin tuna, *Thunnus thynnus*, in the north Pacific Ocean, as determined from the Japanese longline fishery, and implications regarding interactions between the fisheries of the western and eastern Pacific Ocean. FAO Fish. Tech. Pap. 365: 425-459.

Tsuji, S., Itoh, T., Nitta, A., and Kume, S. 1999. The trans-Pacific migration of young bluefin tuna, *Thunnus thynnus*, recorded by an archival tag. Working document submitted to the Second Meeting of the Interim Scientific Committee for Tuna and Tuna-Like Species in the North Pacific. January 15-23, 1999. Honolulu, Hawaii.

Watters, G. 1999. CPUEs of Pacific bluefin tuna in a core fishing area extending from the coast of Japan to 150W: using regression trees to hypothesize about CPUEs for times and areas in which there was no fishing. Document 7. Sixth Joint NRIFSF-IATTC Workshop on Pacific Bluefin Tuna, December 8-9, 1999. Shimizu, Japan. 10p.

Watters, G.M., and Maunder, M.N. 2001. Status of bigeye tuna in the eastern Pacific Ocean. IATTC, Stock Assessment Rep. 1: 109-210.

Biological time-series for the central North Pacific

Jeffrey J. Polovina

Honolulu Laboratory, Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA, 2570 Dole Street, Honolulu, HI 96822-2396, U.S.A. E-mail: Jeffrey.Polovina@noaa.gov

The Northwestern Hawaiian Islands time-series

Since the early 1980s a number of the components of the Northwestern Hawaiian Islands (NWHI) ecosystem have been monitored annually. The following biological time-series are used as indicators of ecosystem dynamics: i) the reproductive success of red-footed booby and red-tailed tropic birds at French Frigate Shoals; ii) the composition of spiny and slipper lobster in the commercial landings at Maro Reef; and iii) the girth of weaned monk seal pups from 6 islands in the NWHI (Table 2).

The reproductive success of these two seabirds has been estimated by US Fish and Wildlife since 1980 as the ratio of number of chicks surviving to fledge to number of eggs laid (Fig. 22). Both seabirds feed on juvenile flying fish and squids around the NWHI, and variation in reproductive success is interpreted as a response to variation in prey availability.

Spiny (*Panulirus margintus*) and slipper lobsters (*Scallarides squamossus*) are both caught in the commercial trap fishery for lobster. While the two species appear to have a similar ecology, the spiny lobster has a 12-month pelagic larval period while the slipper lobster has a 3-month larval period. Fishery data has been collected with logbooks since 1983. Changes in their composition in the commercial catches reflect changes in relative abundance which may reflect changes in oceanographic process around the NWHI (Fig. 23).

Monk seal pup girth has been collected since the early 1980s at many of the islands in the NWHI. Pup girth measured within 2 weeks of weaning is thought to be an indicator of female foraging success during gestation which is transferred to the pup in the form of milk.

The Transition Zone time-series

The Transition Zone time-series are: i) the reproductive success of the black-footed albatross and the Laysan albatross; ii) the catch-per-unit of effort (CPUE) from the US troll fishery for albacore in the North Pacific; and iii) the winter position of the Transition Zone Chlorophyll Front (TZCF) (Table 2).

The reproductive success of the albatross have been estimated since 1980 by US Fish and Wildlife at French Frigate Shoals, as the ratio of chicks that fledge to number of eggs laid (Fig. 23).

Table 2 Biological indicators for the central North Pacific.

Northwestern Hawaiian Island

1. Reproductive success for red-footed booby and red-tailed tropicbird, 1980–present. Source: Hawaii and Pacific Island Refuge, USFWS (Fig. 22).
2. Research and commercial fishery lobster catches, 1983-present. Source: Honolulu Lab, NMFS.
3. Girth of weaned monk seal pups for 6 islands, 1983-present. Source: Honolulu Lab, NMFS.

Transition Zone

1. Reproductive success of black-footed and Laysan albatross, 1980-present. Source: Hawaii and Pacific Islands Refuge, USFWS (Fig. 22).
2. US North Pacific albacore troll fishery CPUE, 1960-present. Source: SWFSC, NMFS. (Fig. 23).
3. Winter position of the Transition Zone Chlorophyll Front, 1997-present. Source: Honolulu Lab, NMFS (Fig. 23).

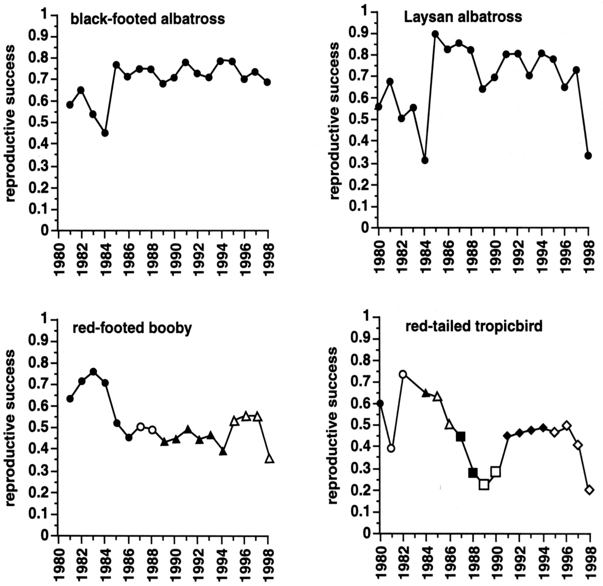


Fig. 22 Reproductive success of 4 species of seabirds nesting at French Frigate Shoal, Hawaiian Archipelago. Data from B. Flint, USFWS, Honolulu, HI.

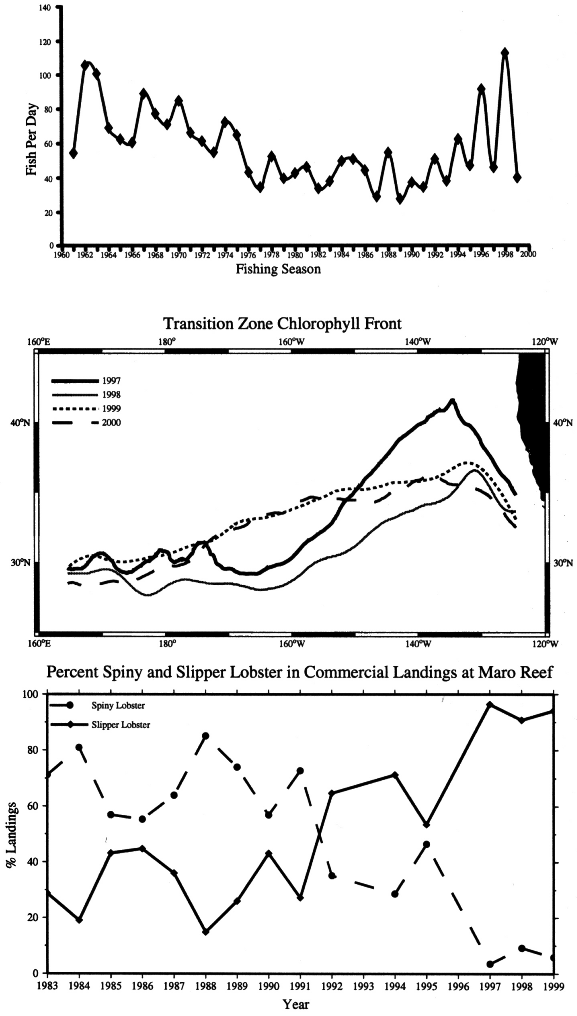


Fig. 23 Top: Catch-per-unit of effort in the US troll fishery for albacore; middle: winter position of the Transition Zone Chlorophyll Front; bottom: percentage of spiny and slipper lobster in commercial lobster fishery at Maro Reef, Hawaiian Archipelago. All data from Honolulu Laboratory, SWFSC, NMFS.

These birds forage north from Hawaii in the Transition Zone and perhaps beyond while rearing chicks. Variation in reproductive success is thought to reflect variation in prey availability.

Fishery data from the US troll fishery for albacore is available since 1961 (Fig. 23). The fishery begins in May in the Transition Zone near midway and follows albacore as they migrate eastward, reaching the coast of North America in the fall. An important part of the variation in troll CPUE is thought to reflect the abundance and availability of albacore in the Transition Zone and hence is likely to be a function of population size and frontal strength.

The position and shape of the TZCF in January and February is measured from satellite ocean color data as the boundary between the high surface chlorophyll water of the Transition Zone, and the low surface chlorophyll water of the subtropical gyre. The boundary is measured as the 0.2mg/cubic ml chlorophyll-*a* contour line estimated with OCTS data in 1997 and Seawifs data beginning in 1998 (Fig. 23).

Interpretation of variation in time-series

The NWHI time-series show changes occurring during the period 1985-1991. Reproductive success of red-footed booby and red-tail tropicbird dropped from about 80% to 40% in the mid-1980s. There was a change in the composition of lobster in the fishery from about 70% spiny and 30% slipper from 1983-1991, followed by a sharp reversal of the proportion of spiny and slipper lobsters in the landings since 1992. Monk seal pup girth dropped at many of the islands in the late 1980s or early 1990s. These trends have previously been interpreted as part of a regime shift in the mid- to late 1980s (Polovina *et al.* 1994, Hare and Mantua 2000). However it is interesting that monk seal pup girth has shown an increase in 1998 and 1999, but no coherent change has been observed in lobster or sea bird data.

In the Transition Zone time-series, the albatross showed an increase in the mid-1980s and a drop in the late 1990s. The albacore CPUE shows a declining trend from the early 1960s to the early 1990s, followed by some evidence of an increase in the later 1990s. The TZCF shows 1999 and 2000 to be different from 1997 and 1998. The increase in albatross reproductive success in the mid-1980s is coherent with the changed in the NWHI time-series. It has been proposed that the decline in albacore CPUE since the mid-1970s was a response to the 1977 regime shift (Al Coan, Richard Parrish, pers. comm.). The changes in the late 1990s in the albatross, albacore, and TZCF may be responses to the strong El Niño and La Niña events or the beginning of a new regime. The change in the TZCF appears to reflect a warming in the central North Pacific and a cooling in the eastern North Pacific in 1999 and 2000, compared to 1997 and 1998 (Polovina and Seki 2000).

References

Hare, S.R., and Mantua, N.J. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Prog. Oceanogr. 47: 103-145.

Polovina, J.J., and Seki, M.S. 2000. Sensors detect biological change in mid-latitude North Pacific. EOS. Oct. 31, pp. 519.

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

Recent progress in salmon migration research in Japan

Hiroshi Ueda[1], Masahide Kaeriyama[2] and Shigehiko Urawa[3]

[1] Field Science Center for Northern Biosphere, Hokkaido University, Kita 9 Nishi 9, Kita-ku, Sapporo 060-0809, Japan. E-mail: hueda@fsc.hokudai.ac.jp

[2] Department of Marine Sciences and Technology, Hokkaido Tokai University, Minamisawa, Minami-ku, Sapporo 005-8601, Japan. E-mail: salmon@dm.htokai.ac.jp

[3] National Salmon Resources Center, Fisheries Agency of Japan, 2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan. E-mail: urawa@salmon.affrc.go.jp

In Japan, almost all chum salmon (*0ncorhynchus keta*) are produced by artificial enhancement programs. The number of adult chum salmon returned to Japan from 1900 through 1970 averaged about 3 million individuals per year, ranging from 1 to 5 million individuals. Since the late 1970s, adult returns have exponentially increased to more than 50 million individuals through the late 1980s, and reached 88 million individuals (57 million individuals in Hokkaido and 31 million individuals in Honshu) in 1996 (Fig. 24). This population size accounted for 70-80% of all the chum salmon caught in the North Pacific Ocean. The number of juveniles released increased from 800 million individuals in the early 1970s to 2 billion individuals in 1982, and has been limited to about 2 billion individuals since the early 1980s (Fig. 24). The rapid increase in chum salmon abundance, however, may have led to population density-dependent effects such as reduction in somatic growth and increase in age at maturity (Kaeriyama 1999). Therefore, it is extremely important to investigate the migration mechanisms of salmon in the North Pacific Ocean.

Since mass marking of hatchery salmon using otolith thermal marks is highly effective for stock identification of salmon, thermal mark programs have been carried out by the National Salmon Resources Center, Fisheries Agency of Japan, for the purpose to investigate ocean migration and survival of each regional salmon stocks. In April 1999, approximately 4 million chum salmon (1998 brood year) with three thermal mark patterns were released from the Chitose Hatchery in Hokkaido. This was the first trial of thermal otolith marking for anadromous salmon in Japan. We are planning to increase the number of thermal mark releases from hatcheries. A computer-programmed chiller system was developed to control water temperature, producing high quality thermal marks in the otoliths of chum salmon. To increase available thermal mark patterns, we employed narrow rings, which were formed at 12 h intervals. In the spring of 2000, approximately 16 million chum and pink salmon (1999 brood year stocks) were released from hatcheries after thermally marked. We expect that more than a hundred million thermally marked chum salmon may be released in the spring of 2003. Figure 24 occupies about 5% of total hatchery releases in Japan (Urawa *et al*. 2000).

Recent rapid advances in biotelemetry technology on free-swimming fish make it possible not only to monitor underwater fish movement in greater detail, but also to analyze physiological aspects of fish behaviour. Three biotelemetrical instruments (ultrasonic transmitter, electromyographic radiotransmitter, and micro-datalogger) have been applied to investigate homing mechanisms in lacustrine sockeye salmon (*Oncorhynchus nerka*) and masu salmon (*O. masou*) in Lake Toya, Japan. These fishes offer good model systems for studying orientation ability in open water, energetics of migration, and environmental preferences of migrating fish. Moreover, hormone implantation experiments have revealed the direct influence of the brain-pituitary-gonadal axis on homing migration of lacustrine sockeye salmon in Lake Shikotsu, Japan. Although each technique has great advantages as well as minor disadvantages for clarifying physiological mechanisms of fish behaviour, combining different physiological biotelemetry has allowed us to understand the physiological mechanisms, and ultimately evolutionary adaptations, that facilitate successful homing migration (Ueda et *al.* 2000).

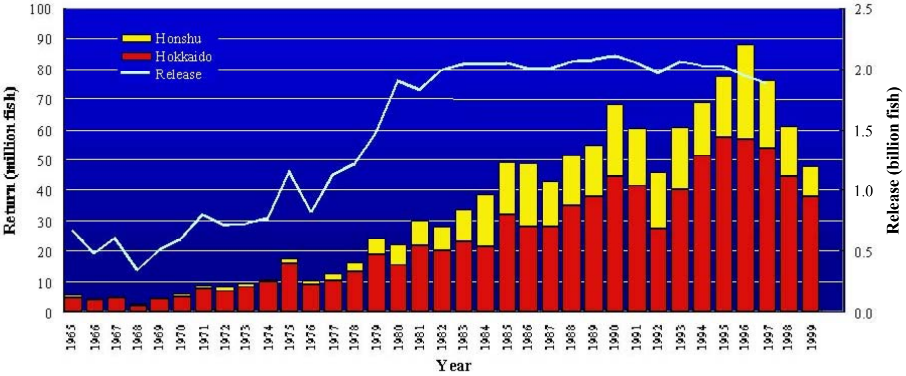


Fig. 24 Annual changes in number of adult returns and juvenile releases of chum in Japan during 1965-1999.

We are also trying to develop an automatic salmon-tracking robot boat that is composed of four interrelated equipment systems: 1) a robot boat, 2.5 m in length, 1.3 m in width, with a loading capacity of 120 kg, operated by two electric thrusters at 2 knots; 2) an ultrasonic tracking system detecting distance and direction of miniature pingers; 3) a signal processing and control system consisting of DGPS, acoustic signal, and gyroscope; and 4) a telecommunication system between a land base and the boat. The final goal of this project is to build a robot boat that can track an acoustic signal acquired from a salmon at a distance of 100 m. In the future, we plan to track salmon using the robot boat in the ocean.

We believe that salmon is one of the key species for monitoring climated-linked changes in biodiversity in the North Pacific Ocean, and will carry out collaborative research to investigate the homing migration and maturing mechanism by means of biotelemetrical as well as fish physiological analyses.

References

Kaeriyama, M. 1999. Enhancement program and stock management of salmonid population in Japan. *In:* Stock Enhancement and Sea Ranching. *Edited by* B. R. Howell, E. Moksness, and T. Svasand. Blackwell Science Ltd., London. pp. 153-167.

Ueda, H., Leonard, J.B.K., and Naito, Y. 2000. Physiological biotelemetry research on the homing migration of salmonid fishes. *In:* Advances in Fish Telemetry. *Edited by* A. Moore and I. Russell. CEFAS, Lowestoft. pp. 89-97.

Urawa, S., Kawana, M., and Ishiguro, T. 2000. Releases of thermally marked salmon from Japan in 1999 and 2000 with a thermal mark plan for 2000 brood year stocks. NPAFC Doc. 461, 7p.

Seabird monitoring program at Teuri Island, Hokkaido, Japan

Yutaka Watanuki

Graduate School of Agriculture, Hokkaido University, North-9, West-9, Kita-ku, Sapporo, Hokkaido 060-8589, Japan. E-mail: ywata@res.agr.hokudai.ac.jp

A seabird monitoring program at Teuri Island (44°25'N, 141°19'E, Fig. 25) is carried out to analyze how annual variation of physical marine processes in the northern part of the Japan Sea affect seabird breeding performance through fish stock change. Target seabird species (Table 3) and time-series are:

- Black-tailed Gulls (BTG): 1980, 1984, 1985, 1987, 1992-2000;
- Slaty-backed Gulls (SBG): 1980, 1984, 1985, 1987, 1992-2000;
- Rhinoceros Auklet (RA): 1984, 1985, 1987, 1992-2000; and
- Japanese Cormorants (JC): 1992-2000.

A few parameters were missing in some years. Parameters including breeding number, timing of breeding (egg laying or hatching), breeding success (clutch size, egg size, no fledgling, chick growth), diet for chicks (prey composition in the diet for chicks, meal size, fish size and number for bill load of RA) are measured according to the Teuri Island Seabird Monitoring Manual (Table 3).

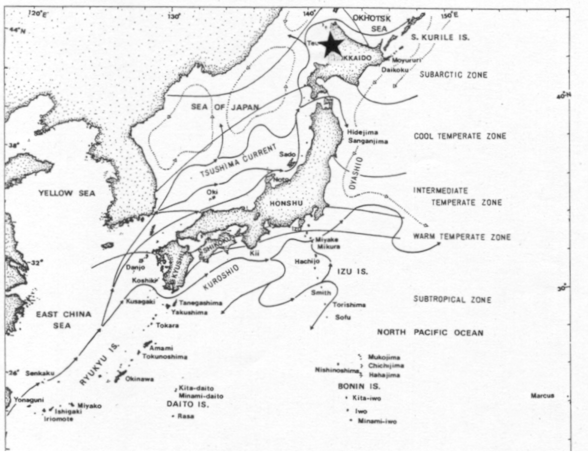


Fig. 25 Map showing the position of Teuri Island (marked by star).

Table 3 Monitoring seabird species and parameter at Teuri island.

	BTG	SBG	RA	JC
Number of nests	●	●		●
Time of egg laying	●	●		●
Time of hatching	●	●	●	●
Egg size	●	●		
Clutch size	●	●		●
Hatching success	●	●	●	●
No. fledgling per nest	●	●	●	●
Chick growth rate	●	●	●	●
Fledgling mass			●	
Fledging period			●	
Fledgling size			●	
Adult size and mass			●	
Prey composition	●	●	●	●
Prey fish size			●	

The breeding numbers of SBG and JC on the entire island are directly counted at the end of egg-laying season (late May). That of BTG is estimated with the number of birds on the entire island and number of nest/number of birds ratio obtained at 3 approximately 10 x 10 m plots. Egg laying, egg dimension, breeding success and chick growth of gull species are measured in a single permanent SBG plot (*ca.* 30 nests) and 2-3 BTG plots (*ca.* 30-60 nests). Each chick is color banded and weighed every 5 days. Those surviving more than 30 and 35 days are assumed to fledge for BTG and SBG, respectively. Nest contents of RA are checked and their chicks are weighed every 5 days in a permanent plot where more than 50 artificial nest boxes are used (at least 30 nests). Nest contents of JC in a semi-permanent plot (more than 30 nests) on a cliff are observed from a distance. JC chicks older than 45 days are assumed to fledge. Chicks of at least 10 nests of JC are weighed every 5 days between late May and late June. Site of chick weighing plots is changed every year. Chick growth rate is calculated as the slope of linear regression through the linear growth stage (5-25 days for SBG, 5-20 days for BTG, 0-20 days for RA, and 0.2-2.0 kg for JC). Fledgling mass and age of RA in the plot and final mass of chicks of two gull species are reported. Body size and mass of more than 30 fledglings of RA captured arbitrarily are reported also.

More than 30 regurgitations from chicks and chick rearing adults are collected from BTG, SBG and JC each year. Wet mass proportion and number of samples contained in each prey categories are measured. About 10 food loads of RA are collected every week from birds landing at night with food. Fish are identified and length and mass are measured. At the same time, body size and mass of these birds are measured. Mass prey composition in the diet for Black-tailed Gulls (BTG) and Rhinoceros Auklets (RA) chicks at Teuri Island is shown in Figure 26.

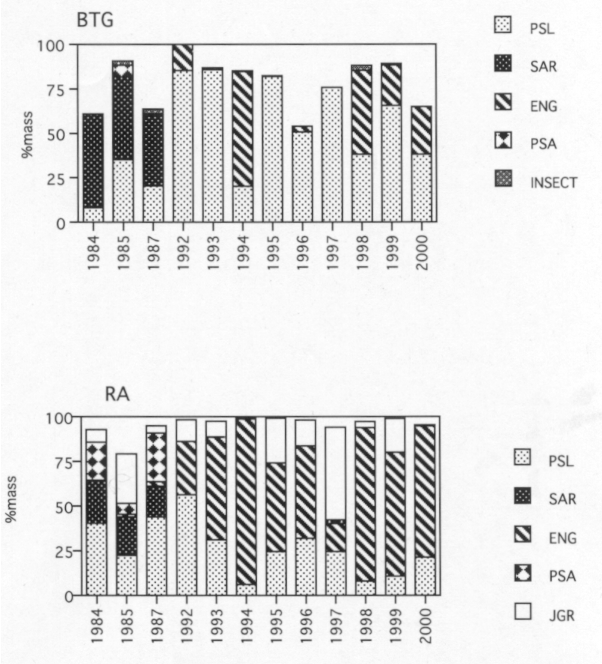


Fig. 26 Between-year difference in mass prey composition in the diet for chicks from Black-tailed Gulls (BTG) and Rhinoceros Auklets (RA) at Teuri Island. Abbreviation are PSL, sandlance; SAR, sardines; ENG, anchovy; PSA, saury; JGR, juvenile Japan Sea greenling.

APPENDIX 1

PICES/CoML/IPRC Workshop on "Impact of Climate Variability on Observation and Prediction of Ecosystem and Biodiversity Changes in the North Pacific"

March 7-9, 2001, East-West Center, University of Hawaii

Workshop Agenda

<u>Wednesday March 7</u>

08:30-09:00 Registration

PLENARY SESSION

09:00-09:20 Opening remarks and overview of workshop objectives from a PICES perspective:
Vera Alexander and *Patricia Livingston*, workshop convenors
09:20-09:40 Overview of the Census of Marine Life program
Cynthia Decker
09:40-10:00 Climate variability in the Pacific Ocean and theories as to its cause
Julian P. McCreary, Jr. –Director, International Pacific Research Center
10:00-10:20 GOOS-LMR Panel recommendations and relationship to CoML
Warren S. Wooster

10:20-10:40 COFFEE BREAK

10:40-11:00 The development of CLIVAR's strategy for the Pacific Ocean
Humio Mitsudera
11:00-11:20 A short overview of POGO and plans for a CoML Workshop on Canadian marine biodiversity, Pacific, Arctic, and Atlantic
Kees Zwanenburg
11:20-11:40 Report of the CoML Pacific Tagging Workshops
David W. Welch
11:40-12:00 Brief discussion of plenary talks and instructions for breakout groups

12:00-13:30 LUNCH

BREAKOUT GROUP SESSIONS

13:30- 15:00 Breakout groups meet
Group 1 Physical/chemical oceanography and climate
Group 2 Phytoplankton, zooplankton, micronekton and benthos
Group 3 Fish, squid, crabs and shrimps
Group 4 Highly migratory fish, seabirds and marine mammals

15:00-15:20 COFFEE BREAK

15:20-17:00 Breakout sessions re-convene

17:30-19:30 RECEPTION

Thursday, March 8

BREAKOUT SESSIONS

08:30-10:00	Breakout sessions re-convene
10:00-10:20	COFFEE BREAK

PLENARY SESSION

10:20-10:40	The work of the Data Buoy Cooperation Panel and the formation of an Action Group for the North Pacific *Brian O'Donnell*
10:40-12:00	Preliminary reports of breakout groups and cross-disciplinary discussion of monitoring needs and opportunities *David L. Mackas*, discussion leader
12:00-13:00	LUNCH

BREAKOUT SESSIONS

13:00-14:30	Breakout sessions re-convene
14:30-14:50	COFFEE BREAK
14:50-16:30	Conclude breakout sessions/prepare breakout group reports

Friday, March 9

PLENARY SESSION

08:30-08:40	Overview of final day objectives
08:40-09:00	Breakout Group 1 Report: Physical/chemical oceanography and climate
09:00-09:20	Breakout Group 2 Report: Phytoplankton, zooplankton, micronekton and benthos
09:20-09:40	Breakout Group 3 Report: Fish, squid, crabs and shrimps
09:40-10:00	Breakout Group 4 Report: Highly migratory fish, seabirds and marine mammals
10:00-10:20	COFFEE BREAK
10:20-11:50	Plenary discussion
11:50-12:30	WORKSHOP CLOSING REMARKS

APPENDIX 2

List of participants

Japan

Dr. Sanae Chiba
Ecosystem Change Research Program
Frontier Research System for Global Change
Sumitomo-Hamamatsucho Building 4 F.
Hamamatsu-cho, Tokyo,
Japan. 105-0013
e-mail: chibas@frontier.esto.or.jp

Dr. Kimio Hanawa
Department of Geophysics
Graduate School of Science
Tohoku University
Aoba, Sendai,
Japan. 980-8578
e-mail: hanawa@pol.geophys.tohoku.ac.jp

Dr. Shin-ichi Ito
Fisheries Oceanography
Tohoku National Fisheries Research Institute
3-27-5 Shinhama,
Shiogama, Miyagi,
Japan. 985-0001
e-mail: goito@myg.affrc.go.jp

Dr. Makoto Kashiwai
Subarctic Fisheries Oceanography Division
Hokkaido National Fisheries Research Institute
116 Katsurakoi,
Kushiro, Hokkaido,
Japan. 085-0802
e-mail: kashiwai@ss.hnf.affrc.go.jp

Dr. Hidehiro Kato
Cetacean Population Biology Section
National Research Institute of Far Seas Fisheries
5-7-1 Orido,
Shimizu, Shizuoka,
Japan. 424-8633
e-mail: katohide@enyo.affrc.go.jp

Prof. Michio J. Kishi
Graduate School of Fisheries Sciences
Hokkaido University
3-1-1 Minato-cho,
Hakodate, Hokkaido,
Japan. 041-8611
e-mail: kishi@salmon.fish.hokudai.ac.jp

Dr. Toru Kobari
Miyagi Prefecture Fisheries Research and Development Center
Japan Science and Technology Co.
97-6 Sodenohama, Watanoha,
Ishinomaki, Miyagi,
Japan. 986-2135
e-mail: toru.k@f3.dion.ne.jp

Dr. Kosei Komatsu
Marine Productivity Division
National Research Institute of Fisheries Science
2-12-4 Fukuura, Kanazawa,
Yokohama, Kanagawa,
Japan. 236-8648
e-mail: kosei@nrifs.affrc.go.jjp

Dr. Yukihiro Nojiri
Global Environmental Research Group
National Institute for Environmental Studies
16-2 Onogawa,
Tsukuba, Ibaraki,
Japan. 305-0053
e-mail: nojiri@nies.go.jp

Dr. Sei-ichi Saitoh
Graduate School of Fisheries Science
Hokkaido University
3-1-1 Minato-cho,
Hakodate, Hokkaido,
Japan. 041-8611
e-mail: ssaitoh@salmon.fish.hokudai.ac.jp

Dr. Hiroyuki Sakano
Resource Enhancement Department
Fisheries Agency of Japan
1-2-1 Kasumigaseki, Chiyoda-ku,
Tokyo,
Japan.
e-mail: hiroyuki_sakano@nm.maff.go.jp

Dr. Yasunori Sakurai
Faculty of Fisheries
Hokkaido University
3-1-1 Minato-cho,
Hakodate, Hokkaido,
Japan. 041-8611
e-mail: sakurai@pop.fish.hokudai.ac.jp

Dr. Naonobu Shiga
Lab. of Marine Biodiversity
Graduate School of Fisheries
Hokkaido University
3-1-1 Minato-cho,
Hakodate, Hokkaido,
Japan. 041-8611
e-mail: nao@fish.hokudai.ac.jp

Dr. S. Lan Smith
Global Warming Group
Carbon Cycle Project
Frontier Research System
SEAVANS, N, 7F, 1-2-1 Shiba Ura, Minato-ku,
Tokyo,
Japan. 105-6791
e-mail: lanimal@frontier.esto.or.jp

Prof. Takashige Sugimoto
Ocean Research Institute
University of Tokyo
1-15-1 Nakano-ku,
Tokyo,
Japan. 164-8639
e-mail: sugimoto@ori.u-tokyo.ac.jp

Dr. Kazuaki Tadokoro
Ecosystem Change Research
Frontier Research System for Global Change
1-18-16 4F, Hamamatsu-cho, Minato-ku,
Tokyo,
Japan. 105-0013
e-mail: denden@frontier.esto.or.jp

Prof. Hiroshi Ueda
Toya Lake Station for Environmental Biology
Faculty of Fisheries
Hokkaido University
Kita 9, Nishi 9, Kita-ku,
Sapporo, Hokkaido,
Japan. 060
e-mail: hueda@ccms1.hucc.hokudai.ac.jp

Dr. Yutaka Watanuki
Laboratory of Animal Ecology
Graduate School of Agriculture
Hokkaido University
North-9, West-9, Kita-ku,
Sapporo, Hokkaido,
Japan. 060-8589
e-mail: ywata@res.agr.hokudai.ac.jp

Dr. Akihiko Yatsu
National Research Institute of Fisheries Science
2-12 Fukuura, Kanazawa-ku,
Yokohama,
Japan. 256-8648
e-mail: yatsua@nrifs.affrc.go.jp

Mr. Takahito Iida
Lab. of Marine Environment & Resource Sensing
Graduate School of Fisheries Sciences
Hokkaido University
3-1-1 Minato-cho,
Hakodate, Hokkaido,
Japan. 041-8611
e-mail: tiida@salmon.fish.hokudai.ac.jp

Mr. Kohei Mizobata
Lab. of Marine Environment & Resource Sensing
Graduate School of Fisheries Sciences
Hokkaido University
3-1-1 Minato-cho,
Hakodate, Hokkaido,
Japan. 041-8611
e-mail: mizobata@salmon.fish.hokudai.ac.jp

Korea

Dr. Young-Shil Kang
National Fisheries Research and Development Institute
408-1 Shirang-ri, Kijang-gun,
Pusan,
Republic of Korea.
e-mail: yskang@haema.nfrda.re.kr

Dr. Suam Kim
Department of Marine Biology
Pukyong National University
599-1 Daeyeon 3-dong, Nam-gu,
Pusan,
Republic of Korea. 608-737
e-mail: suamkim@pknu.ac.kr

China

Prof. Fangli Qiao
First Institute of Oceanography
State of Oceanic Administration
Xian-Xia-Ling Road,
Qingdao, Shandong,
People's Republic of China. 266061
e-mail: lagfd@public.qd.sd.cn

Prof. Qi-Sheng Tang
Yellow Sea Fisheries Research Institute
Chinese Academy of Fishery Sciences
106 Nanjing Road,
Qingdao, Shandong,
People's Republic of China. 266071
e-mail: ysfri@public.qd.sd.cn

Canada

Dr. Richard J. Beamish
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road,
Nanaimo, B.C.,
Canada. V9R 5K6
e-mail: BeamishR@pac.dfo-mpo.gc.ca

Dr. Douglas F. Bertram
Canadian Wildlife Service
5421 Robertson Road,
Delta, B.C.,
Canada. V4K 3N2
e-mail: bertramd@pac.dfo-mpo.gc.ca

Dr. David L. Mackas
Fisheries and Oceans Canada
Institute of Ocean Sciences
P.O. Box 6000,
Sidney, B.C.,
Canada. V8L 4B2
e-mail: MackasD@pac.dfo-mpo.gc.ca

Mr. Gordon A. (Sandy) McFarlane
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road,
Nanaimo, B.C.,
Canada. V9R 5K6
e-mail: McfarlaneS@pac.dfo-mpo.gc.ca

Dr. Richard E. Thomson
Fisheries and Oceans Canada
Institute of Ocean Sciences
P.O. Box 6000,
Sidney, B.C.,
Canada. V8L 4B2
e-mail: ThomsonR@pac.dfo-mpo.gc.ca

Dr. Daniel M. Ware
Earth and Ocean Sciences
University of British Columbia
3674 Planta Road,
Nanaimo, B.C.,
Canada. V9T 1M2
e-mail: ware_mrc@island.net

Dr. David W. Welch
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road,
Nanaimo, B.C.,
Canada. V9R 5K6
e-mail: WelchD@pac.dfo-mpo.gc.ca

Russia

Dr. Andrei S. Krovnin
Russian Federal Research Institute of Fisheries
& Oceanography (VNIRO)
17 V. Krasnoselskaya Street,
Moscow,
Russia. 107140
e-mail: akrovnin@vniro.ru

Dr. Vyacheslav B. Lobanov
V.I. Il'ichev Pacific Oceanological Institute
43 Baltiyskaya Street,
Vladivostok,
Russia. 690041
e-mail: lobanov@poi.dvo.ru

United Kingdom

Dr. Sonia D. Batten
Sir Alister Hardy Foundation for Ocean Science
1 Walker Terrace, The Hoe,
Plymouth,
United Kingdom. PL1 3BN
e-mail: soba@wpo.nerc.ac.uk

U.S.A.

Dr. Vera Alexander
Dean, School of Fisheries and Ocean Sciences
University of Alaska
245 O'Neill Bldg.,
Fairbanks, AK 99775-7220
U.S.A.
e-mail: vera@ims.alaska.edu

Dr. Harold Batchelder
College of Oceanic & Atmospheric Sciences
Oregon State University
104 Ocean Administration Building,
Corvallis, OR 97331-5503
U.S.A.
e-mail: hbatchelder@oce.orst.edu

Dr. Steven J. Bograd
NOAA/NMFS
Pacific Fisheries Environmental Laboratory
1352 Lighthouse Avenue,
Pacific Grove, CA 93950
U.S.A.
e-mail: sbograd@pfeg.noaa.gov

Dr. Richard D. Brodeur
College of Ocean & Atmospheric Sciences
Oregon State University
Newport, OR 97365
U.S.A.
e-mail: Rick.Brodeur@noaa.gov

Dr. David M. Checkley, Jr.
Marine Life Research Group
Scripps Institution of Oceanography
9602 La Jolla Shores Drive,
La Jolla, CA 92093-0218
U.S.A.
e-mail: dcheckley@ucsd.edu

Dr. Anne B. Hollowed
Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA
7600 Sand Point Way NE,
Seattle, WA 98115
U.S.A.
e-mail: Anne.Hollowed@noaa.gov

Dr. Rita Horner
School of Oceanography
University of Washington
Box 357940,
Seattle, WA 98195-7990
U.S.A.
e-mail: rita@ocean.washington.edu

Ms. Patricia Livingston
Alaska Fisheries Science Center
7600 Sand Point Way NE,
Seattle, WA 98115-0070
U.S.A.
e-mail: Pat.Livingston@noaa.gov

Mr. Allen Macklin
Pacific Marine Environmental Laboratory
7600 Sand Point Way NE,
Seattle, WA 98115-6349
U.S.A.
e-mail: macklin@pmel.noaa.gov

Dr. Bernard A. Megrey
Alaska Fisheries Science Center
7600 Sand Point Way NE,
Seattle, WA 98115
U.S.A.
e-mail: Bern.Megrey@noaa.gov

Dr. H. Geoffrey Moser
Southwest Fisheries Science Center
P.O. Box 271,
La Jolla, CA 92038
U.S.A.
e-mail: Geoff.Moser@noaa.gov

Dr. James E. Overland
Pacific Marine Environmental Laboratory
Oceanic and Atmospheric Research, NOAA
7600 Sand Point Way NE,
Seattle, WA 98115-0070
U.S.A.
e-mail: James.E.Overland@noaa.gov

Dr. William T. Peterson
Estuarine & Ocean Ecology
Hatfield Marine Science Center
National Marine Fisheries Service
2030 S. Marine Science Drive,
Newport, OR 97365
U.S.A.
e-mail: Bill.Peterson@noaa.gov

Dr. Jeffrey J. Polovina
Chief, Ecosystem & Environment Investigation
National Marine Fisheries Service, NOAA
Honolulu Laboratory
2570 Dole Street,
Honolulu, HI 96822-2396
U.S.A.
e-mail: Jeffrey.Polovina@noaa.gov

Dr. Warren S. Wooster
School of Marine Affairs
University of Washington
3707 Brooklyn Avenue,
Seattle, WA 981105-6715
U.S.A.
e-mail: wooster@u.washington.edu

Organizations

CLIVAR (Climate Variability & Predictability Program)
Dr. Humio Matsudera
International Pacific Research Center
University of Hawaii
2525 Correa Road,
Honolulu, HI 96822
U.S.A.
e-mail: humiom@soest.hawaii.edu

CoML (Census of Marine Life) Program
Dr. Cynthia Decker
Consortium for Oceanographic Research and Education
Suite 800, 1755 Massachusetts Ave. NW,
Washington, DC 20036
U.S.A.
e-mail: cdecker@brook.edu

DBCP (Data Buoy Cooperation Panel)
Mr. Ron McLaren
Meteorological Service of Canada
Environment Canada
700-1200 W. 73rd Avenue,
Vancouver, B.C.,
Canada. V6P 6H9
e-mail: Ron.McLaren@ec.gc.ca

DBCP (Data Buoy Cooperation Panel)
Mr. Brian O'Donnell
Meteorological Service of Canada
Environment Canada
700-1200 W. 73rd Avenue,
Vancouver, B.C.,
Canada. V6P 6H9
e-mail: Brian.O'Donnell@ec.gc.ca

EVOS (Exxon Valdez Oil Spill) Trustee Council
Dr. Robert Spies
Applied Marine Sciences
4-749 Bennett Drive, Suite L,
Livermore, CA 94550
U.S.A.
e-mail: spies@amarine.com

GEM (Gulf Ecosystem Monitoring) Program
Dr. Phillip Mundy
Exxon Valdez Oil Spill Restoration Office
645 G Street, Suite 401,
Anchorage, AK 99501
U.S.A.
e-mail: Phil_mundy@oilspill.state.ak.us

GOOS (Global Ocean Observing System Project)
Dr. Michael Laurs
NOAA National Marine Fisheries Service
Honolulu Laboratory
2570 Dole Street,
Honolulu, HI 96822
U.S.A.
e-mail: Mike.Laurs@noaa.gov

IATTC (Inter-American Tropical Tuna Commission)
Dr. Robert Olson
8604 La Jolla Shores Drive,
La Jolla, CA 92037
U.S.A.
e-mail: rolson@iattc.ucsd.edu

IPHC (International Pacific Halibut Commission)
Dr. Steven Hare
P.O. Box 95009,
Seattle, WA 98145-2009
U.S.A.
e-mail: hare@iphc.Washington.edu

IPRC (International Pacific Research Center)
Dr. Julian McCreary
International Pacific Research Center
School of Ocean & Earth Science & Technology
University of Hawaii
2525 Correa Road,
Honolulu, HI 96822
U.S.A.
e-mail: all@musashimaru.soest.hawaii.edu

PICES (North Pacific Marine Science Organization)
Dr. Alexander S. Bychkov
C/o Institute of Ocean Sciences
P.O. Box 6000,
Sidney, B.C.,
Canada. V8L 4B2
e-mail: bychkov@ios.bc.ca

PICES (North Pacific Marine Science Organization)
Dr. Skip McKinnell
C/o Institute of Ocean Sciences
P.O. Box 6000,
Sidney, B.C.,
Canada. V8L 4B2
e-mail: mckinnell@ios.bc.ca

POGO (Partnership for Observation of the Global Oceans)
Dr. Kees Zwanenburg
Marine Fish Division
Bedford Institute of Oceanography
P.O. Box 1006,
Dartmouth, NS
Canada. B2Y 4A2
e-mail: Zwanenburgk@mar.dfo-mpo.gc.ca