PICES SCIENTIFIC REPORT No. 22 2002

PICES Science: The first ten years and a look to the future

PICES Scientific Report No. 22
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PICES Science: The first ten years and a look to the future

Edited by

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August 2002
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

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INTRODUCTION

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The North Pacific Marine Science Organization (PICES) celebrated its tenth anniversary in 2001. To mark this occasion, the Science Board topic was chosen as "Ten years of PICES science: Decadal-scale scientific progress and prognosis for a regime shift in scientific approach". This symposium was held on October 8, 2001, at the opening of the Tenth Annual Meeting of PICES, in Victoria, Canada. Nine papers were presented during this session, eight of which are included in this volume.

The symposium was designed as a celebration and reflection on the first ten years of scientific progress by PICES, and to provide a look to the future of the marine sciences in the North Pacific. Current or recent Chairmen of the Scientific Committees of PICES (see Figure 1 for a diagram of the organizational structure of PICES) were invited to review the history and major accomplishments of their Committees, and to look forward to critical issues and concerns for the future. Each of these "disciplinary" presentations was followed by an invited presentation, often by someone not normally associated with PICES, which took a broad view of the grand themes, issues and challenges facing that discipline. This format provides an interesting dialogue between where PICES is now and how it got here, and where it could/should go in the future.

In the first paper Warren S. Wooster, as one of the principal founders of PICES and its first Chairman, provides an overall history of the events leading to the formation of the organization and its major accomplishments. He also suggests future extensions of PICES' role in the North Pacific, including possibly providing more specific information or advice to policy makers on the state of the North Pacific Ocean.

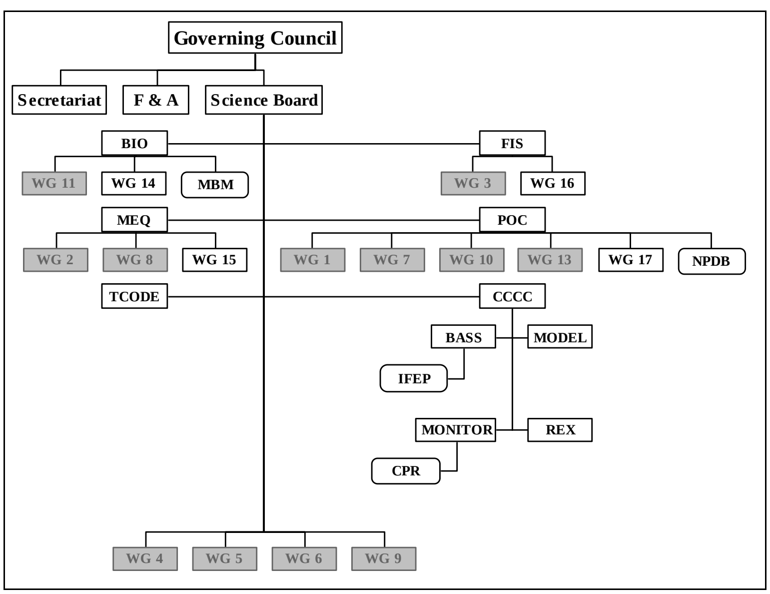

Fig. 1 Organizational chart of North Pacific Marine Science Organization (PICES). Boxes in grey indicate disbanded groups.

Paul H. LeBlond reviews the history of the Physical Oceanography and Climate Committee (POC), and comments on POC's potential role in developing marine operational modelling. D. E. Harrison and Neville Smith provide a complementary view on the significance and importance of the future of ocean prediction and forecasts.

Tsutomu Ikeda and Patricia A. Wheeler review the history of the Biological Oceanography Committee (BIO). They distil three primary themes from the past ten years of PICES activities in biological oceanography: (1) regional and basin-scale comparisons of lower and upper trophic levels; (2) the importance of life history strategies, alternate food webs, and understudied groups of organisms; and (3) the roles of trace metals and biogeochemical cycling. The "independent" broad overview is presented by Timothy R. Parsons, who provides a critical and thought-provoking commentary on the maturity of biological oceanography as a branch of the marine sciences, and what is needed to help it to mature.

Douglas E. Hay *et al.* have written a critical review of the role played by the Fishery Science Committee (FIS) in helping to understand changes in fish populations in the North Pacific. They conclude that while the FIS Committee has done an excellent job at facilitating communication of fisheries science around the Pacific, its contribution to initiating collaborative scientific projects regarding the health of fisheries and mechanisms affecting the abundance of living marine resources has been more marginal. Hay *et al*. discuss a theme that is repeated in a number of the presentations from the Scientific Committees: that some committees have concentrated on enhancing communication of science (for example through symposia at the PICES Annual Meetings), whereas others have also emphasized developing new collaborative scientific activities.

One committee, which has focussed on the latter aspect (while not ignoring the former), is the Marine Environmental Quality Committee (MEQ). Richard F. Addison *et al*. describe the events leading to their hosting of a practical workshop on comparisons and development of common assessment methodologies for marine environmental quality problems. This paper is followed by Macdonald *et al.*, who present a very thorough review of the stresses on the North Pacific marine system, how these should be studied, and how PICES might contribute to their study and to understanding their significance.

The final paper in this symposium (and in this volume) is by Perry *et al.*, who examine the history, objectives, accomplishments and problems of the primary inter-disciplinary program of PICES, the Climate Change and Carrying Capacity (CCCC) Program. This program was designed and implemented to bridge across the four "disciplinary" committees of PICES, and to specifically engage and consciously involve physical and biological oceanographers, fishery scientists and, though to a lesser extent, marine environmental quality scientists in an integrated program to study one of the major drivers of change in the North Pacific: climate change.

A map of the PICES area (Fig. 2) identifies key geographic features and locations mentioned in the papers included in this volume. In addition, an Appendix at the end of the volume deciphers the numerous acronyms referred to in these papers.

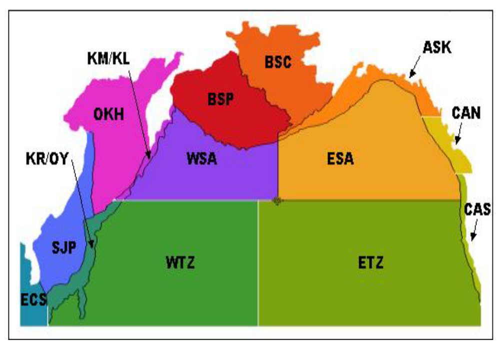

Fig. 2 Sub-regions in the PICES area (north of 30°N and including the marginal seas) of the North Pacific Ocean. ASK - Gulf of Alaska Continental Shelf; BSC - Bering Sea Continental Shelf; BSP - Bering Sea Pelagic; CAN – California Current North; CAS – California Current South; ECS - East China Sea; ESA - Eastern Subarctic; ETZ - Eastern Tropical Zone; KM/KL - Kurile Islands Region; KR/OY - Kuroshio/Oyashio Region; OKH - Sea of Okhotsk; JP - Sea of Japan; WSA - Western Subarctic; WTZ - Western Tropical Zone.

The accomplishments and products from PICES research activities are still being produced, and many more have yet to appear. PICES has recently been very successful at publishing the papers presented in the many symposia and sessions during its Annual Meetings in special volumes or sections of established scientific journals. This has greatly helped the dissemination of "PICES science", and the marine sciences generally, in the North Pacific. Over the first ten years, scientists of the PICES member nations have learnt to work together productively, as evidenced by the many reports of PICES Working Groups and multi-authored papers cited in the reviews in this volume. The challenge for PICES in the next decade is to move beyond a focus on scientific communications into a defining role of the principal scientific issues in the North Pacific, and perhaps into providing consensus scientific advice on critical marine problems facing the nations of the North Pacific. If the past can be used to predict the future, it should be a very active and exciting next ten years for PICES.

PICES - the first decade, and beyond

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While PICES celebrates its tenth anniversary, its origins can be traced back more than 25 years. Early informal discussions of the need for such an organization took place at an FAO Technical Conference on Fishery Management in Vancouver in 1973. More active consideration began at the University of Washington in 1976, and the first informal meeting on the subject occurred in 1978. Between then and March 1992, when the PICES Convention was signed, there were 8 other informal and formal reunions, involving participants from most of the present member countries. While some time was required to develop mutual understanding of what such an organization could accomplish, the long gestation period was mostly due to the shifting political relations among the countries concerned.

Early in the discussions, it became clear that interests of the proposed organization would not overlap with those of international organizations operating in the region. These were either global and broad in scope, or regional and specialized, in most cases for fishery management. PICES was envisioned as a regional organization, similar in many ways to the International Council for the Exploration of the Sea, ICES, in the North Atlantic, and was to be devoted to marine science in its broad aspects, and particularly to the interactions between the physical ocean environment and the ecosystems that function therein. This focus became particularly relevant as the impact of climate variations and the threat of climate change became apparent.

In its first decade, PICES considered a wide array of problems, including those of specific regions, such as the Okhotsk Sea and Oyashio region, the Bering Sea, the subarctic gyre, and the Japan/East Sea; circulation modeling, carbon dioxide, and the iron fertilization experiment; monitoring, data exchange and quality control; pollution assessment methodology; coastal pelagic fisheries, marine birds and mammals, crabs and shrimps, and harmful algal blooms. The major program on Climate Change and Carrying Capacity incorporates an interdisciplinary, integrative, and comparative approach, encompasses estimations of ecosystem carrying capacity and will shed light on the implications of climate changes for fisheries management. These efforts continue as the problems evolve and new ones arise.

The coming decade may include more cooperative operational efforts, for example, in establishing an effective ecosystem monitoring system, and in data and information exchange and analysis in order to generate regular and timely ecosystem status reports, and to provide scientific assessment and advice to its members and to interested regional organizations. The goal of PICES should be to continue and enhance services to its members and to their scientists.

This may be the first PICES meeting for some, while others can trace their connection back to the dim past when PICES was struggling to be born. While we speak of the first decade, the actual history, from the first gleam in its parents' eyes to the present, covers more than 25 years. If I outline some of that history, it may help to understand the present personality of the Organization and to foretell where it might be going.

Marine research is accomplished in large part by marine scientists whose specialties reflect the broad and interwoven nature of the ocean, whose approaches range from the abstract to the applied, and whose sponsors include universities, government agencies and private corporations.

Since the physical and biological processes that operate in the ocean recognize no man-made boundaries, marine research is inherently an international as well as interdisciplinary undertaking. In studying a complex system like the ocean, cooperation among scientists of different persuasions is always complicated, and even more so when they come from different countries and cultures with different languages. The need for successful cooperative efforts has led to the establishment of international organizations to facilitate those efforts. Of those organizations concerned to a significant degree with some aspect of marine science, one can distinguish two principal categories, that of non-governmental and that of intergovernmental character, with each having its special focus and motivation, *e.g.*, science or resource management, and its geographical scale, *e.g.*, global or regional.

To come quickly to the bottom line, PICES is regional and intergovernmental with a broad interest in advancing scientific knowledge of the ocean. In the course of its development, these characteristics were all negotiated, and the decisions drew upon the player's experience with global organizations (*e.g.*, Intergovernmental Oceanographic Commission, IOC and the Food and Agriculture Organization, FAO) and with regional specialized bodies (*e.g.*, International North Pacific Fisheries Commission, INPFC). Particular note was taken of the long success of an analogous organization in the North Atlantic, the International Council for the Exploration of the Sea, ICES. While the designers drew heavily on the ICES experience, they were also well aware of the significant geographical and political differences between the two regions.

When I moved to Seattle, in 1976, I was challenged by two colleagues, Don McKernan and Lee Alverson, to think about developing a new international organization to support the scientific investigation of the North Pacific, a sort of Pacific ICES (hence the nickname PICES). The first informal meeting to discuss the need for such an organization, was held in early 1978 and involved scientists from Canada and the United States. At the second such meeting a year later, participants from Japan and the USSR were included. Then there was a long delay, for a variety of reasons that reflected the international politics of the time.

Not until April 1986, were the next international discussions held, when participants from the four countries were joined by observers from China. The pace then quickened. Not only were discussions more frequent, but they were more formal and among governments rather than just among interested individuals. By December 1989, the convention was drafted and a year later was accepted. Following an intergovernmental organizational meeting in March 1992, PICES was ready to hold its first Annual Meeting ten years ago, in Victoria, B.C., in October of that year. Russia replaced the USSR, and Korea soon became the sixth member state.

Rather than regaling readers with anecdotes from this long gestation period, I think it would be more useful to examine early aspirations, to compare them with accomplishments to date and to speculate on where this might all lead.

When the first informal meeting occurred, the Law of the Sea (LOS) negotiations were still underway and coastal states were preparing to assume jurisdiction over coastal waters, both for resource exploitation and for research. These circumstances flavored the questions addressed, such as the following:

- Who are the participants in marine scientific research in the North Pacific, and how do they interact politically and scientifically? What are their objectives in seeking cooperation and/or coordination of marine scientific research in the region?
- What are appropriate functions for the proposed scientific organization? How should the region of interest be defined? Should membership in the proposed organization be restricted to countries bordering the region? Are there existing international organizations that could carry out the functions proposed for the new organization?
- What international arrangements for consultation on fishery matters are likely to survive the LOS negotiations, and to what extent are they likely to carry out the functions of the proposed organization? What should be the role of the proposed organization with regard to the formulation of advice to member governments or to appropriate regional organizations? Can such advice be responsive to the collective requirements of members and yet be effectively insulated from political influence?

It seems curious now that so much concern was expressed at the meeting over consultation on fishery matters and on providing advice to member governments when the original impetus had centered mostly on cooperative scientific investigation. But the purpose of the new organization as proposed then will not sound strange to you:

- To promote the development of cooperative research activities and the exchange of information concerning (1) the North Pacific marine environment and its interactions with land and atmosphere, (2) uses of the North Pacific and its living and non-living resources, and (3) the effects of man's activities on the quality of the marine environment.

These goals would be achieved through exchange of data and information; review of research plans, programs, and progress; identification of critical research problems and of methods appropriate for their solution; planning, development, and coordination of cooperative investigations of problems of common interest; and evaluation and interpretation of available data and information from the scientific point of view.

When, after eleven years, a meeting was held to draft the PICES Convention, a spokesman for the United States Delegation opened discussion on the continuing need for the organization:

The need for a PICES has not diminished in the last year. Potential conflicts and uncertainties in how to respond to contentious questions in the northern North Pacific have arisen in large part from lack of scientific understanding of the issues involved. These issues are difficult and complex. Their consideration often requires data not generally available as well as the exchange and pooling of ideas among scientists that is now difficult to achieve, in part because some existing scientific institutions are tied to management responsibilities so that relevant data are not exchanged freely nor analysed objectively. Existing organizations tend to be narrowly conceived so that all dimensions of problems cannot be examined (i.e., they are mono- rather than multi-disciplinary), or they are so broad in membership and scope that their attention to a single region, especially one in high northern latitudes, is only transitory at best.

The general characteristics of PICES were soon agreed, and the draft Convention was accepted in late 1990. A few months before the organizational meeting, in early 1992, a scientific workshop was held in Seattle to review the state of knowledge in selected fields, to list relevant ongoing research, to identify research gaps and priorities, and to consider joint action that might be developed through PICES. Several Working Groups (WG) were set up to consider selected topics.

The climate change group sought a description of the changing climate that would elucidate the processes involved and allow for prediction of the evolution of the physical and biological system. The Bering Sea group proposed studies of the relationships and variability among components of the physical and biological environment with regard to circulation, productivity, and biological interactions. The fishery oceanography group asked what governs fish resources, species, composition, and biomass in the North Pacific and Bering Sea and emphasized the importance of interactions among organisms and between them and the physical environment. Finally, the environmental quality group discussed problems of nutrient loading and eutrophication, the fate of chronic and persistent chemical pollutants, and the role of the North Pacific in waste disposal, in terms of environmental changes and ecosystem responses.

These discussions all converged on a common scientific problem:

- What is the nature of the subarctic Pacific ecosystem (or ecosystems) and how is it affected over periods of months to centuries by changes in the physical environment, by interactions among components of the ecosystem, and by human activities?
- So what is an appropriate way to assess PICES accomplishments in respect to the scientific questions mapped out nearly ten years ago?

One approach is to identify specific activities and products. From the beginning, there have been four standing Scientific Committees, in biological oceanography (BIO), fishery science (FIS), marine environmental quality (MEQ), and physical oceanography and climate (POC). From these have arisen temporary Working Groups that are disbanded when their tasks are completed. The sixteen established until now have looked at various aspects of the problems identified in 1991 with topics ranging from a specific sub-region, the Okhotsk Sea and Oyashio Region, to the broad questions of climate change, shifts in fish production, and fisheries management (Table 1).

Two major issues have been addressed by special, more permanent bodies, both of them established in 1994. Data exchange has always been seen as a central and continuing issue in cooperative research, especially that on very large systems where pooling of information is essential. The incorporation of biological data, ranging from tiny plankton to enormous whales, presents particular problems. An early Working Group has evolved into a standing Technical Committee on Data Exchange, TCODE. In addition to reviewing technical aspects of data exchange, TCODE has identified and made available on the PICES web site an inventory of the major ocean databases in the subarctic Pacific.

The second continuing body arose during discussions on the possibility that more juvenile salmon were being pumped into the ocean from hatcheries than could be sustained by the ecosystem where they were feeding. In other words, the carrying capacity of the system for salmon was being challenged. In response, it was decided to create what has become a major research program on Climate Change and Carrying Capacity, CCCC (a.k.a. the Four Seas), in cooperation with the international GLOBEC program (Global Ocean Ecosystem Dynamics). CCCC has an Implementation Panel and Task Teams on the basin scale component, regional scale studies, and development of conceptual/theoretical and modeling studies. Subsequently a Task Team on monitoring was added. The CCCC Program is a major effort to wrestle with many of the scientific questions identified back in 1991.

Another measure of PICES activity is the list of subjects discussed in scientific sessions of the Annual Meetings. These have steadily increased in number, from the single major symposium on climate change and northern fish populations at the First Annual Meeting to the eleven symposia and topic sessions at the present meeting. These have covered all the topics of interest to the standing Scientific Committees plus others of broader scope identified by the Science Board. From my count, some 60 topics will have been highlighted by the end of PICES X (Table 2).

A major scientific conference in March 2000 was entitled "Beyond El Niño" and concerned climate variability and marine ecosystem impacts, from the tropics to the Arctic. This not only had the interdisciplinary and ecosystem approach that has characterized PICES from the beginning, but was a first cooperative effort with four international fishery commissions in the North Pacific, those that deal with management of tropical (IATTC) and extra-tropical tuna (ISCTNP), Pacific halibut (IPHC), and high seas salmon (NPAFC).

Yet another measure of PICES scientific activity has been its scientific publications, not only the 19 scientific reports arising mostly from Working Groups but also several substantial monographs. These include a large volume (739 pages) on climate change and northern fish populations that resulted from the 1992 PICES I symposium, a major synopsis on the Bering Sea, and special volumes of *Progress in Oceanography* on ecosystem dynamics in the eastern and western gyres of the subarctic Pacific, and on North Pacific climate regime shifts. These will soon be joined by papers from the "Beyond El Niño" symposium (Table 3).

I think it is reasonable to argue that the majority of these activities and products arose or became evident through the efforts of PICES. Of course, there would likely have been some cooperative and collective activities as there were in the past, and the marine scientific world was already moving towards ecosystem approaches and inter-disciplinarity – we did not invent the idea back in 1978! But I have serious doubts that anything close to the breadth of interest and involvement displayed by PICES members in the last ten years and evident at the present meeting could have occurred had the Organization not existed.

What next? I understand that the government of Mexico is seriously considering membership. This will of course increase our geographical, but more important, our intellectual coverage. The coming decade is likely to see an expansion of cooperative operational efforts, for example, in establishing an effective ecosystem monitoring system and in data and information exchange and analysis. This could lead to the generation of regular and timely ecosystem status reports that could be provided to PICES members and to interested regional organizations.

These reports would incorporate climate, oceanographic, and fisheries data from national and other sources and would include descriptions of the current state of the ecosystem and recent and longer-term changes therein, including the abundance and distribution of various of its biological components. To the extent possible, now-casts and forecasts of probable future conditions would be made and widely distributed.

Until now, PICES members, unlike those of ICES, have shunned any sort of advisory capacity for PICES, largely because of fishery politics in the region. However, I believe that once PICES has developed its periodic ecosystem status reports, their availability will constitute a form of useful, yet apolitical, advice that members will welcome. This service could be a significant contribution to member governments as PICES pursues its continuing efforts "to promote and coordinate marine scientific research in order to advance scientific knowledge of the area concerned and of its living resources".

Table 1 PICES Working Groups and CCCC Program.

No.	Working Group/CCCC Program		Year
1.	Okhotsk Sea and Oyashio Region	POC	1992-1993
2.	Development of common assessment methodology for marine pollution	MEQ	1992-1994
3.	Dynamics of small pelagics in coastal ecosystems • renamed WG on Coastal pelagic fish	FIS	1992 1993-1995
4.	Data collection and quality control • renamed WG on Data exchange • replaced with Technical Committee on Data Exchange, TCODE	SB	1992 1993 1994
5.	Bering Sea	SB	1992-1996
6.	Subarctic gyre	SB	1992-1994
7.	Modeling of the subarctic North Pacific circulation	POC	1993-1995
8.	Practical assessment methodology	MEQ	1994-2000
9.	Subarctic Pacific monitoring	SB	1994-1997
	Scientific Steering Committee for PICES-GLOBEC Climate Change and Carrying Capacity Program, CCCC • renamed CCCC Implementation Panel • established Task Teams: BASS (basin scale component), REX (regional scale studies), MODEL (development of conceptual/theoretical and modeling studies) and MONITOR (development of PICES monitoring program)		1994 1995
10.	Circulation and ventilation in the Japan/East Sea	POC	1995-1999
11.	Consumption of marine resources by marine birds and mammals	BIO	1995-1999
12.	Crabs and shrimps	FIS	1995-2001
13.	Carbon dioxide in the North Pacific	POC	1997-2002
14.	Effective sampling of micronekton to estimate ecosystem carrying capacity	BIO	1997
15.	Ecology of harmful algal blooms in the North Pacific		1999
16.	Climate change, shifts in fish production, and fisheries management		1999

Table 2 Scientific sessions at PICES Annual Meetings and selected symposia/workshops.

Year	Scientific Session
1992	Climate change and northern fish populations
1993	• Long-term monitoring from platforms of opportunity (SB) • High resolution paleoecological studies in the subarctic Pacific (BIO) • Shifts in fish abundance and species dominance in coastal seas (FIS) • Priority chemical and biological contaminants in the North Pacific ecosystem (MEQ) • Ocean circulation and climate variability in the subarctic Pacific (POC)
1994	• Structure, trophic linkages, and ecosystem dynamics of the subarctic Pacific (SB) • Structure and ecosystem dynamics of the subarctic transition zone North Pacific - is the east like the west? (BIO) • Recruitment variability of clupeoid fishes and mackerels (FIS) • Interdisciplinary methodology to better assess and predict the impact of pollutants on structure and function of marine ecosystems (MEQ) • Physical processes and modeling of the subarctic Pacific and its marginal seas (POC)
1995	• Marine carrying capacity: fact or fiction? (SB) • Factors affecting the balance between alternative food web structures in coastal and oceanic ecosystems (BIO) • Density-dependent effects on fluctuations in the abundance of marine organisms (FIS) • Sources, transport and impact of chemical contaminants (MEQ) • Circulation in the subarctic North Pacific and its marginal seas, and its impacts on climate (POC)
1996	• Methods and findings of retrospective analysis (SB) • Regional and interannual variations in life histories of key species (BIO) • Processes of contaminant cycling (MEQ) • Exchanges of water, organisms, and sediment between continental shelf waters and the nearby ocean (POC)
1997	• Ecosystem dynamics in the eastern and western gyres of the subarctic Pacific (SB) • Micronekton of the North Pacific: Distribution, biology and trophic linkages (BIO/FIS) • Harmful algal blooms: Causes and consequences (BIO/MEQ) • Models for linking climate and fish (FIS/BIO) • Processes of contaminant cycling (MEQ) • Circulation and ventilation of North Pacific marginal and semi-enclosed seas (POC)
1998	• The impacts of the 1997/98 El Nio event on the North Pacific Ocean and its marginal seas (SB) • Controlling factors for lower trophic levels (especially phytoplankton stocks) (BIO) • Climate change and carrying capacity of the North Pacific: Recent findings of GLOBEC and GLOBEC-like programs in the North Pacific (FIS/CCCC) • Science and technology for environmentally-sustainable mariculture (MEQ) • Contaminants in high trophic level biota - linkages between individual and population responses (MEQ/BIO) • Decadal variability of the North Pacific climate (POC) • Carbon cycle in the North Pacific Ocean (POC/BIO)
1999	• The nature and impacts of North Pacific climate regime shifts (SB) • Modeling and prediction of physical processes in the subarctic North Pacific: Progress since 1994 (POC) • Coastal eutrophication, phytoplankton dynamics, and harmful algal blooms (MEQ/BIO) • Ecological impacts of oil spills and exploration (MEQ) • GLOBEC and GLOBEC-like studies and application to fishery management (FIS) • Recent findings of GLOBEC and GLOBEC-like programs in the North Pacific (BIO/CCCC)
2000	• "Beyond El Niño": A conference on Pacific climate variability and marine ecosystem impacts, from the tropics to the Arctic (March 23-26) • Subarctic gyre processes and their interaction with coastal and transition zones: physical and biological relationships and ecosystem impacts (SB) • Prey consumption by higher level predators in PICES regions: implications for ecosystem studies (BIO) • Recent progress in zooplankton ecology study in PICES regions (BIO/CCCC) • Short life-span squid and fish as keystone species in North Pacific marine ecosystems (FIS) • Large-scale circulation in the North Pacific (POC) • North Pacific carbon cycling and ecosystem dynamics (POC/BIO/JGOFS) • Recent findings and comparisons of GLOBEC and GLOBEC-like programs in the North Pacific (CCCC/GLOBEC) • Environmental assessment of Vancouver Harbor: results of an international workshop (MEQ) • Science and technology for environmentally sustainable mariculture in coastal areas (MEQ)
2001	• "Impact of climate variability on observation and prediction of ecosystem and biodiversity changes in the North Pacific" Workshop (March, 7-9) • Ten years of PICES science: Decadal-scale scientific progress and prognosis for a shift in scientific approach (SB) • Plankton size classes, functional groups and ecosystem dynamics: causes and consequences (BIO/JGOFS) • Migrations of key ecological species in the North Pacific Ocean (FIS) • Coastal ocean processes responsible for biological productivity and biological resource distribution (POC) • The physics and biology of eddies, meanders and rings in the PICES region (POC/BIO/FIS) • Sediment contamination - the science behind remediation standards (MEQ) • Physical oceanography to societal valuation: assessing the factors affecting coastal environments (MEQ) • Emerging issues for MEQ: a 10-year perspective (MEQ) • Physical, chemical, and biological interactions during harmful algal blooms (MEQ/BIO/POC) • A decade of variability in the physical and biological components of the Bering Sea ecosystem: 1991-2001 (CCCC) • Results of GLOBEC and GLOBEC-like programs (with emphasis on a possible 1999 regime shift) (CCCC)

Table 3 PICES Scientific Reports.

No.	Year	Title
1.	1993	Part 1. Coastal Pelagic Fishes (Report of WG 3) Part 2. Subarctic Gyre (Report of WG 6)
2.	1995	The Okhotsk Sea and Oyashio Region (Report of WG 1)
3.	1995	Monitoring Subarctic North Pacific Variability (Report of PICES -STA Workshop)
4.	1996	Science Plan, Implementation Plan (Report of the PICES-GLOBEC International Program on Climate Change and Carrying Capacity, CCCC)
5.	1996	Modelling of the Subarctic North Pacific Circulation (Report of WG 7)
6.	1996	Proceedings of the Workshop on the Okhotsk Sea and Adjacent Areas
7.	1997	Summary of the Workshop on Conceptual/Theoretical Studies and Model Development and the 1996 MODEL, BASS and REX Task Team Reports (CCCC)
8.	1998	Multilingual Nomenclature of Place and Oceanographic Names in the Region of the Okhotsk Sea
9.	1998	PICES Climate Change and carring Capacity Workshop on the Development of Cooperative Research in Coastal Regions of the North Pacific
10.	1999	Proceedings of the 1998 Science Board Symposium on the Impacts of the 1997/98 El Niño Event on the North Pacific Ocean and its Marginal Seas
11.	1999	PICES-GLOBEC International Program on Climate Change and Carring capacity. Summary of the 1998 MODEL, MONITOR and REX Workshops, and Task Team Reports
12.	1999	Proceedings of the Second PICES Workshop on the Okhotsk Sea and Adjacent Areas
13.	2000	Bibliography of the Oceanography of the Japan/East Sea
14.	2000	Predation by Marine Birds and Mammals in the Subarctic North Pacific Ocean (Report of WG 11)
15.	2000	Report on the 1999 MONITOR and REX Workshops, and the 2000 MODEL Workshop on Lower Trophic Level Modeling (CCCC)
16.	2001	Enviromental Assessment of Vancouver Harbor Data Report for the PICES Practical Workshop (WG 8)
17.	2001	PICES-GLOBEC International Program on Climate Change and Carring Capacity. Report of the 2000 BASS, MODEL, MONITOR and REX Workshops, and the 2001 BASS/MODEL Workshop
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
19.	2001	Commercially Important Crabs, Shrimps and Lobsters of the North Pacific Ocean (WG 12)

Other publications resulting from PICES activities:

Beamish, R.J. (Ed.). 1995. Climate change and northern fish populations. Canadian Special Publication of Fisheries and Aquatic Sciences 121. 739 p.

Beamish, R.J., Kim, S., Terazaki, M., Wooster, W.S. (Eds.). 1999. Ecosystem dynamics in the eastern and western gyres of the subarctic Pacific. Progress in Oceanography 43 (2-1).

Loughlin, T.R. and Ohtani, K. (Eds.). 1999. Dynamics of the Bering Sea. University of Alaska Sea Grant. 825 p.

Hare, S.R., Minobe, S., Wooster, W.S. (Eds.). 2000. North Pacific climate regime shifts. Progress in Oceanography 47 (2-4).

McKinnell, S., Brodeur, R., Hanawa, K., Hollowed, A., Polovina, J. and Zhang, C.-I. (Eds.). 2001. Pacific climate variability and marine ecosystem impacts. Progress in Oceanography 49 (1-4).

The Physical Oceanography and Climate Committee: The first decade

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The birth of POC

International scientific organizations have a long gestation period; they are eventually carried to a successful birth by repeated emphasis on the need for their existence. Discussions leading to the creation of PICES lasted over fifteen years (W. S. Wooster, PICES Press 1(1), 1992). Before the first formal PICES Annual Meeting, before the Convention for a North Pacific Marine Science Organization entered into force on March 24, 1992, a Scientific Workshop was convened in Seattle at the invitation of the United States (December 11-13, 1991). The purpose of the workshop was to review the state of knowledge, to identify gaps and priorities, and to consider where joint action under the new PICES convention would be most appropriate.

Four topics were selected for discussion at the workshop: climate change, the Bering Sea, environmental quality and fisheries oceanography. It is easy to recognize in these topics, with some modification, the origin of the four Scientific Committees of PICES. The issues debated by the Climate Change working group are clearly reflected in future concerns of the Physical Oceanography and Climate Committee (POC). The principal scientific question identified then was "to obtain a description of the climate change in such a way that the processes involved in climate change can be understood". Participants emphasized the need for easier and freer data exchange among North Pacific Rim countries, and also concluded that the "present exchange of ideas is not adequate". Participants also stressed the need for joint investigations and collaboration within existing international programs (*e.g.,* WOCE, JGOFS).

The existing Scientific Committees of PICES (BIO, FIS, MEQ, POC) emerged from the workshop discussion groups and were first provisionally established at the organizational meetings in March 1992, and confirmed as permanent committees at PICES II, in October 1993. In the words of our first Chairman: "These committees are more disciplinary-oriented than the discussion topics were, and reflected the experience of ICES which had found that committees centered on specific disciplines provided a home for specialists in those disciplines. The trick then was to get the committees to work together on interdisciplinary topics of common interest, leading to joint sessions and symposia. This is certainly the current practice in PICES. " (W. Wooster, priv. com. June 12, 2001).

It did not take long for POC to begin its work in earnest. At the First Annual Meeting (PICES I, Victoria, October 1992), Dr. Yutaka Nagata (Japan) was elected Chairman of the Committee. That meeting set the tone for POC's work in the years to come: an open and friendly forum, where ideas were welcome and seriously debated, and where exploration and understanding of the ocean was always the primary goal. Members agreed that one of POC's most important roles should be to facilitate collaboration in international scientific programs. They also identified four important topics to be addressed through the formation of Working Groups: ocean circulation and climate variability in the Subarctic Pacific; the Okhotsk Sea and the Oyashio Region; new technologies and observing strategies; and data collection and quality control. These topics have provided the main focus for POC's deliberations over the years.

Circulation of the North Pacific

Understanding the circulation of North Pacific waters as well as the nature of its variability is clearly a theme of common interest and great importance to all PICES members. At the very first PICES Annual Meeting, the Science Board created an interdisciplinary, inter-committee Working Group (WG 6) on the Subarctic Gyre, with the task of reviewing current description and understanding of ocean circulation and climate variability in the subarctic North Pacific, identifying gaps, reviewing information on the biomass of major trophic levels - with special reference to carrying capacity for salmon - as well as reviewing the state of understanding of processes affecting primary and secondary production. Quite a task!

In addition, WG 6 was to identify key scientific questions and propose collaborative programs to advance knowledge and test major hypotheses. As much of the above was also the realm of interest of the international GLOBEC program, the Working Group was to advise which PICES and GLOBEC objectives could be linked.

The work of WG 6 gave rise to a variety of questions about the functioning of the subarctic Pacific ecosystem. It stimulated further interest on the part of POC, which convened a scientific session on "Ocean circulation and climate variability" at PICES II and launched a Working Group (WG 7) on Modelling of the subarctic North Pacific circulation at the same meeting. WG 7 was to review the state of the art in physical modelling, identify gaps as well as the kind of information required to improve circulation models. This Working Group, co-chaired by Drs. Paul LeBlond (Canada) and Masahiro Endoh (Japan), brought together leading ocean modelers in meetings in Vancouver (June 1994) and at PICES III in Nemuro (October 1994). A final report was presented to POC at PICES IV in 1995, and published as PICES Scientific Report No. 5.

A number of conclusions and recommendations were made by WG 7 to improve the results of numerical modeling. The unavailability of high resolution bathymetric data, especially in strategically sensitive coastal areas, was found to be a limitation on the accuracy of coastal circulation models. More comprehensive ocean property atlases were felt to be needed and better quality and availability of meteorological information was deemed crucial to ocean modeling. The Working Group also expressed strong support for satellite-based ocean observing missions. Workshops on modeling, to familiarize the PICES community with model results and their limitations as well as the improvement of visualization techniques, were strongly advocated. This latter suggestion was eventually implemented by the PICES Technical Committee on Data Exchange (TCODE) through a Workshop on Data Visualization at PICES VIII in Vladivostok.

Modeling of the North Pacific circulation has remained a central concern of POC over the years. PICES scientists were invited to present their results in scientific sessions on "Physical processes and modeling of the subarctic North Pacific and its marginal seas" at PICES III (Nemuro, 1994) and on "Modeling and prediction of physical processes in the subarctic North Pacific: Progress since 1994" at PICES VIII (Vladivostok, 1999). Members of POC interested in ocean modeling have also played an important role in the MODEL Task Team of the Climate Change and Carrying Capacity (CCCC) Program. Given the ever growing importance of numerical models in exploring and describing ocean circulation as well as their emerging operational role in marine forecasting, POC is likely to continue to be keenly interested in ocean modeling.

Okhotsk Sea and Oyashio

At PICES I, the Science Board gave its blessing to a POC Working Group (WG 1) on the Okhotsk Sea and the Oyashio, an area of great oceanographic importance which would also hold POC's interest for a number years. WG 1 was to review the present level of knowledge of the oceanic circulation and water mass modification in the area of interest, identify gaps, review studies relating chemical, biological and geological regimes, and encourage planning of observations and interdisciplinary experiments. The group, under the chairmanship of Dr. Lynne D. Talley (U.S.A.), met in Nemuro, Japan, in September 1993, and prepared an extensive review (published as PICES Scientific Report No. 2: The Okhotsk Sea and Oyashio Region), identifying deficiencies in current understanding and recommending studies which would address these weaknesses. WG 1 also recommended that a follow-up meeting be held in Russia so as to fully engage Russian experts.

At its following meeting (PICES II, Seattle, 1993) POC devoted half its session to reviewing and discussing WG 1's report, which it enthusiastically endorsed. POC supported the Working Group's recommendation that a follow-up meeting be held in Vladivostok, so that more extensive Russian contributions could be incorporated in the review of the Sea of Okhotsk and Kuril region.

Subsequently, an extensive workshop was held in Vladivostok (June 19-24, 1995), under the co-chairmanship of Vyacheslav B. Lobanov (Russia), Yutaka Nagata and Lynne D.Talley; 97 papers were presented on all aspects of ocean sciences in the area of interest. Workshop participants reviewed oceanographic and fisheries information and discussed data exchange (to be improved) and possible joint investigations (to be encouraged). Proceedings of the Vladivostok workshop on the Okhotsk Sea and adjacent areas were published as PICES Scientific Report No. 6. POC agreed that PICES should maintain a continuing interest in the region and suggested that another workshop be held a few years hence to assess progress.

A second Okhotsk Sea workshop was held in Nemuro, in the fall of 1998, under the direction of the same three convenors. Participants focused on recent advances in the physical oceanography of the Sea of Okhotsk, discussed research activities of mutual interest, and recommended that PICES endorse and support international cooperative projects in the Sea of Okhotsk, the Kuril Islands region and the Western Pacific Gyre. Proceedings of the Nemuro workshop are available as PICES Scientific Report No. 12.

One of the recommendations of the first Vladivostok workshop was that PICES prepare a multilingual nomenclature of geographical and oceanographic features of the Sea of Okhotsk and its surroundings, so as to ensure clarity and eliminate ambiguity in reporting place names. The nomenclature, establishing correspondences between names of land and marine features in Russian, Japanese and English, was completed in 1998 and published jointly by PICES (PICES Scientific Report No. 8) and the Marine Information Research Center of Japan (MIRC).

Japan/East Sea

Another marginal sea of great interest**,** especially to western Pacific PICES members, is the Sea of Japan or East Sea (as it is called in Korea). A Working Group on the Circulation and ventilation of the Japan/East Sea (WG 10) was created at PICES IV (Qingdao, 1995), with Co-Chairmen Drs. Sang-Kyung Byun (Korea) and Christopher N. K. Mooers (U.S.A.). Terms of reference were very similar to those assigned to the Okhotsk Sea Working Group (WG 1), however with a different geographical focus and a stronger emphasis on physical oceanography. Members of the Working Group met in Fukuoka, Japan, in February 1997, and again just before the PICES VI in Pusan (October 1997), where POC devoted a special scientific session to papers on the Japan/East Sea.

Among its findings, WG 10 noted that the level of regional scientific communication and cooperation was excellent, but that scientific access by researchers to the EEZs of the surrounding countries remained "the greatest limitation to international cooperative studies". A strong recommendation to PICES was that it should foster and encourage international scientific programs in the area, helping smooth the path to data exchange and access to EEZs.

WG 10 also provided a valuable forum for joint studies of the Japan/East Sea through support of, and collaboration with, the CREAMS program (Circulation Research of East Asian Marginal Seas). A CREAMS workshop, held jointly with PICES at PICES VII (Fairbanks, 1998), extended the discussion beyond the traditional physical oceanography core of CREAMS to include ecosystem studies. Follow-up workshops, in Seoul, in April 1998, and in Vladivostok, in May 2000, have contributed to strenghtening the PICES-CREAMS collaboration. In the wake of these discussions, the October-November 2000 "PICES Cruise" of R/V *Professor Gagarinskiy*, so called because it took Russian scientists from Vladivostok to PICES IX in Hakodate, made multidisciplary observations towards a comprehensive study of the ecosystem structure of the northern Japan/East Sea.

An extensive annotated bibliography of the oceanography of the Japan/East Sea prepared by Dr. Mikhail A. Danchenkov (Russia) was published as PICES Scientific Report No. 13. POC has continued to emphasize its support for the CREAMS and Japan/East Sea Office of Naval Research (U.S.A.) program as a working example of effective international collaboration. Additional workshops jointly sponsored by PICES are planned.

The Bering Sea

At PICES I, the Science Board created an interdisciplinary Working Group (WG 5) on the Bering Sea, with the mandate to review knowledge of the circulation, ocean properties and their variability, and the ecosystem and its response to environmental variability. Although POC was not formally responsible for WG 5, it took a keen interest in its progress and supported its work. POC also supported the efforts of NOAA to bring together the Bering Sea Ecosystem Biophysical Metadatabase.

CO_2 in the North Pacific

The North Pacific is recognized as an important sink for atmospheric CO_2 in the ocean, and plays an important role in controlling long-term climate change. POC turned in earnest to the “Climate” part of its mandate and, jointly with the Biological Oceanography Committee (BIO), recommended at PICES VI (Pusan, 1997) the creation of a Working Group on CO_2 in the North Pacific. This Working Group (WG 13), under co-chairmanship of Drs. Yukihiro Nojiri (Japan) and Richard A. Feely (U.S.A.), first met at a two-day workshop at PICES VII (Fairbanks, 1998), where members reviewed the state of knowledge of air-sea CO_2 exchange and the mechanisms controlling it, and planned their future work.

Among the first priorities identified was the need to carry out comparisons of measurement techniques between various laboratories, in order to establish quantitative standards in estimating dissolved inorganic carbon, total alkalinity and $^{13}C/^{12}C$ of inorganic carbon in sea water. A first PICES-sponsored intercomparison (technical workshop) brought together participants in Tsukuba (April 1999); a second exercise focused on improving the quality of alkalinity measurements and led to a second meeting, also in Tsukuba (October 2000). A joint BIO/POC scientific session at PICES IX (Hakodate, 2000) gathered physicists, chemists and biologists, on the topic of “North Pacific carbon cycling and ecosystem dynamics”.

Having addressed measurement standards, WG 13 turned its attention to the task of data integration and synthesis, a topic first explored at a workshop held jointly with the PICES Technical Committee on Data Exchange (TCODE) in Sidney, B.C., Canada, in January 2001. Workshop participants recommended (among other things) that PICES work together with international data centers to compile an International North Pacific Data Inventory for CO_2 and CO_2-related data (Dickson 2001). A follow-up workshop, again co-sponsored by WG 13 and TCODE, was held in Tokyo on July 31-August 2, 2001, to discuss the implementation of the data integration proposals made at the Sidney workshop.

Oceanographic processes

Most scientific sessions sponsored by POC, as well as those held under joint sponsorship with the Science Board and other scientific committees, focused on themes already selected for the attention of Working Groups. For example, the “Ocean circulation and climate variability in the subarctic Pacific” theme of PICES II and the “Physical processes and modeling of the subarctic North Pacific and its marginal seas” theme of PICES III supported the activities of WG 6 and WG 7. The theme of circulation and its variability was addressed again at the PICES IX session on “Large-scale circulation in the North Pacific”. The important modeling theme was also returned to at PICES VIII, where a session was devoted to “Modeling and prediction of physical processes in the subarctic North Pacific: Progress since 1994”.

Connections between ocean variability and climate change was the focus of PICES IV scientific presentations on “Circulation in the subarctic North Pacific and its marginal seas and its impact on climate” and PICES VII, with papers addressing “Decadal variability of the North

Pacific climate". A joint session with BIO at PICES IX on "North Pacific carbon cycling and ecosystem dynamics" supported the work of WG 13. Closer inter-disciplinary presentations were planned for PICES X with topic sessions on "Coastal ocean physical processes responsible for biological productivity and biological resource distribution" and on "The physics and biology of eddies, meanders and rings in the PICES region" (jointly with BIO and FIS).

In some cases, scientific papers were solicited on more specific themes. For example, presentations on "Exchanges between continental shelf waters and the nearby ocean" of PICES V addressed coastal processes which were further explored in PICES VI in a session devoted to the "Circulation and ventilation of North Pacific marginal and semi-enclosed seas", which also supported the work of WG 10.

Input to inter-disciplinary programs

A number of Working Groups, special committees and Task Teams created by PICES have also attracted the interest and participation of the Physical Oceanography and Climate Committee. POC was a strong supporter of the creation of WG 9 on Monitoring of the Subarctic Pacific, and kept itself appraised of its progress. POC has supported and encouraged the work of TCODE. POC members have also been influential participants in the development of the CCCC Program and especially of its MODEL and MONITOR Task Teams.

Other concerns

While the work of POC is most clearly manifested through the activities of its Working Groups and the selection of topics for scientific sessions at PICES Annual Meetings, a number of other issues have repeatedly been raised at POC meetings, some of them with specific impacts on PICES business.

As in many inter-governmental organizations, there is a tendency for PICES meetings to be dominated by scientists working for government agencies. Early on, POC advocated increased participation by non-government researchers, particularly from universities, who have much to offer in ocean sciences. POC also strongly supported initiatives to increase participation by younger scientists in PICES meetings.

Research funding is often preferentially directed towards new ideas, sometimes at the detriment of long-term monitoring programs. POC emphasized the importance of maintaining a balance between routine monitoring and directed observational programs in support of specific scientific objectives.

At one of its early meetings, POC advocated the idea of "State-of-the-Ocean" reports, describing conditions in various parts of the subarctic North Pacific. Thanks to official encouragement and the enthusiasm of a few volunteers, the idea germinated into the regional overviews now regularly appearing in PICES Press.

As a means of handling the many requests for special publications or translations put to them by scientists from member countries, POC and other committees suggested the creation of a Publications Committee, which has since developed procedures to consider such issues.

Every year, POC has re-affirmed the need for international collaboration in ocean studies, and the role which PICES, as a treaty organization, can play in facilitating exchanges and access to national EEZs for scientific investigations. The support of CREAMS, mentioned earlier, and recommendations for continuation of the La Perouse/Soya Project implemented by Russian and Japanese laboratories, are examples of the positive role which PICES can play.

New technologies

Technological improvements play an important role in ocean exploration. From its very beginning, POC has recognized the importance of new technologies and observing strategies, as well as data collection and management, for the progress of oceanographic studies. POC recommended to PICES a closer collaboration with CLIVAR and GOOS programs.

At its meetings in 1998, 1999 and 2000, POC emphasized and endorsed a closer collaboration of PICES member countries to develop and implement the Argo program and co-sponsored an Argo meeting in Sidney, B.C., Canada, in March 2001.

POC also initiated contacts with NEAR-GOOS (the North East Asian Regional component of the Global Ocean Observing System) project, under development by the Intergovernmental Oceanographic Commission (IOC/WESTPAC) for the Japan, East China Sea and Yellow Sea area. As a result, a closer cooperation has developed between PICES and NEAR-GOOS in the form of an exchange of expertise in developing international observing systems and a multidisciplinary ecosystem approach to ocean studies. PICES experts and representatives attended the NEAR-GOOS meetings in September 1999 and August 2001. Conversely, NEAR-GOOS representatives attended the PICES Annual Meetings in Vladivostok (1999) and Hakodate (2000).

A continuing role for POC

In the formative decade of PICES, the Physical Oceanography and Climate Committee has acted as a focus for scientific discussions of the oceanography of the subarctic North Pacific and its marginal seas; it has brought together in friendly and mutually beneficial collaboration scientists from member countries; and it has actively enhanced participation of physical oceanographers and climatologists in interdisciplinary programs.

As PICES refines its purpose of advancing "scientific knowledge about the ocean environment, global weather and climate change, living resources and their ecosystems, and the impact of human activities", the Physical Oceanography and Climate Committee will continue to be a preferred forum for exchange of ideas and information on issues of common interest to signatories.

Marine issues facing PICES members are both local and basin-scale. Local issues, while affected by local circumstances, have a great degree of commonality: coastal management, pollution, aquaculture, marine tourism, near-shore fisheries. Within the next decade, one should expect significant advances in operational modeling of the coastal environment. Ocean scientists and engineers from PICES member countries will strongly benefit from the exchange of ideas and technology on this issue. POC could play a useful role in creating a Working Group which would review the state of the art and the practical prospects of marine operational modeling.

Basin-scale issues such as climate change and regime shifts affect all parties. Characterization, recognition and eventually prediction of oceanic regime shifts is the central problem in understanding the long-term variability of the North Pacific. POC can continue to provide leadership by focusing the efforts of PICES scientists on this issue.

An understanding of the physics of the ocean and of its interaction with the atmosphere is an essential and basic component of all these issues. This is where POC comes in. POC members will continue to explore and suggest means of collaboration to enhance and accelerate understanding of ocean circulation properties and interactions with the atmosphere. Combining focused topic sessions, Working Groups with well-defined mandates, and interdisciplinary tasks (within the Climate Change and Carrying Capacity Program, for example) has provided an attractive and fruitful formula to engage physical oceanographers, modelers and climate scientists.

Acknowledgements

Information for this review was gathered from the Annual Reports of PICES as well as from issues of PICES Press. I wish to thank the Secretariat for providing additional documentation. Thanks also to Drs. Yutaka Nagata and Vyacheslav B. Lobanov, respectively first and third Chairmen of POC, for their input and comments.

Ocean observing systems and prediction - the next ten years

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Toward a new era of oceanography

The twentieth century was a remarkable period for oceanography. We learned much about the fundamental distribution of properties of the seas and the balances that govern our ocean. We now know, among other things, why the ocean surface currents do not follow the wind; why the circulation in the Oceans is dominated by large basin-wide gyres; why there are swift currents in the west; why the tropical circulation is different from that at high latitudes; why coastal regimes differ from open ocean regimes; why the water properties in the Southern Ocean are intimately connected to conditions in the North Atlantic; why the temperature of the tropical Pacific Ocean matters to climates in the United States, South Africa and Australia; and why human activities now may change sea level toward the end of this century. The advances in knowledge have been great.

If we were to characterize the last century, it might be in terms of science and discovery and the building of knowledge and understanding (Smith 2001). The advances have required innovation in observations, in theoretical research, and in the development and construction of numerical models. Technological innovation has been critical, first to construct instruments that could measure, with accuracy and precision, in the harsh environment of the ocean, and more recently, to enable remote and autonomous measurements; to paralle code, run and analyze ocean models; and to provide rapid exchange and analysis of data via the Internet.

Other speakers will have to summarize the many accomplishments from the many individual and collaborative scientific and technical endeavors of recent decades. As we look forward to the next decade, we see opportunities to exploit our ocean knowledge and our growing technological capabilities for the betterment of humankind and the advance of our understanding of how the ocean affects the physical, chemical and biological state of our planet.

In this paper we place particular focus on the possibilities of a global ocean observing system and the gradual move toward oceanography as a more operational activity. In several ways oceanography is following the path developed by meteorology, implementing operational observation and forecast systems, yet in other ways there are significant differences. For meteorology, forecast skill is the dominant paradigm, an exemplar that seems equally applicable to climate forecasting, particularly that associated with El Niño. However, the rich living and non-living resources of the ocean, the critical importance attached to the coastal and marine environment, and the rich biodiversity of the oceans, among other things, make quantitative knowledge of the ocean state important in its own right. The market for ocean state estimates and forecasts ("marine services") exists now and we will attempt to show that we have the knowledge, technology and community "spirit" to develop a robust, sustained system of ocean observations, products and services that will serve us for this decade and beyond.

For the most part we focus on physical oceanography, and systems that have been developed with a view toward operational oceanography. There are of course many aspects that we ignore within this discipline, and even more from related disciplines.

The global ocean observing system

The history of widespread ocean observation began in the middle of the nineteenth century, when merchant sailing vessels started a systematic effort to collect and exchange information on weather and the state of the seas on their trade routes. Well over a century passed before any attempt was made to build on these pioneering efforts a systematic system for ocean observation. A major step forward in basin-scale observing efforts was implemented during Tropical Ocean Global Atmosphere (TOGA), for which a tropical Pacific-wide research observing system was designed, deployed and operated. In the last decade of the twentieth century, it became clear that a permanent observing system for the ocean was viable and sustainable. It took many years of planning and discussion before the ocean community started to widely endorse such an effort. The Ocean Observing System Development Panel (OOSDP 1995) provided a template for the global ocean observing system for climate, and this template has been adapted and modified by many as we move toward a sustained observing system (Nowlin 1999; Nowlin *et al.* 2000).

At the First International Conference for Ocean Observing Systems for Climate, agreement was reached on the essential elements of the observing system for the next decade and beyond (Smith and Koblinsky 2001). The system would include:

- Sea surface temperature measurements from satellites (visible, infrared, microwave) and *in situ* platforms (surface drifters, moorings, volunteer observing vessels);
- Surface vector winds from satellites and *in situ* instruments;
- Sea surface height variability from satellite altimeters and *in situ* measurements from tide gauges for the long-term climate record and validation (also needs good sea surface level pressure measurements);
- Upper ocean temperature and, where practical, salinity measurements from a variety of networks including the tropical moored buoys, Argo, the ship of opportunity XBT network (now principally in high-density and frequently repeated modes), other moorings and hydrography;
- Surface and upper ocean current measurements;
- Tracers and carbon measurements from hydrography for transport and inventory calculations; and
- Air-sea fluxes from ocean reference sites and lines, and from operational met models.

Smith and Koblinsky (2001) and the other papers in that volume provide a more comprehensive account of the many different contributions of which the above form just a part. The most important message is that the technology for a truly global ocean observing system exists now, based on both satellite and *in situ* technologies. There is also ample evidence that there is the collective will to realize such a system. Indeed, many nations have already made significant commitments.

Ocean state estimation

An important complement to the ability to observe the oceans is the ability to routinely assimilate this information, and to provide methods for exploiting this information for broader scientific and socio-economic benefit. In many instances it is not knowledge of the current state of the ocean at some location and depth that matters, but rather the inferences that can be drawn from this information and that at many other locations. These inferences are often applicable at locations far removed from the source information and, in many cases, involve fields and parameters not connected with oceanography (for example, rainfall estimates in North America or Indonesia). It is not the intent here to discuss these many applications in detail, but rather to provide a description of the systems that are being built to underpin synthesis and interpretation, and, in particular, the process of using ocean models to assimilate data, a procedure we refer to here as ocean state estimation.

Ocean state estimation, or ocean data assimilation is an optimization problem. Given a set of dynamical equations with associated estimates of model errors, and a set of ocean data with associated estimates of observational errors, and an error functional ("cost function") that is to be minimized, a variety of data assimilation techniques exist for approximating the ocean state that best satisfies the various constraints. Viewed as a four-dimensional space-time problem, the challenge is to blend measurements of the ocean state distributed irregularly in both space and time to produce regular (gridded) estimates of the ocean state for the present and past, and as appropriate for the future (forecasts).

These procedures are commonplace in meteorology and weather forecasting, and are becoming more common in climate and ocean applications. At present, ocean state estimation is performed operationally by some government efforts, and in research mode by an increasing number of research efforts. Each of these is limited to some extent by the available data, both for making and evaluating the skill of the operational estimates.

Many nations have agreed that a new push to expand our ocean data asssimilation efforts is needed and have begun to participate in the Global Ocean Data Assimilation Experiment (GODAE; Le Traon *et al.* 2001; IGST 2000), which is to have its intensive work period between 2003 and 2005.

The operational meteorology community has been making products with data assimilation for almost half a century, and offers valuable experience for the ocean community to draw upon. GODAE sponsors workshops to ensure that the ocean community benefits from the experiences of the meteorology community.

Issues for ocean state estimation

In comparison with meteorology, operational oceanography is immature. The observing systems are not complete and those networks that are established mostly have short records. The models and data assimilation methods are also immature. The models often display significant biases relative to observations. The data assimilation systems are limited by our ability to measure and model skillfully the many of the energetic scales of the ocean, including strong currents and mesoscale eddies. Nevertheless, considerable progress has been made in operational ocean forecasting and in climate forecasting, using a variety of methods.

The simplest form of data assimilation is objective interpolation, which requires the specification of the data errors and the covariance functions between the variables. Optimal interpolation (OI) has been widely used in oceanography since the mid-1970s, and variants are still used in several operational analysis and climate prediction systems. The method offers valuable perspective, because the utility of OI products is easily seen to depend critically on the specified statements of uncertainty. The OI product is only as good as the data distribution and covariance and error estimates.

Operational meteorology teaches us that we must work hard to learn how best to specify the full range of data and model errors, covariances and cost functions, if we seek useful ocean products. In many parts of the world ocean we do not have enough data to make dependable estimates of these quantities. Indeed, it is probably in the area of knowledge of (parameterized) processes and subgrid scale motions that we suffer most severely from a data shortage. Is the community prepared to invest in "local dynamics" experiments in these regions? In their absence we must go forward with assumptions of unclear utility, having unclear impact on our product skill.

Research based on operational meteorology products also teaches us that it can take some years before such products have sufficient skill to yield the desired insights into the kinematics and dynamics of the atmosphere. Atmospheric science research now depends heavily on operational products and periodic "re-analyses" of the historical atmospheric data set.

We must expect a learning period of increasing skill with our operational ocean products, and not be discouraged by early efforts. Having wide community access to the ocean products and wide community examination and feedback concerning their utility, will be essential for rapid progress in their skill and usefulness.

Data transmission, quality control (QC) and dissemination issues

Getting ocean data back from the marine environment promptly, effectively and cost-efficiently is key for many marine services. There appears to be a need in excess of what Service ARGOS can provide. Access to these data and to the products made from them is also necessary if the ocean community is to benefit.

The meteorology community has considerable infrasture dedicated to these tasks, *e.g.*, the World Weather Watch's Global Telecommunications System and the various national meteorological service product distribution pipelines. The ocean community needs capable Information Technology infrastructure to meet its needs.

As "research quality" QC is done on the historical data sets, there is also a need to be able to keep track of what has been done, and make it possible for researcher, policy-makers and re-analysis efforts to find the version(s) of the data sets most likely to be useful to them.

Based on our history, it is unlikely that there will be a "definitive" QC data set for the ocean in the foreseeable future; one group's noise is another group's signal. Various national efforts are in place and under development to address these issues.

GODAE is taking the lead to provide interfaces to the variety of different efforts that are in place and under development. The United States is supporting development and operation of a GODAE real time data and ocean product server sited at Fleet Numerical Meteorology Oceanographic Centre (FNMOC) in Monterey, CA, U.S.A.

The WMO's Joint Commission on Oceanography and Marine Meteorology (JCOMM) is also devoting effort to a range of data set issues. Technology for low power, low cost data transmission and data sharing also exist.

Ocean forecasts

As noted earlier, it is the ability to draw inferences from ocean measurements in regions and fields remote from the data site, that is perhaps the most valuable aspect of the global observing system infrastructure. However, the methodology of ocean state estimation only takes us part of the way. The most immediate way we can use such a data set is as a basis for producing an ocean or climate forecast, the so-called initial-value problem. Given a faithful estimate of the state of the ocean today, we can forecast the ocean state. For some variables we can hope to have forecast skill for several weeks, perhaps even months.

Our ability to do this is limited by several factors. Firstly, we are limited in our ability to observe the current state of the ocean and, secondly, the methods and models we use to produce the estimate have limitations, in many cases quite severe. As the previous sections have indicated, we have made considerable progress in addressing both these issues but most accept that there is still a long way to go (the challenge lies with GODAE and the several operational oceanography centers at the moment).

But more fundamentally the ocean is a chaotic medium, with small perturbations growing over time through non-linear interactions and feedbacks. The growth of such errors places natural limits on predictability, the degree to which one can determine a future state of the system. At present, our knowledge of ocean predictability is scant, principally because there has not been the need to determine predictability limits up till this point. The other issue is that the ocean is being continually forced by the atmosphere, which itself is unpredictable over certain time and space scales. So, while we anticipate internal ocean circulation errors may grow relatively slowly (perhaps 3-4 weeks at mid-latitudes), we must also take account of far more rapid error growth in surface forcing fields.

These issues notwithstanding, considerable progress has been made in ocean and climate forecasting with several centers routinely producing forecasts of the ocean state.

In some cases, such as El Niño, the oceans and atmosphere interact in such a way as to introduce modes of variability that seemingly have much longer time scales of predictability. This is the basis for several experimental and operational climate forecast systems. The extent to which other climate phenomena are predictable is receiving intensive study now, through CLIVAR and other programs.

As noted in the opening section, one of the distinguishing aspects of oceanography is the fact that many applications involve knowledge of the ocean and marine environment, in some cases in the past. We are not only interested in forecasts of the future but also in "forecasts" of the ocean state for locations and variables separated from the measurements. For the oil and gas industry, this might take the form of statistics for extreme currents near the bottom at a specific location. For the fishing industry it might be forecasts of advection and vertical circulation for ocean dispersal of larvae. For coastal management, it might be boundary conditions for local coastal management models. In all cases the challenge is to extrapolate and infer fields that are not directly measurable and, like forecasts in time, errors arise from both the limitations of the methods and from natural error growth (unpredictability).

GODAE is making considerable progress in developing links to value-adding communities where such activities take place. PICES may well be one of those communities though we recognize the immaturity of the endeavor at present. Such connections will require experimentation and much dialogue.

The coming decade

It does seem the ocean communities of the world are willing to embrace the concept of:

- a sustained ocean observing system (satellite and *in situ*);
- modern data transmission and data serving infrastructure;
- dedicated ocean product development and production efforts;
- wide community access and examination of the ocean products;
- community feedback so that the OS and the products will improve.

Given this acceptance, the coming decade will provide many opportunities for innovative applications and science.

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Ocean impacts from the bottom of the food web to the top: Biological Oceanography Committee (BIO) retrospective

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As one of the four core Scientific Committees of PICES, the unique mission of the Biological Oceanography Committee (BIO) is to promote and coordinate biological oceanography and interdisciplinary research in the northern North Pacific Ocean. BIO plays a key intermediary role with respect to the other PICES Standing Committees. For example, lower trophic levels may be the most directly affected by processes considered by the Physical Oceanography and Climate Committee (POC). These lower trophic levels then, affect and are affected by the upper trophic levels. BIO interacts with the Fisheries Science Committee (FIS) to provide scientific advice on ecological roles of lower and higher trophic level organisms on fisheries. BIO also plays a central role in defining "normal" conditions against which changes of interest to Marine Environmental Quality Committee (MEQ) can be measured. At the same time, BIO is responsible for developing scientific programs for annual and inter-session meetings, for formation of Working Groups on key areas of interest, for participation in the CCCC Implementation Panel and Task Teams, and for coordinating activities with other international and national programs. Here we summarize the 10-year record of the progress of BIO toward these goals.

Members and phases of development

The past and current BIO members are shown in Table 1. During the initial phase (1992-1995), BIO generated its own scientific programs for Annual Meetings (Table 2). In the intermediate phase (1996-1998), BIO organized joint sessions with other Scientific Committees (Table 2) and sponsored the formation of two Working Groups (Table 3). In the third phase of development (1999-2001), BIO further expanded efforts for jointly sponsored sessions with other Scientific Committees and the CCCC Program (Table 2), and developed interactions with other relevant international organizations (Table 3).

Activities of Working Groups

Working Group 11: *Consumption of marine resources by marine birds and mammals in the PICES region* (Co-Chairmen: Hidehiro Kato of Japan and George L. Hunt of U.S.A.). The Working Group was formed to tabulate available data on population sizes and diet composition of marine birds and mammals, and to calculate their seasonal and annual prey consumption to evaluate their predation effects on intermediate and lower trophic levels within the PICES region. To facilitate comparison and summarization, the PICES region (30ºN to the Bering Strait) was divided into 14 sub-regions (Introduction to this volume, Fig. 2) based on oceanographic features. While the quality and quantity of information was not uniform across the sub-regions, the Working Group revealed that at least 47 marine mammal species and 135 seabird species inhabit the PICES region. Estimates of abundance exceed 10,000,000 marine mammals and 200,000,000 seabirds. Seabirds and marine mammals are widely distributed throughout the PICES region. The mean size of individuals ranges from 28 kg to over 10,000 kg for marine mammals and from 20 g to 8,000 g for marine birds. Pooling available estimates of the western PICES sub-regions (approximately 49% of the total PICES region), total prey consumption by marine mammals is estimated to be 13 million tons during summer (June-September, 122 days) per year. Estimates for predation by seabirds are 1 million tons in sub-region BSC, 0.5 million tons in sub-region ASK, and 50 thousand tons in sub-region CAS. For the estimates covering the entire PICES region, there are still gaps of information to be filled (for details

Table 1 Biological Oceanography Committee members.

Chairmen		
M. M. Mullin (1992-1995) P. A. Wheeler (1996-1998) T. Ikeda (1999-2001)		
Members		
Canada: K. L. Denman (1992-2000) D. L. Mackas (1992-) T. R. Parsons (1992-1997) P. J. Harrison (1998-) A. Pena (2001-)	Korea: S. Y. Hong (1996-1998) J. U. Lee (1996-1997 S. K. Yi (1996-1997) J. H. Shim (1998-) S. Yoo (1998-) W. S. Kim (1999-)	China: Y. Q. Chen (1992-) R. Wang (1992-1998) B. L. Wu (1992-1995) M. Y. Zhu (1996-) S. Son (1999-)
Russia: B. N. Kotenev (1996-) V. I. Radchenko (1996-) V. V. Sapozhnikov (1996-)	Japan: T. Ikeda (1992-1995, 1997-) T. Sugimoto (1993-2000) A. Tsuda (1996-) M. Kishi (2001-)	U.S.A: L. Jones (1992-2000) M. M. Mullin (1992-2000) P. A. Wheeler (1992-) R. D. Brodeur (2001-) M. Dagg (2001-)

see PICES Scientific Report No. 14 published in 2000). With recognition that information about marine mammals and birds is important for the research on ecosystem dynamics in the PICES region, Working Group 11 was restructured and reformed as Marine Birds and Mammals (MBM) Advisory Panel since 1999 to fulfill its research objective.

Working Group 14: *Effective sampling of micronekton to estimate ecosystem carrying capacity* (Co-Chairmen: Richard D. Brodeur of U.S.A. and Orio Yamamura of Japan). The major objective of the Working Group is to obtain and tabulate data on consumption and biomass of micronekton in the PICES region, together with improvement of its sampling gears. "Micronekton" comprises adult euphausiids, mesopelagic fish, mysids, pelagic shrimps and cephalopods.

In addition to creating data inventories of micronekton in the North Pacific, topics under discussion are geographic zonation design (by adapting the sub-region system used by Working Group 11 mentioned above), reproduction, early life history and demographic rates; prey-predator relationships and rates (diet composition, food consumption rates, predators and predation rates, parasites and diseases); and sampling considerations (net towing, acoustics, visual design).

Review of BIO strategic plan

During its development, BIO set six goals for coordinating biological oceanography within PICES (Table 4). Here we state each goal and progress towards its implementation. Overall, BIO had great success in stimulating and coordinating research in biological oceanography within the PICES framework. Over the last decade, the extent of this success is highlighted by the international and interdisciplinary work summarized above, that covers physical oceanography and climate, upper and lower trophic levels of the marine ecosystem, stimulation of the long-term observational studies and modeling efforts of the PICES-GLOBEC CCCC Program, and expansion of coordinated interdisciplinary harmful algal bloom studies into the PICES region. Our recent efforts with the marine mammals and birds, and micronekton, will continue the facilitation of studies of ocean impacts from the bottom of the food web to the top in the North Pacific Ocean.

Table 2 BIO topic sessions at the PICES Annual Meetings.

Year	Sponsor	Title/Conveners
PICES II (1993)	BIO	• Paleoecological studies in the subarctic Pacific. (Convener: M. M. Mullin)
PICES III (1994)	BIO	• Structure and ecosystem dynamics of the subarctic and transition zone of the North Pacific. Is the east like the west? (Co-Conveners: A. Taniguchi and R. D. Brodeur)
PICES IV (1995)	BIO	• Factors affecting the balance between alternative food webs structures in coastal and oceanic ecosystems. (Co-Conveners: R. Wang and M. Omori)
PICES V (1996)	BIO	• Regional and interannual variations in life histories of key species. (Co-Conveners: D.L. Maskas and T. Ikeda)
PICES VI (1997)	BIO/FIS BIO/MEQ	• Mickonekton of the North Pacific: Distribution, biology and trophic linkages. (Co-Conveners: R. D. Brodeur, K. Kawaguchi and Q. S. Tang) • Harmful algal blooms: Causes and consequences. (Co-Conveners: R. Forbes and J. H. Shim)
PICES VII (1998)	BIO POC/BIO MEQ/BIO	• Controlling factors for lower trophic levels (especially phytoplankton stocks). (Co-Conveners: V. Alexander, A. Taniguchi and P. J. Harrison) • Carbon cycle in the North Pacific Ocean. (Co-Conveners: S. Tsunogai and C. S. Wang) • Contaminants in higher trophic level biota-linkages between individual and population responses. (Co-Conveners: R. F. Addison and L. Jones)
PICES VIII (1999)	BIO/CCCC MEQ/BIO	• Recent findings of GLOBEC and GLOBEC-like programs in the North Pacific. (Co-Conveners: M.D. Ohman and V.I. Radchenko) • Coastal eutrophication, phytoplankton dynamics and harmful algal blooms. (Co-Conveners: D. L. Garrison and T. Orlova)
PICES IX (2000)	BIO BIO/CCCC POC/BIO	• Prey consumption by higher trophic level predators in the PICES regions: Implications for ecosystem studies. (Co-Conveners: G. L. Hunt and H. Kato) • Recent progress in zooplankton ecology study in PICES regions. (Co-Conveners: T. Ikeda, W. S. Kim, M. M. Mullin and D. W. Welch) • North Pacific carbon cycling and ecosystem dynamics. (Co-Conveners: K. L. Denman, S. R. E. Emerson and T. Saino)
PICES X (2001)	BIO POC/BIO/FIS MEQ/BIO/POC	• Plankton size classes, functional groups and ecosystem dynamics: Causes and consequences. (Co-Conveners: A. Pena, T. Saino and P. A. Wheeler) • The physics and biology of eddies, meanders and rings in the PICES regions. (Co-Conveners: W. R. Crawford, J. J. Polonina and T. Sugimoto) • Physical, chemical and biological interactions during harmful algal blooms. (Co-Conveners: H. G. Kim, F. J. R. Taylor and V. L. Trainer)

Table 3 Summary of other annual activities.

Year	Annual activities
PICES I (1992)	• recommended the collection and dissemination of the schedules for cruises in the subarctic Pacific by major research vessels of the member nations • discussed possible coordinated research topics by member nations
PICES II (1993)	• recommended the development of straw man proposal for PICES-GLOBEC
PICES IV (1995)	• recommended WG 11: Consumption of marine resources by marine birds and mammals in the PICES region
PICES V (1996)	• recommended increased BIO representation for CCCC-IP, REX Task Team (Hunt) and MODEL Task Team (Jones) • Zhang was appointed to SCOR WG 105 as PICES representative and as rapporteur to BIO and FIS for SCOR WG 105
PICES VI (1997)	• recommended WG14: Effective sampling of micronekton to estimate ecosystem carrying capacity
PICES VII (1998)	• recommended PICES/ICES collaboration for ICES zooplankton workshop in 2000 • supported formation of Iron Fertilization Experiment Advisory Panel
PICES VIII (1999)	• recommended establishment of Advisory Panel on Marine Birds and Mammals
PICES IX (2000)	• convened BIO/MBMAP Technical Workshop "The basis for estimating the abundance of marine birds and mammals, and the impact of their predation on other organisms". (Co-Convenors: G. L. Hunt and H. Kato) • presented a proposal on ICES/PICES/GLOBEC Symposium on Comparative zooplankton ecology at ICES/PICES Zooplankton Ecology Workshop in Honolulu (approved by ICES and international GLOBEC) • published PICES Scientific Report No. 14 "Predation by marine birds and mammals in the subarctic North Pacific Ocean"

Table 4 Strategic plan and progress.

Goal	Progress
Improve cooperation with other PICES components	Accomplished by sponsoring many joint topic sessions with CCCC, POC, MBM Advisory Panel at PICES IX, and with POC, FIS, and MEQ at PICES X
Enhance interaction with relevant international organizations	BIO proposed a joint ICES/PICES/GLOBEC Symposium on Comparative zooplankton ecology to be held in May 2003
Increase involvement in specific recognized scientific issues	BIO participated in a workshop on "Designing the iron fertilization experiment in the subarctic Pacific" in Tsukuba, Japan, 2000, and plans participation in field experiments in 2001 and beyond
Improve community attendance and participation in Committees, Task Teams and Working Groups	This remains a problem area
Improve inter-sessional work via e-mail leading to shorter and more efficient Annual Meetings	This has only been partly successful. More e-mails do not necessarily lead to shorter meetings
Increase travel support for student participation at Annual Meetings	PICES is providing partial support for some students and young scientists, but BIO does not have data available to document extent or details

Scientific themes and future prospects

A distillation of BIO activities over the last decade generates three primary themes: (1) regional and basin-wide comparisons of lower and upper trophic levels, (2) importance of life histories, alternate food webs, and understudied groups of organisms for ecosystem analysis, and (3) role of trace metals and biogeochemical cycling in controlling biological production and the carbon cycle. We will not attempt to give a comprehensive overview of these themes, but provide some illustrative examples of leaps forward and remaining gaps in our understanding.

A major early success of PICES interest in basin scale comparisons is presented in the special issue of *Progress in Oceanography* on "Ecosystem dynamics in the eastern and western Gyres of the Subarctic Pacific" (Beamish *et al.* [Eds.] 1999). Harrison *et al.* (1999) noted higher nutrients and chlorophyll in the west compared to the east but similar levels of primary production (Table 5). Mackas and Tsuda (1999) concluded that there is some evidence that the western Gyre is more productive than the Alaska Gyre (Fig. 1), but noted that more research is needed to determine if there is a permanent east-west gradient. More important for ecosystem analysis is the recognition of interannual and interdecadal changes and links to climate variability. Mackas and Tsuda (1999) described evidence of long-term shifts in biological characteristics such as size structure and life history timing for subarctic zooplankton, and concluded that "Comparisons of both present ecosystem state and historical precursors among different parts of the North Pacific are likely to be essential for development of this understanding" (of changes in the pelagic ecosystem that are large in amplitude, but are widely and unevenly spaced across decades). A significant expansion of this work on the importance of nutrients in controlling the levels of primary production in the eastern and western gyres, is the application of satellite data on the distributions of nitrate (inferred from temperature) and phytoplankton (inferred from ocean color as a measure of chlorophyll). Using such data, Goes *et al.* (2001) showed how the onset of El Niño resulted in *depressed* phytoplankton production in the Gulf of Alaska, but *increased* phytoplankton production in the following spring and summer in the western North Pacific (Fig. 2).

A second theme emerging in the progress of biological oceanography of the North Pacific Ocean is variation or deviation from traditional food webs along with recognition of woefully understudied groups of organisms. A striking example of a change in food web structure is the unusual appearance of coccolithophore blooms in the Bering Sea (Fig. 3), concurrent changes in relative abundances of copepods and euphausids (Napp and Hunt 2001, Stockwell *et al.* 2001), and massive die-off of short-tailed shearwaters (*Puffinus tenuirostris*), an apex predator in the south-eastern Bering Sea (Baduini *et al.* 2001). Another example of a major change in foob web structure is the seven-fold increase in gelatinous zooplankton in the Bering Sea (Fig. 4) that may result from a competitive interaction between jellyfish and walleye pollock (Brodeur *et al.* 1999, 2002). Both of these changes in the Bering Sea appear to be related to climate changes, but the underlying causes and interactive effects remain to be determined. A special issue of *Progress in Oceanography* will cover "Variability in the Bering Sea Ecosystem" (Macklin *et al.* [Eds.] 2002).

Table 5 Comparison of primary production and phytoplankton biomass, and physical and chemical environmental factors between the Western Subarctic Gyre (WSG) and Alaskan Gyre (AG) in summer (from Shiomoto *et al*. 1998).

Parameter	WSG	AG
Primary production (mg C m^{-2} d^{-1})	663 ± 86; 751 ± 94	642 ± 55
Chl concentration (mg L^{-1})	1.03 ± 0.15; 0.82 ± 0.05	0.4
Chl standing stock (mg m^{-2})	28.6 ± 2.9	22.9 ± 1.6
Surface primary productivity (mg C mg Chl $^{-1}$ d $^{-1}$)	33.4 ± 2.5	51.3 ± 5.6
Temperature < 50 m (^{o}C)	3.0 – 9.5	6 - 12
Euphotic zone depth (m)	24 - 49	57- 82
Nitrate + nitrite concentration (μM)	10.4 – 22.9	6 - 17

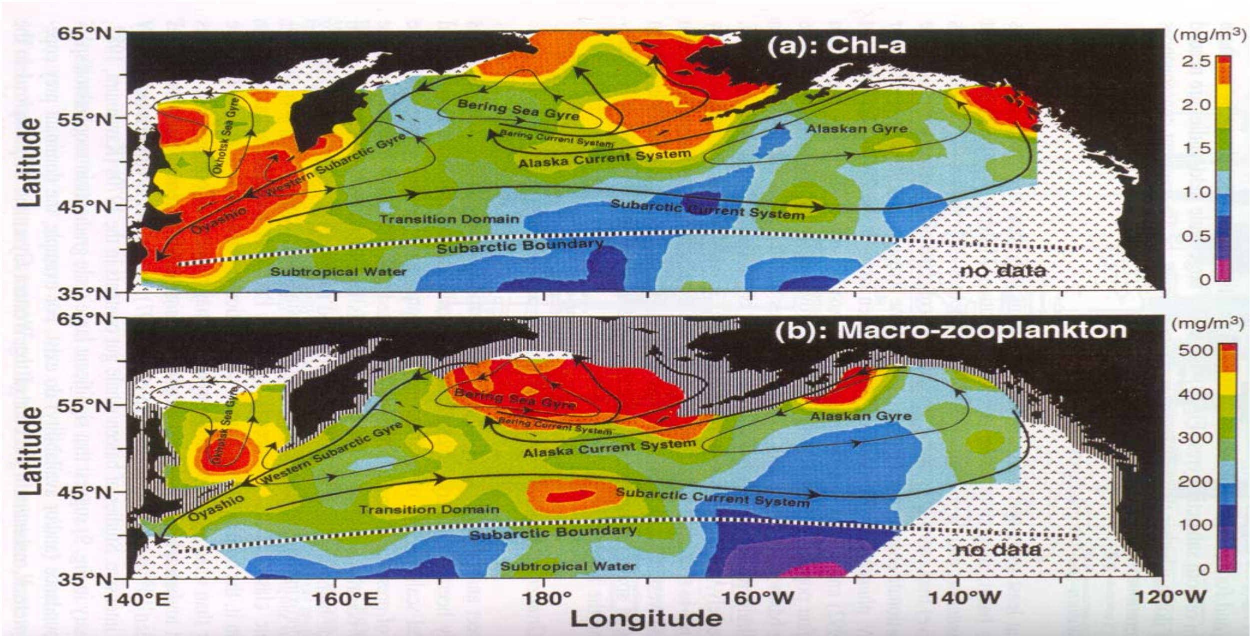

Fig. 1 Average summer season distributions of upper ocean chlorophyll concentration (upper panel), and zooplankton biomass (lower panel) in the subarctic Pacific, overlaid with the circulation pattern. Figure courtesy of K. Tadokoko, modified by colorization and addition of circulation streamlines from Sugimoto and Tadokoro, 1997. Figure 8 from Mackas and Tsuda (1999).

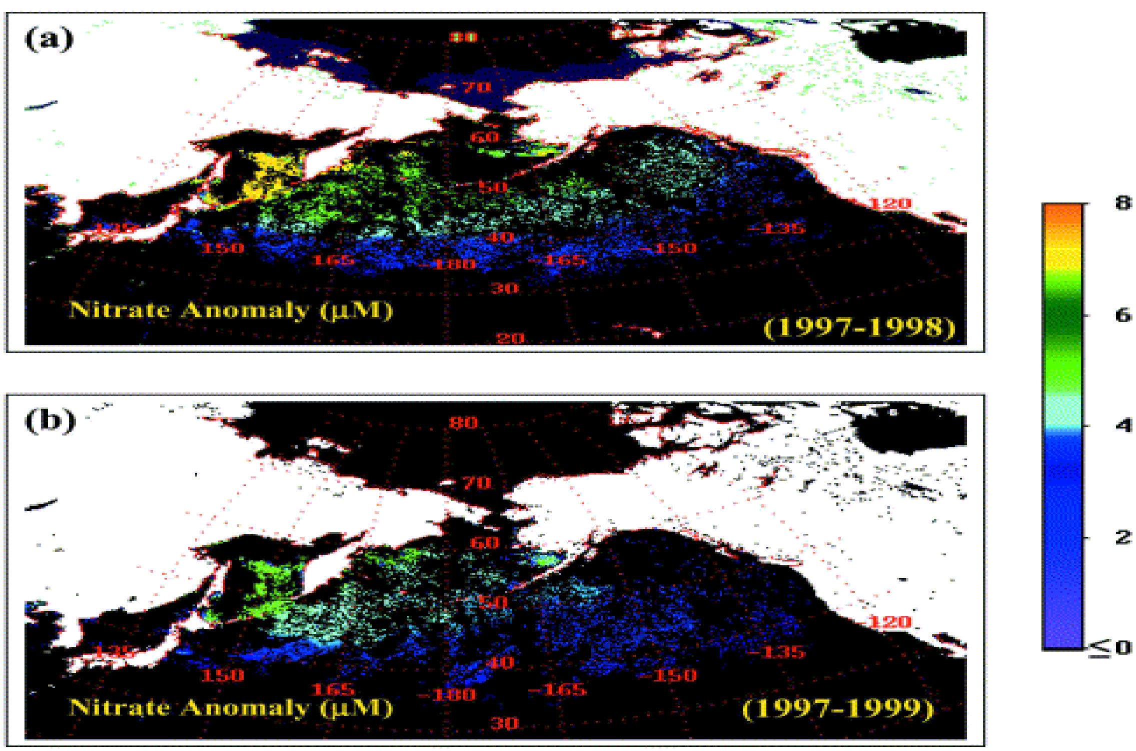

Fig. 2 Anomaly plots showing the difference in sea surface nitrate concentrations between a) 1998 and 1997 and b) 1999 and 1997. Figure 3 from Goes *et al*. (2001).

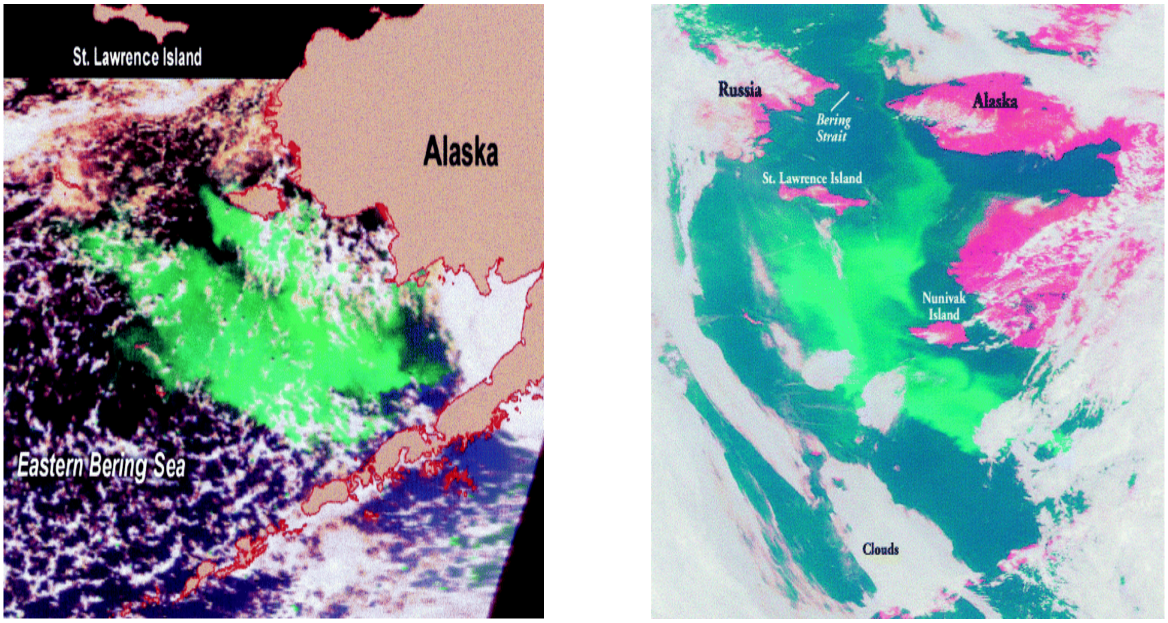

Fig. 3 SeaWIFS composite true color image of coccolithophore bloom in the eastern Bering Sea (left panel). SeaWIFS false color image showing the extension of a filament of the bloom northward to the Bering Strait (right panel). Both images are from Napp and Hunt (2001).

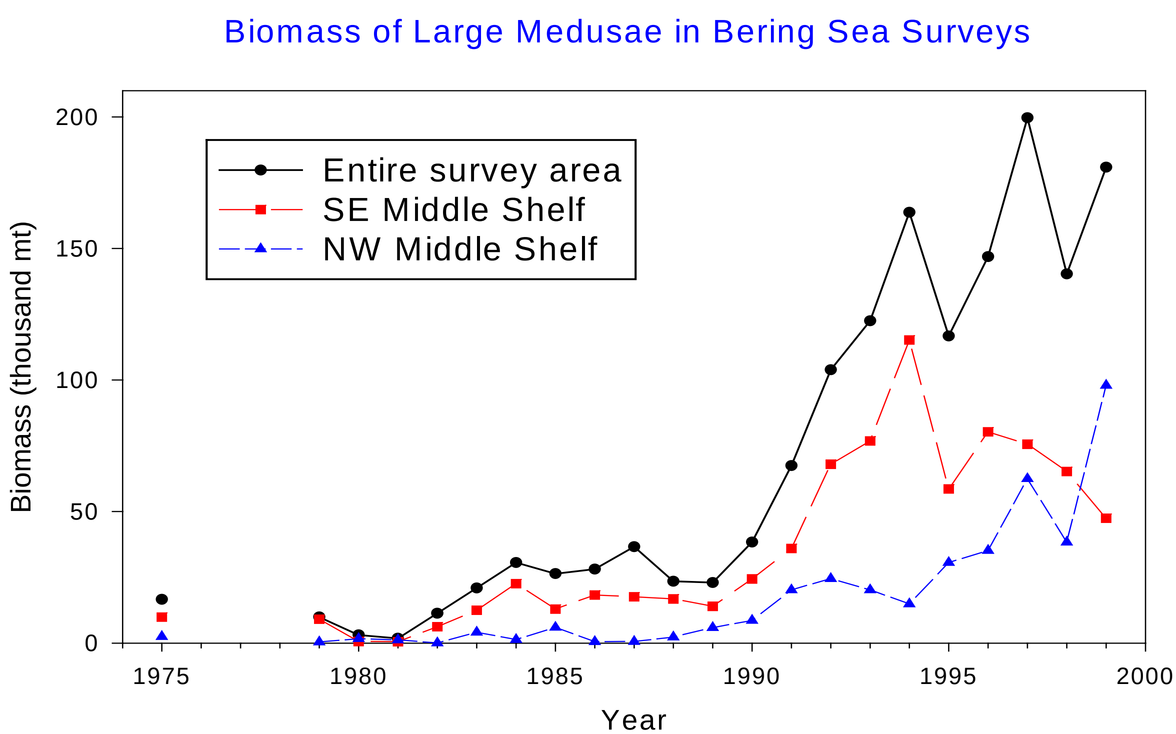

Fig. 4 Biomass of medusae collected on the eastern Bering shelf from 1975-1999. Figure 2 from Brodeur *et al.* (2002).

The understudied groups of organisms in the North Pacific Ocean include micronekton and marine birds and mammals. Micronekton include small squid, migratory midwater fish and shrimps, that are difficult to sample quantitatively. Mackas and Tsuda (1999) demonstrate the importance of micronekton by partitioning the consumption of copepod production (*Neocalanus*) in the subarctic Pacific (Fig. 5). Their analysis suggests that approximately one-third of the total predation of *Neocalanus* is likely to be due to squids, myctophids, shrimp and deep-living chaetognaths. Work is underway by WG 14 to develop and improve methods for sampling and assessing the role of microzooplankton in the North Pacific.

Marine birds and mammals comprise another major understudied group in the North Pacific ecosystem. As part of the east-west gyre comparison, Springer *et al.* (1999) reviewed the gross distribution of seabirds and certain marine mammals in the North Pacific gyres to compare their east-west distributions. The available information indicates that seabird biomass in the western gyre is three-fold greater than that in the eastern gyre. Cetaceans (prior to overharvesting) were also more abundant in the western gyre. Both of these observations suggest higher productivity in the western gyre as was also suggested by Mackas and Tsuda (1999) and by Goes *et al.* (2001). Hunt *et al.* (2000) compiled more extensive data on biomass distribution and prey consumption and identified major gaps in the survey of marine birds and mammals in the regional areas depicted in Figure 2 (Introduction to this volume). As better observational data become available it is clear that populations of marine birds and mammals fluctuate with changing climate conditions.

Current work in the southeast Bering Sea demonstrates major changes in the importance of large whales in the 1990s in terms of predation and carbon cycling (Tynan 2001). Combinations of long-term observations of abundances and migrations with measures of consumption demonstrate dramatic changes in the roles of large whales as top predators in the southeast Bering Sea (Tynan 2001). It is only by increasing our knowledge of the abundance and activity of these important groups, that we will have sufficient information to understand and predict possible changes in the ecosystem resulting from climatic or anthropogenic changes.

Finally, the role of trace metals and biogeochemical cycling in controlling biological production and the carbon cycle has, and will, continue to receive attention in studies of the North Pacific. The role of iron as an important trace metal limiting phytoplankton production was first recognized in the subarctic Pacific by the late John Martin. Investigations in the Gulf of Alaska demonstrate an important role of iron and light in regulating diatom growth (Fig. 6, Harrison *et al.* 1999). Their results support the conclusion that iron limits the primary productivity of the large cells (especially diatoms) except in the winter when iron and light become co-limiting. The small phytoplankton do not appear to be iron limited, but are mainly controlled by microzooplankton grazers. The potential effect of iron on the subarctic ecosystem continues to be an important area of investigation with a PICES supported field program planned for 2002-2003.

Studies of carbon cycling have been jointly sponsored by BIO and POC through workshops and topic sessions, and the most recent results will be presented in a special issue of *Deep-Sea Research* II in 2002. Other examples of important aspects of biogeochemistry in the North Pacific include re-evaluation of estimates of nitrogen fixation in the Pacific Ocean and globally (Karl *et al.* 2001), and the impact of microbial food webs in both the Pacific and the Atlantic Oceans. These issues will be covered in a special issue of *Progress in Oceanography* on "Plankton size classes, functional groups, and ecosystem dynamics: Causes and consequences" (Bychkov and Pena [Eds.] 2003). We anticipate that such studies will continue to be an important part of PICES activities through the next decade.

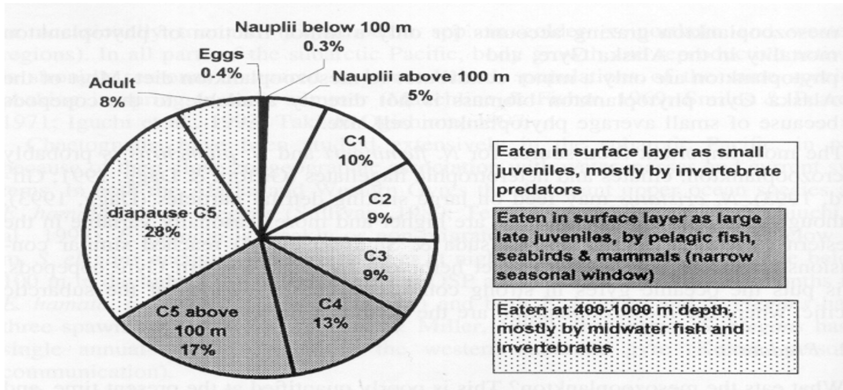

Fig. 5 Fate of *Neocalanus plumchrus* production, as estimated from a life-stage partitioning of mortality weighted by individual body size. Shading indicates degree of availability to different sets of predators. About one-third (unshaded) is in the upper layer on small nauplii and early copepodites, and is probably available mostly to invertebrate predators. Slightly over one third (sloped lines) is on larger C3-C5 copepodites during the brief time window before they leave the surface layer. This fraction is the only one likely to be directly available to the larger planktivorous pelagic fish, sea birds and marine mammals. It is also available to invertebrates and migratory micronecton. The remainder occurs below the upper 150 m, mostly on diapausing C5 and adults (stippled); this fraction is likely to be available primarily to midwater micronekton. Figure 5 from Mackas and Tsuda (1999).

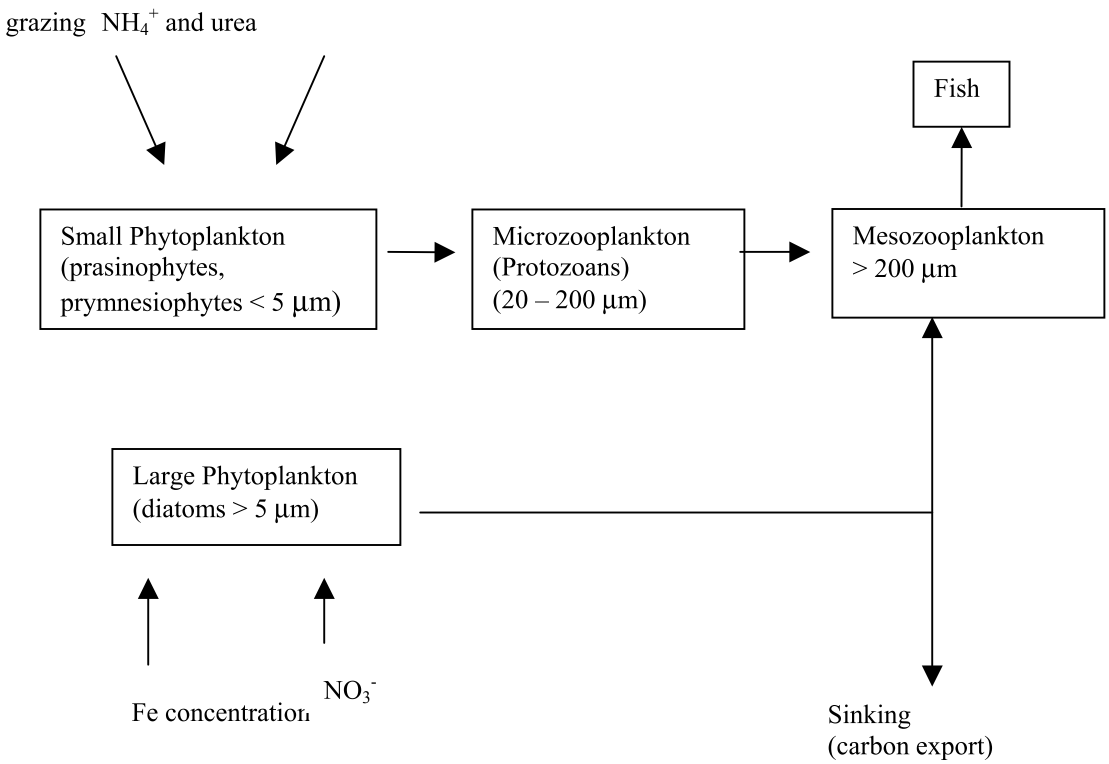

Fig. 6 Simple food change at Station P showing bottom-up control of large phytoplankton by Fe and top-down control of small phytoplankton by microzooplankton grazing. Figure 8 from Harrison *et al.* (1999).

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Future needs for biological oceanographic studies in the Pacific Ocean

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A personal introduction

My academic career started in agriculture, then I obtained my doctorate in the faculty of medicine, and only after this did I become aware of ecology as a science applied to fisheries. I had learned to gather data on complex problems in agriculture and medicine, analyse the data and form conclusions. When I started to study the biology of the sea in the late 1950s, it was apparent that biological studies were dominated by fisheries science. This science had a different approach to those that I had learned earlier – fisheries science was dominated by a theory on population dynamics in which there was little agreement between the data and the theory. The literature was full of stock/recruitment curves in which the data points seldom, if ever, fell on a line supporting the theoretically assumed relationship. Fisheries scientists were not responsible for collecting these data; they came largely from fish catch and the scatter of points was assumed to reflect inaccuracies in catch data rather than any fault in the ecological theory. At the same time, other branches of ecology had evolved in a largely conceptual sense characterised by a language of terms which were difficult to define precisely, such as biocoenosis, niche and neutralism – some of which also required further definition such as hypervolume niche, realised niche, etc. There was also a heavy use of probability statistics, particularly in fisheries science, which substituted for a lack of real understanding of processes. The whole science seemed to be more an expression of mystical faith than an understanding of Nature.

At that time, biological oceanography was in its infancy and had been largely concerned with measuring plankton abundance and nutrients, with little attempt to couple life in the sea with the ocean environment. It was not until the late 1940s (*e.g.*, Riley 1946) that some dynamic processes were described. These efforts remained largely unnoticed until the early 1970s when some awkward questions were asked by society regarding such practical problems as ocean pollution and declining fish stocks. These questions required a more pragmatic approach to the science of the sea and, in the case of fisheries, a more scientific approach was called for in order to provide some realistic answers ("The Marine Revolution", Ray 1970). I believe that this revolution is still underway and that the key to our understanding of life in the sea lies in the accumulation of extensive new data, such as has already changed the course of other biological sciences (*e.g.*, agriculture and medicine). We should also avoid the promulgation of any ecological theories or models (such as the historical dominance of Population Dynamics in fisheries science), if they are not based on factual relationships, which can be further tested from subsequently collected data.

In summary to my introduction, I believe that studies on the biological dynamics of marine life have fallen far behind other branches of applied biology, such as agriculture and medicine. I do not believe that this is due entirely to a lack of financial support, but that we have in the past been heading in a wrong scientific direction. We have a lot of catching up to do.

The holistic approach to ecosystem understanding

The basic model

The need to include environmental or climatic changes in models aimed at ecosystem understanding can be given as shown in Figure 1. In this model we include the forcing functions of climate on the ecosystem and predator control through fish abundance, which is itself controlled by the extent of fisheries at the other end. There are two potential short cuts, which I believe are to be avoided at all cost. The first is to assume that fish abundance can be determined from some probability relationship directly with climate. There are numerous examples in the literature in which strong correlations have been shown to occur between a physical parameter, such as wind, and a fish population, only to see the correlation collapse after a few years. For example, Drinkwater *et al.* (1996) reviewed a number of papers that related temperature to lobster abundance. They concluded that increased lobster catches could not be related to temperature, in spite of several earlier findings to the contrary. In fact, it seems intuitively correct that no species could have evolved with a heavy dependence on a single environmental factor that is highly variable.

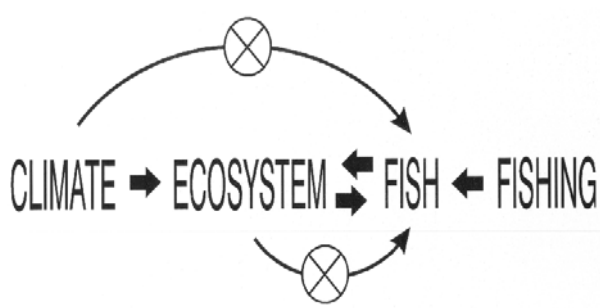

Fig. 1 A general relationship between climate, the ecosystem and fisheries indicating two alternate pathways for study which have been proved largely unacceptable in the past.

The second tempting short cut in the model above, is to consider only how the ecosystem affects fish abundance and to leave out the climate as a more or less random function. An example of how this too does not work is given by Trites *et al.* (1999) who used Ecopath and Ecosim models to account for an almost four-fold increase in pollock biomass and other changes that occurred over two time periods following changes in whaling and fishing in the Bering Sea. The mass-balance models *per se* failed to account for the observed changes, but there was a strong indication that environmental factors affecting primary production and recruitment were more important than predator/prey interactions alone. Thus mass balance ecosystem models that do not include climate variability cannot provide reliable information on trends in marine fish production. 'Quick fix' models that are not based on this fundamental understanding of ocean ecosystems should be avoided.

The problem of scaling results

Biological oceanographers have been studying the oceans on two different scales. One involves very large-scale events over long time periods, such as the identification of regime shifts in fisheries data (*e.g.*, Beamish *et al.* 2000; Klyashtorin 1997). The other involves much more detailed studies of ecosystem relationships which are carried out over relatively small areas (*e.g.*, Robinson and Ware 1994) and, in some cases, inside mesocosms (*e.g.*, Andersen *et al.* 1987). Because of the amount of data on different parameters that are required by the latter studies, they cannot be performed over vast areas. The problem is how to project the small-scale studies into the large scale studies to give us some understanding of how whole ocean systems can change.

This problem can be partly resolved if ecosystem understanding can be focused on a critical period in the life cycle of a fish. For example, Beamish and Mahnken (1999) have described critical size/critical period events in the life of coho salmon. The first event is density-dependent predation when the salmon enter the sea, and the second event is density independent and related to mortality of the young smolts in the fall and winter months depending on how well they fed during the summer. Thus the need to study the whole of the coho salmon ecosystem is narrowed to two critical periods. Another example is found in Kruse and Tyler (1989) who describe several critical periods related to climate in the reproduction of the English sole.

A more general presentation of this idea is given by Bax *et al.* (1999) who describe "leverage points" as points in time and space within an ecosystem where particular components are most vulnerable to change. This is illustrated in Figure 2 where various critical points are identified in an ecosystem model. These are identified in order to suggest to managers of fisheries resources where the ecosystem becomes highly dependent on a particular process. For example, the quantity of phytoplankton sinking out of the water column versus that which remains suspended, is a point that divides the primary production between the pelagic and benthic ecosystems. Or in another example, both the precautionary approach to

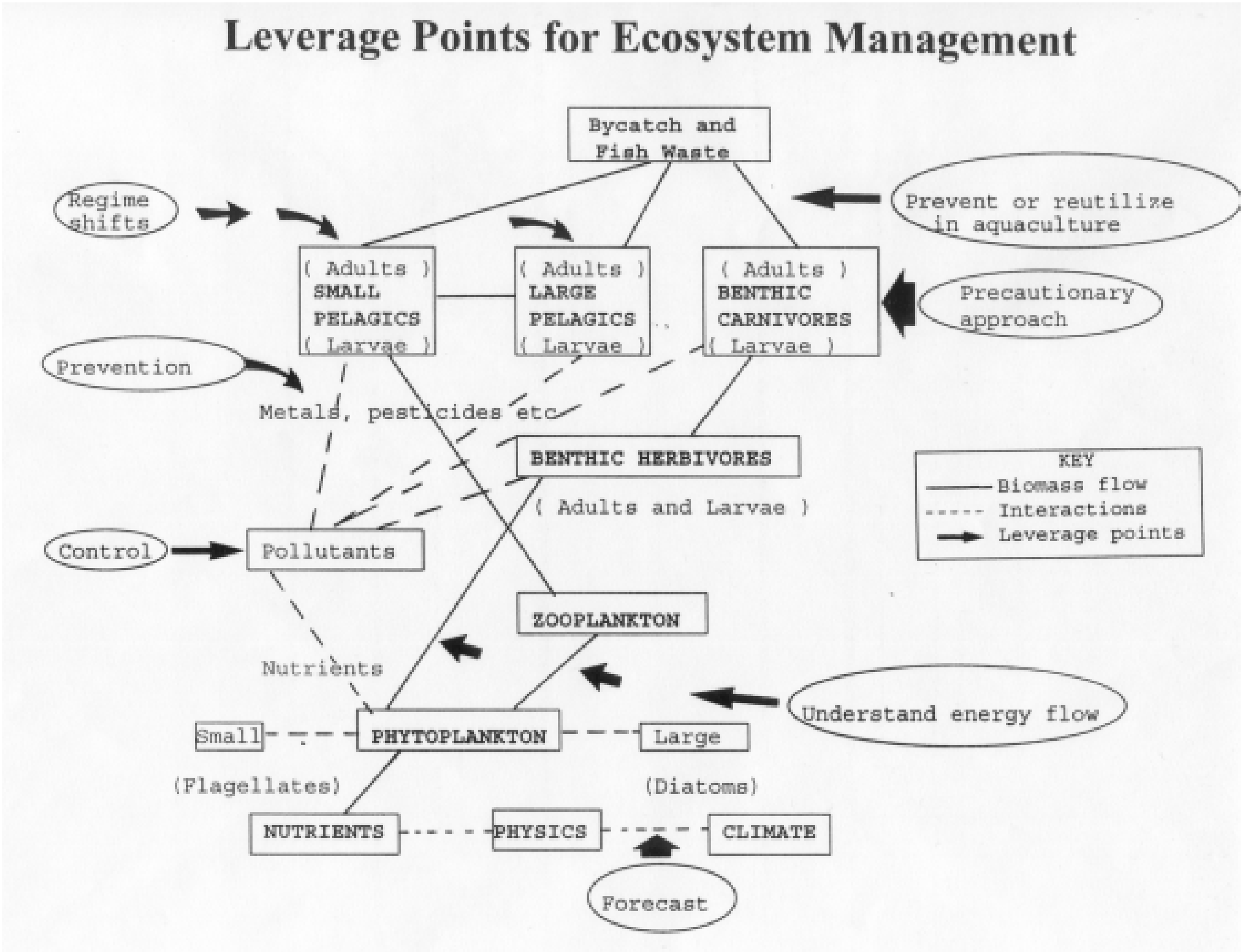

Fig. 2 A marine ecosystem model indicating "leverage points" of particular importance to management (adapted from Bax *et al.* 1999).

catching fish and the occurrence of regime shifts are critical points in predator control of the ecosystem. The role of bycatch in the ecosystem is generally ignored and should be included along with plans to utilize this high quality protein, such as in aquaculture. Pollution is another "leverage point", especially the eutrophication of coastal waters, which now appears to be widespread. By identifying these points, the problem of applying detailed small-scale data to large ecosystems may become more tractable.

Gathering new kinds of data over large areas and long time scales

Recently, the idea of "operational oceanography" has been defined as the application of science to provide timely, accurate, value-added oceanographic products and services that affect decisions of clients. This is a very broad definition and it is made in order to include a wide range of user agencies. However, among these, operational oceanography is mandated to include real-time information on changes in ocean environments and primary productivity, with forecasts of their impact on ocean ecosystems. The purpose of this desideratum is to better manage and protect the fisheries resources of the ocean (Bancroft, personal communication). Thus gathering of biological data needs to be part of operational oceanography if we are to supply data for forecasting ecosystem change. This will require new methods and new programs.

Although methodology seems a mundane part of science, in fact about half of the Nobel prizes awarded annually have been essentially for gaining scientific insight using a new method. Methods form the basis of data collection, and accumulated data are our only source of understanding ecosystems. I do not want to dwell on the past, but I want to look at some of the newer techniques that are becoming available to study the vast expanse of the oceans. We need new and original ways of gathering data at minimum expense. While I cannot review techniques, which are yet to be invented, it serves my purpose in drawing attention to the value of methodology, to briefly review some of the new techniques that have recently impacted biological oceanography. For example:

- New ways of taking multiple samples of plankton, nutrients and the physical characteristics of water masses are essential. Such equipment replaces the traditional plankton net and bottle casts, and can be towed off commercial vessels; programs have to be developed for the North Pacific (*e.g.*, using Batfish and BIONESS samplers).
- New and better ways of counting and sizing plankton are also needed using more sophisticated instruments, which may sometimes be borrowed from medical science (*e.g.*, the flow cytometer).
- Satellite sensing is a wonderful way of covering vast areas of ocean, and the chlorophyll maps which are now available give real-time pictures of events that were not available until only a few years ago. It would be helpful if the size of the phytoplankton could also be measured from space through some light-scattering device.
- The Argo program for examining the physical structure of the world's oceans with profiling CTDs is another advancement of great benefit to biological oceanographers.
- DNA analysis can be used by oceanographers in many ways; for example, in the correct identification of species and the tracing of discrete fish stocks.
- Automated oceanographic buoys need to be employed extensively throughout the oceans to continually monitor many biological, chemical and physical parameters.

These are but a few examples of new methods that will give biologists better time/space data coverage of the oceans. I would like to add in conclusion to this section, that many of these data can only be collected through international co-operation. This is where organisations, such as the North Pacific Marine Science Organization (PICES), can play a vital role in ocean exploration.

Models

There are many different models that can be applied to marine ecosystems depending on whether one is modelling the dispersion of a pollutant, species migrations, food chains, food webs, including or excluding physical forcing functions, and so on. Steele's (1962) pioneering work on trophodynamics, Ryther's (1969) food chain examination of fish production, and Odum's (1967) biological circuitry models were among the first ecosystem models. Much larger models that include physical forcing of the ecosystem, such as the European Regional Seas Model (ERSEM – Baretta *et al.* 1995), have developed over the years together with more complex models dealing primarily with trophic interactions (*e.g.*, Ecopath, Polovina 1984). What is the optimal size of an ecosystem model? When the question being asked is very specific, such as in the case of carbon dioxide flux, then the model can be relatively simple (*e.g.*, Woods and Barkmann 1993). Or in the case of fisheries, in order to keep models manageable, they should be written to deal with specific parts of the ecosystem, such as that described by Robinson and Ware (1994) for an upwelling system and four species of fish. Complex models are not necessarily better than simple models.

For the estimation of "carrying capacity" and for some aspects of climate change, models based on size relationships (*e.g.*, Sheldon *et al.* 1982) may be sufficient to give useful predictions for regional forecasts. Such models have the advantage of being largely independent of species identification which is especially helpful for the plankton community, while at the other end of the spectrum, fish catch can be analysed in terms of the size of fish required (*i.e.*, a large biomass of small fish or a smaller biomass of large fish).

In addition to the concepts above, genetic change may also need to be added to some models (see Grant and Waples 2000). This becomes especially important when one considers that a fishery is often inadvertently selecting for particular genetic characteristics (*e.g*., size).

Biological coefficients

In formulating equations for trophodynamic studies, it is necessary to research the values used for biological coefficients in various relationships. This includes determining and revising different forcing, physiological and phasing functions as defined in Lalli and Parsons (1999). Many of these values are fairly well known for the phytoplankton community such as the parameters of the P *vs* I curve. However, for higher trophic levels there is a need to research many relationships. For example, how turbulence and mixing interacts with the plankton and fish community is not fully known.

As another example, I believe that one very important number to study is ecological efficiency. In a paper by Pauly and Christensen (1995, Fig. 2), the authors chose a number for the transfer efficiency by surveying the literature for the most commonly used value. Since most of these values were not determined independently, a great deal of copying of a 10% value had occurred (probably based on a paper by Slobodkin, 1961), and this value was then assumed to be the most probably correct value for the authors to use in their discussion. As Baumann (1995) pointed out, choosing the most popular value of 10 % is not justification of its validity. The transfer efficiency derives its name from the useful concept of how much energy or biomass is transferred between trophic levels. It is really better thought of as the ecological efficiency (E), which is defined the same way. (However, some authors have used the term "transfer efficiency" to indicate the ratio of primary to secondary production, which is really only an indicator of the ecological efficiency; for small differences in these terms, see Parsons *et al.* (1988).

The ecological efficiency is equal to the multiple of the growth efficiency (K) and the ecotrophic efficiency (E_c), and it has been pointed out (Parsons *et al.* 1988) that, for many aquatic organisms, growth efficiencies are of the order of 30% and the amount of lower trophic levels consumed annually (E_c) is at least 80%. Thus one would expect ecological efficiencies in the sea to be closer to 20% than the popular figure of 10%. Recent discussion of the high ecotrophic efficiency in aquatic habitats is given by Cyr and Pace (1993), and there are a number of independent estimates of ecological efficiencies (*e.g*., Sheldon *et al*. 1977; Iverson 1990; Gaedke and Straile 1994; Parsons and Chen 1994), all of which generally indicate values >15%. A more detailed account of this discussion is given in Parsons and Lalli (1988), and I suggest that this is an example of the kind of physiological value that is widely used, but poorly known, and which therefore requires some fundamental research.

The need to accurately know the various biological coefficients that are used in models is an on-going problem that requires maximum cooperation between the experimental physiologist and the field oceanographer.

Ecosystem structure

It is apparent that a large amount of marine biomass is being excluded from ecosystem studies, either because there are no data on some parts of the food chain, or because traditional focus has always been towards commercially exploitable predators. Thus there are few studies leading to ecosystems models, which include the jellyfish of the sea, non-commercial fishes and migratory mesopelagic fishes. Further quantification is needed of the bacterial loop (*e.g*., Azam *et al.* 1991). In particular, the recycling of photosynthetic products (see Kirchman 2000, for review) now appears to be very important in some environments where the whole ecosystem may depend on the recycling. With anywhere from 10^5 to 10^9 bacteria per ml of seawater, it almost appears that their previously neglected role in holding the food chain of the sea together might be crudely analogous to the missing dark matter in the universe. Bacterial cycles will also require more information on the role of zooflagellates (*e.g*., Fenchel 1982). In addition, the dynamics of viral response to an algal bloom (*e.g*., Yager *et al.* 2001) needs to be understood under different oceanic conditions. The pelagic/benthic boundary layer (*e.g.*, Smith *et al.* 2001) forms another area for which much more understanding is required, particularly in connection with the large fisheries in the continental seas. The inclusion of more biology in our concept of ecosystem structure appears to me to be essential for the future.

Another problem in studying ecosystem structure is to keep in mind that more than one set of environmental factors can give the same result. An example of this is in the physiological dynamics of phytoplankton blooms (Parsons and Takahashi 1973). It can be shown, for example, that phytoplankton ecology may be dominated by flagellates under conditions of deep mixed water columns and low light, and also under conditions of stable water columns with low nutrients, and under conditions of eutrophication when silicate may limit diatom growth. There is often, therefore, no single explanation for ecological phenomena; cause and effect may be proportioned to a number of causative agents.

The relationship between plankton distributions and small-scale physical disturbance has recently thrown some light on how animals manage to graze particulate matter when it is so sparsely distributed. While the concentration of prey items has been easily measured, it now appears that the aggregation of prey (*i.e.*, patchy distrubtion) is just as important a number as the concentration. The effects of small-scale turbulence summarised by Seuront (2001) are (1) to increase the rate of the nutrient flux around non-motile phytoplankton cells, (2) to decrease the physical coagulation of phytoplankton cells, and (3) to increase predator/prey encounter rates. Processes involved with aggregation and physical turbulence need to be studied further (*e.g.*, Incze *et al.* 2001).

Conclusion

In conclusion, I have tried to emphasise that biological oceanography, including the fish of the sea, is still a young science. We need to collect much more data using new techniques, and we need to learn how to better integrate our results into dynamic models. My talk has emphasised the ecosystem approach as being a focal point of biological oceanographic studies, but this is not intended to distract from studies on species or communities, which I would tend to describe under the different heading of marine biology. In the field pertaining directly to fisheries science, there is no 'quick fix' via inadequate biological models. Fisheries science as part of biological oceanographic studies will only advance if it engages in fundamental studies on ocean ecosystems.

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Ten years FIS in PICES: An introspective, retrospective, critical and constructive review of Fishery Science in PICES

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Introduction

The city of Victoria was the venue for the first and tenth anniversary meetings of PICES. This city has many reminders of its origins in the British Empire, and these illustrate an element of PICES. Within 100 m of the Conference Centre, there are statues and references to Rudyard Kipling, a British Nobel laureate poet who became symbolic of the British Empire. Perhaps his most famous line is from the "Ballad of East and West" which begins: "*OH, East is East and West is West, and never the twain shall meet,…*". The "twain" was the supposed cultural discontinuity between the east and west that Kipling thought was so great it would never be bridged. Clearly, the sentiments of this line do not apply to PICES. During the first ten years of PICES, east has met west, repeatedly and successfully - and this is an excellent achievement of PICES. On the other hand, some might say that within PICES there still are a number of "twains", unrelated to "east" or "west", that have yet to be bridged, especially inter-disciplinary differences in perception and outlook among physical and biological oceanographers and fisheries biologists. In this report we make references to these differences, as we try to provide both a critical and constructive review of fisheries science in PICES. We acknowledge the many accomplishments of PICES but we also comment on its deficiencies. We conclude with a suggestion that the Organization should re-examine its roots and mandate, and ask how PICES can respond to meet the developing challenges of marine science.

In our opinion, an introspective re-evaluation of PICES is warranted at this time and we provide a justification from a fisheries perspective. In the ten years since PICES formed, many fisheries throughout the world have unexpectedly destabilized. In a sense, as fisheries scientists, we did not get much right in fisheries management in the 1990s. Some stocks collapsed while others increased, sometimes dramatically. Well-known examples would include declines and/or recoveries of Pacific salmon, groundfish species, the California sardine and Japanese sardine. Of course, fish stock declines are well-known in other parts of the world, but the extent of change in the world's marine fish stocks may be greater than is realized. This assertion is based on the observation that there are a number of instances where massive changes have occurred among smaller or less-well-known stocks, including, for example, several species of smelts (Osmeridae) in the North Pacific. New revelations on the concept of decadal-scale regimes and how they might affect fisheries have emerged (Steele 1996) and calls for ecosystem-based management have increased (NRC 1999; NMFS 1999). Some of the recent changes in fisheries have had large social and economic impacts. In British Columbia, changes in fisheries have devastated some coastal communities, of which many are First Nations. In Canada, and elsewhere, fisheries management agencies and scientists have been subjected to intense criticism. In this report, we suggest that organisations like PICES could do much more to bring more reliable information to those who want to better understand the issues.

PICES is a key scientific organization in the North Pacific, and the Fishery Science Committee (FIS) is the main structural component of fisheries science within PICES. First we ask about PICES: "what has PICES done to help clarify or assist with solutions to these problems in marine resources?" Second, we ask of FIS: "has FIS done anything in the last decade that will make a difference?" We cannot provide a definitive answer to either question, but we attempt the following: (i) for the question about PICES activities, we examine the existing structure of PICES and evaluate this against what the original founders of PICES indicated that PICES *should do* about fisheries science; (ii) for the question about FIS activities, we present a brief history of FIS in PICES and compare the effort and results of FIS activities in PICES with those of other Scientific Committees.

We test three hypotheses. *Hypothesis 1*: time devoted to FIS issues at Annual Meetings is lower than that of other Scientific Committees (POC - Physical Oceanography and Climate, BIO - Biological Oceanography, MEQ - Marine Environmental Quality). *Hypothesis 2*: time devoted to FIS issues at Annual Meetings is decreasing in recent years (relative to that of other Scientific Committees. *Hypothesis 3*: the numbers of pages of scientific reports devoted to issues of concern to FIS is lower than those devoted to other Scientific Committees. Also, we review the main objectives of PICES, as set out in the founding statutes, and provide an evaluation of the first ten years of PICES activities against these objectives. Then we briefly compare the structure of PICES with the Atlantic counterpart organization, ICES. We conclude with some suggestions for modifications in the structure and function of PICES, and FIS activities in PICES, and general PICES activities for the next decade.

Methods and materials

Data and information sources

We used PICES Annual Reports that provide minutes of all FIS meetings since 1994 (see references to "PICES"). This information was supplemented by references to some PICES Scientific Reports and Wooster and Callahan (1994).

Tests of hypotheses

To test the first and second hypotheses, we classified and quantified FIS activities at Annual Meetings (topics, symposia, working groups) based on analysis of PICES meeting schedules from 1993 to 2001 (see PICES Abstracts in references). The quantification was limited to time *within* formal meetings, so sessions hosted by CCCC Task Teams (REX, BASS and MODEL) were not included, but CCCC and Science Board (SB) were included (see below for more explanation of GLOBEC, also Perry *et al.*, this volume). We estimated the sum of time (hrs) devoted to each Scientific Committee including FIS. The cumulative hours for each session (usually in units of 4 hours, so one 8-hour day = two 4-hour sessions) were summed for each year from 1993 to 2001. We quantified the cumulative hours of "fishery science" topics presented by other groups, including some for BIO, POC, MEQ and CCCC. We compared FIS to other committees and activities. We used Excel spreadsheets to record the data. Data were analysed with Minitab© software.

To test the third hypothesis we reviewed all scientific publications from PICES and estimated the number of pages devoted to subject matter of interest to each committee. This included all PICES Scientific Reports and special publications of selected papers presented at various meetings organized and co-sponsored by PICES. We classified the content of the papers according to whether the subject material was, or was not, of direct relevance to fishery science. When a paper was clearly of interest to fishery science plus another subject area, such as physical oceanography, we counted the entire paper as of interest to fishery science.

Review of PICES activities

To evaluate present PICES activities with those suggested by the founders of PICES, we consulted the key publication "The PICES papers" (Wooster and Callahan 1994) that provides a brief scientific history of PICES, and presents the main tenets of the scientific objectives of the Organization.

Contrasting PICES to other organizations

As a guide to what PICES structure, function and activities could occur, we briefly examine the present structure of ICES, the namesake organization in the Atlantic and a clear model for development of the basic structure of PICES during the formative stages in the 1980s. Also, we briefly comment on the structure and function of some of the other scientific organizations in the North Pacific, and on how these organizations interface with PICES.

Results

A short history of FIS in PICES

The Fishery Science Committee was initiated in October 15, 1992, with Danuel M. Ware (Canada) named as the first Chairman. Members were from four member nations: Canada, Japan, People's Republic of China and U.S.A. In October 1993, Qi-Sheng Tang (China) became the second Chairman of FIS. In that year the first FIS Working Group (WG 3) on "Dynamics of small pelagics in coastal ecosystems" was formed, chaired jointly by John Hunter (U.S.A.) and Tokio Wada (Japan). By 1995, Republic of Korea and Russia joined PICES, and additional members joined FIS. Working Group 3 presented their final report. In 1996, Chang-Ik Zhang (Korea) became the third Chairman of FIS and a new WG 12 on "Crabs and shrimps" was formed with Robert S. Otto (U.S.A.) and Vitaly E. Rodin (Russia) as Co-Chairmen. In 1999, Douglas E. Hay (Canada) became the fourth Chairman and in 2000, a third WG 16 was formed on "Climate change, shifts in fish production and fisheries management" with Richard J. Beamish (Canada) and Tokio Wada (Japan) as Co-Chairmen. In 2001, the WG 12 report was completed. During this period the FIS Committee developed many scientific sessions, sometimes held in co-operation with other Scientific Committees (see below). FIS also sponsored special meetings and symposia that led to a number of scientific reports (see below).

FIS activities in PICES

The main activities of FIS in PICES have been: (a) the development of symposia and topic sessions, sometimes in conjunction with other Scientific Committees; (b) supporting specific Working Groups, usually with a term of 3 years, to address and prepare a report considered of key interest to PICES; (c) convening special meetings of FIS usually during Annual Meetings, to discuss and report on fishery science issues. The minutes of all meetings are recorded in the PICES Annual Reports.

Since 1994, FIS sponsored one or more topic sessions each year, sometimes in co-operation with other Scientific Committees (Table 1). Topics varied widely and represent more than 75 hours of scientific presentations. Since its inception, FIS has established three Working Groups, of which the results for two are complete, while the third is in progress. A forth Working Group has been proposed to start later in 2002. The dates, topics and Chairmen of the Working Groups are shown in Table 2. FIS has sponsored publications such as special volumes in *Progress in Oceanography* (Beamish *et al.* 1999 and McKinnell *et al.* 2001) and by Alaska Sea Grant (Loughlin and Ohtani 1999). The list of pages corresponding to FIS-sponsored reports within the PICES Scientific Report (PSR) Series, showing the approximate number of pages related is shown in Table 3.

FIS in PICES - comparison and contrast to other Scientific Committees: POC, BIO and MEQ

The cumulative hours of sessions by all four Scientific Committees were constant at 30-40 hours per year (Fig. 1). The hours of FIS sessions

Table 1 Topics sessions sponsored by the Fishery Science Committee at PICES Annual Meetings.

Year	Topic
1994	Recruitment variability of clupeoid fishes and mackerels
1995	Density-dependent effects on fluctuations in the abundance of marine organisms
1996	Ecological effects of truncated age and size distributions and fishing on fish populations
1997	Models for linking climate and fish (FIS/BIO)
	Micronekton of the North Pacific (FIS/BIO)
1998	Climate change and carrying capacity in North Pacific (FIS/CCCC)
1999	GLOBEC and GLOBEC-like studies and application to fishery management
2000	Short life-span squid and fish as keystone species in North Pacific ecosystems
2001	Migration of key ecological species in the North Pacific Ocean
	The physics and biology of eddies, meanders and rings in the PICES region

Table 2 FIS Working Groups: Dates, subjects and chairmen.

Years	Subject	Chairmen
1993 - 1995	Small pelagics (WG 3)	J. Hunter and T. Wada
1995 - 2001	Crabs and shrimp (WG 12)	R. Otto and V. Rodin
1999 - 2002	Fisheries and climate (WG 16)	R. Beamish and T. Wada
2002	In preparation	

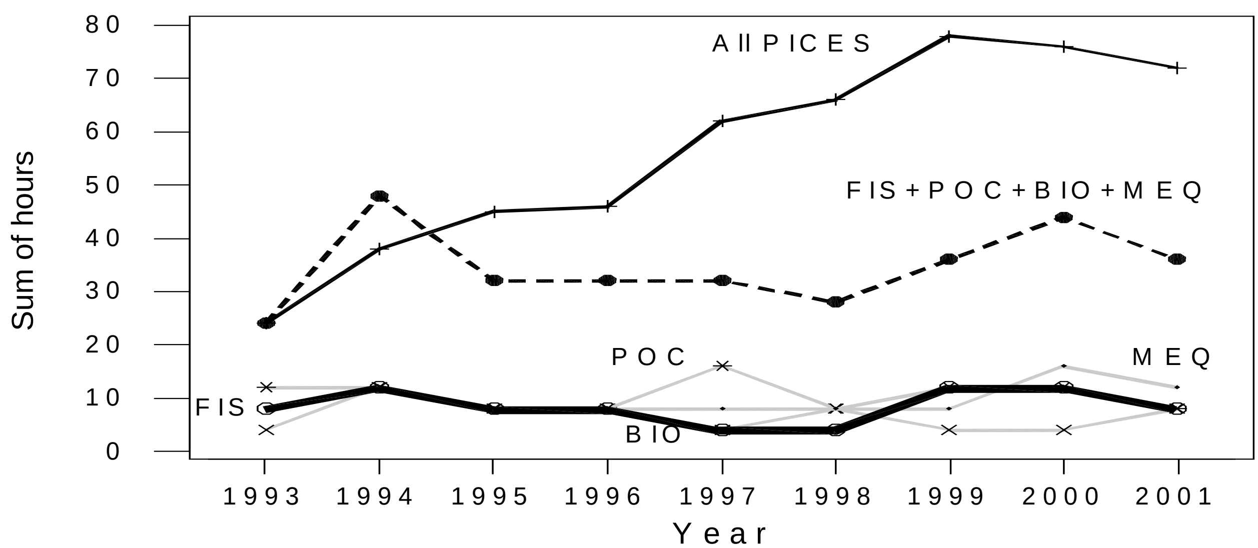

Fig. 1 The sum of hours of FIS sessions in PICES Annual meetings, 1993-2001. The solid dark line on the bottom indicates the total number of hours of FIS sessions during Annual Meetings, at about 10 hours per year, roughly similar to those of other Scientific Committees (POC, BIO and MEQ) indicated by grey lines. The sum of all the four committee sessions is shown as a dashed line, at about 40 hours per year. The total time for all PICES sessions, however, has steadily increased with time until 1999-2001, when it remained at about 70 hours. This increase is mainly related to the inclusion of sessions associated with GLOBES activities, especially the CCCC sessions.

Table 3 Scientific publications resulting from FIS activities in PICES, shown by year, and sponsors. The approximate number of pages in the publication and an estimate of the numbers of pages related to FIS inputs are indicated.

Year	Title	Sponsorship	All pages	FIS pages	POC pages
1993	Part 1. Coastal Pelagic Fishes Part 2. Subarctic Gyre (PSR 1)	FIS WG 3 (part 1) SB WG 6 (part 2)	130	24	106
1995	Okhotsk Sea and Oyashio regions (PSR 2)	POC WG 1	227	0	227
1995	Monitoring Subarctic North Pacific variability (PSR 3)	Science Board, STA (Japan)	94	0	
1996	Science Plan, Implementation Plan (Report of the PICES-GLOBEC International Program on Climate Change and Carrying Capacity, CCCC) (PSR 4)	CCCC Program	64	15	
1996	Modelling of the Subarctic North Pacific Circulation (PSR 5)	POC WG 7	91	0	91
1996	Proceedings of the Workshop on the Okhotsk Sea and adjacent areas (PSR 6)	POC	426	200	226
1997	Summary of the Workshop on Conceptual/Theoretical Studies and Model Development and the 1996 MODEL, BASS and REX Task Team Reports (CCCC) (PSR 7)	CCCC Program	93	30	
1998	Multilingual Nomenclature of Place and Oceanographic Names in the Region of the Okhotsk Sea (PSR 8)	POC	57	0	57
1998	PICES Climate Change and Carry Capacity Workshop on the Development of Cooperative Research in Coastal Regions of the North Pacific (PSR 9)	CCCC Program	59	10	
1999	Proceedings of the 1998 Science Board Symposium on the Impacts of the 1997/98 El Niño Event on the North Pacific Ocean and its marginal Seas (PSR 10)	Science Board	130	21	
1999	PICES GLOBEC International Program on Climate Change and Carring Capacity. Summary of the 1998 MODEL, MONITOR, REX Workshops, and Task Team Reports (PSR 11)	CCCC Program	88	88	
1999	Proceedings of the Second PICES Workshop on the Okhotsk Sea and Adjacent Areas (PSR 12)	POC	203	0	203
2000	Bibliography of the Oceanography of the Japan/East Sea (PSR 13)	PICES	99	0	
2000	Predation by Marine Birds and Mammals in the Subarctic North Pacific Ocean (PSR 14)	BIO WG 11	165	0	
2000	Report on the 1999 MONITOR and REX Workshops, and 2000 MODEL Workshop on Lower Trophic Level Modeling (PSR 15)	CCCC BIO	140	60	
2001	Environmental Assessment of Vancouver Harbour Data Report for the PICES Practical Workshop (PSR 16)	MEQ	202	40	
2001	Report of the 2000 BASS, MODEL, MONITOR and REX Workshops, the 2001 BASS/MODEL (PSR 17)	CCCC BIO	118	50	
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" (PSR 18)	PICES, Census of Marine Life	205	90	
2001	Commercially Important Crabs, Shimps and Lobsters of the North Pacific Ocean	FIS WG 12	79	79	
	All PICES Reports		2670	707	910

were relatively constant at 10-12 hours, or approximately one-quarter of the total session time for all Committees. The hours for all PICES sessions, however, has increased - reflecting developments of special Science Board symposia and inclusion of sessions and symposia associated with the CCCC Program. These two items have accounted for almost half of the PICES Annual Meetings in recent years. When expressed as a percentage of total time at meetings, FIS topics decreased since the First Annual Meeting (Fig. 2), but this same trend is seen for all Committees. This decrease is not associated with a reduction in FIS activities, rather it is an increase in total PICES activities during Annual Meetings.

There is a total of about 2,670 published pages of PICES scientific reports, of which about 700 are derived from FIS topics (Table 3). In contrast, the number of POC pages is about 900, slightly greater but not by much. Therefore, from the data shown in Table 3, which are only approximate, one could not conclude that publications of FIS topics were severely under-represented, relative to other Scientific Committees in PICES.

We maintain, however, that to have all fishery science represented by a single Scientific Committee with only one-quarter of all the scientific sessions, is a severe under-representation of the marine science composition of member countries. The remedy for this is the expansion of fishery science activity in PICES.

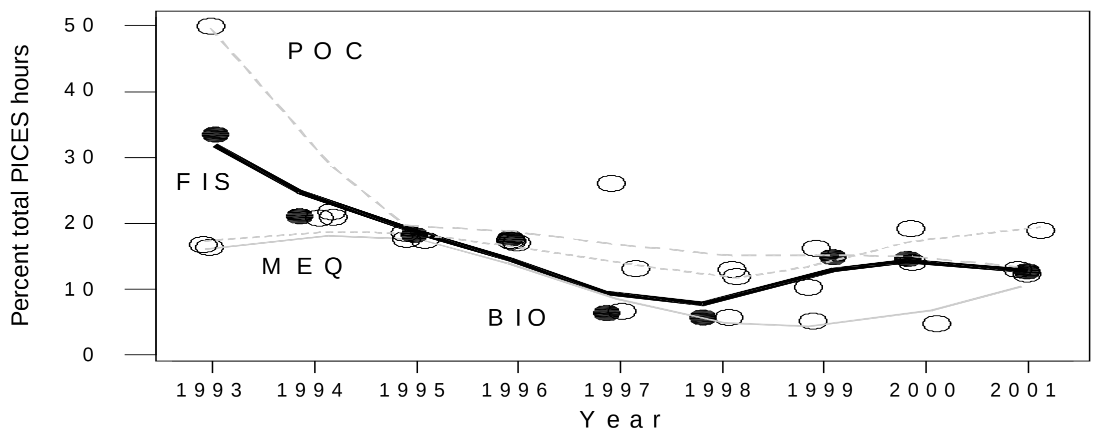

Fig. 2 The percentage of time devoted to scientific sessions from each Scientific Committee during PICES Annual Meetings, 1993-2001. The solid dark line (and closed circles) indicates the percentage of time that FIS sessions contributed at them. The time for other Scientific Committees are shown as a grey dashed line (POC), a grey dotted line (MEQ) and a thin solid grey line (BIO).

The vision and objectives of PICES: Review and evaluation of the first ten years

Several key original scientific tenets of PICES, as prepared by its founders are shown below, followed by an evaluation *(in italics).*

The general purpose of the Organization as stated in Article III of the PICES Convention shall be:

(a) to promote and co-ordinate marine scientific research in order to advance scientific knowledge of the Convention area (*i.e.*, North Pacific) and of its living resources, including but not necessarily limited to research with respect to the ocean environment and its interactions with land and atmosphere, its role in and response to global weather and climate change, its flora, fauna and ecosystems, its uses and resources, and impacts upon it from human activities; and

Evaluation*: To our knowledge, aside from the exchange of information at PICES Annual Meetings, relatively little dedicated activity has occurred in this regard, especially in FIS issues. (We comment further on this below.)*

(b) to promote the collection and exchange of information and data related to marine scientific research in the Convention Area.
***Evaluation**: To our knowledge, there has been little collection and exchange of fisheries information occurring directly as a result of PICES, although the current FIS WG 16 will address this issue. This issue will also be addressed in some GLOBEC-type activities, of which PICES is a keen sponsor.*

More specific objectives of PICES are indicated in Article V (Functions of the Governing Council Organization). The original documents do not identify the Fishery Science Committee, specifically, as charged with the task of achieving PICES objectives, because the structure of PICES was not established. In fact, the scientific administrative structure was not defined beyond the requirement for a "Scientific Board". The FIS Committee, as a member of the Science Board, is the organizational component that advises and implements the directives of the Governing Council relative to fisheries activities. Part 1 of Article V states that the scientific functions of the Governing Council shall be:

(a) to identify research priorities and problems pertaining to the area concerned (*i.e*., North Pacific) as well as appropriate methods for their solution;
***Evaluation**: To our knowledge, such has yet to be prepared. There are lists of research priorities, however, for small pelagics (from FIS WG 3) and crabs and shrimps (from FIS WG 12).*

(b) to recommend co-ordinated research programs and related activities pertaining to the area concerned, which shall be undertaken through the national efforts of the participating Contracting Parties;
***Evaluation**: To our knowledge there has been little attempt to develop co-ordinated international research field programs. Some limited programs may have occurred, but such programs, when they do take place, might have happened in the absence of PICES (through bilateral agreements, etc.), or, through related initiatives, such as programs fostered through GLOBEC initiatives. In this sense, it may be unfair to conclude that there has been no PICES role in such programs, but probably it is accurate to conclude that relatively little internationally co-ordinated research has emanated directly from PICES, especially in fisheries.*

(c) to promote and facilitate the exchange of scientific data, information and personnel;
***Evaluation**: To our knowledge relatively little exchange of scientific data in fisheries has occurred directly, and no exchange of scientific personnel as a result of PICES activity. Probably the main reason for these shortcomings is related to limited funds.*

(d) to consider requests to develop scientific advice pertaining to the area concerned;
***Evaluation**: To our knowledge, PICES has not yet received any requests to provide scientific advice to member governments or any other agency.*

(e) to organize scientific symposia and other scientific events; and
***Evaluation**: Without doubt, the organization of scientific meetings has been a successful aspect of PICES. The last decade has seen the development of a first rate scientific meeting that accompanies the Annual Meeting. The scientific meetings are successful, in part because of a vibrant mixture of disciplines, including oceanography and fisheries. We endorse this activity, and encourage more interactions - with the qualification that the objective should be to provide meaningful, useful scientific information in support of fisheries issues. This is an important point, because we note that the Annual Meeting is the foremost scientific activity of PICES. If important issues in fishery science are not addressed in the next ten years, in a way that can make a difference to how we understand and conduct fisheries in the North Pacific, then PICES may have little to justify its continued existence.*

(f) to foster the discussion of problems of mutual interest.
***Evaluation**: To our knowledge, little discussion has occurred except within the context of Annual Meetings. It is possible, however, that some aspects of this original objective have been achieved by the FIS Working Groups. Clearly, however, there is much more that could be done to meet this original objective.*

Discussion

Successes of PICES

We acknowledge the fine achievements of PICES. The Annual Meetings have developed into first rate international scientific meetings. Further, the PICES Secretariat has done a superb job of producing high-quality scientific publications in a timely manner. Our position is, however, that fishery science is under-represented in PICES, and we recommend expanding its role in the Organization. We emphasize that we are advocating an "expansion", not a re-apportionment of existing resources. We do not advocate that such an expansion should occur at the expense of existing committees or activities. We acknowledge and salute the developing inter-disciplinary rapport between fishery science and other disciplines. Continued development is essential for the future of PICES.

Fishery science in PICES - a contrast to ICES

Clearly, the name and structure of PICES were modelled after ICES (the acronym for the original Atlantic organization: International Council for the Exploration of the Sea). The structures are similar in the sense that ICES is a scientific organization, consisting of scientific committees and working groups, and which holds annual scientific meetings, etc. There are, however, some key differences. Among 4 Scientific Committees, PICES has a single Fishery Science Committee and two Oceanographic Committees. ICES consists of 7 scientific committees, of which there is only a single oceanographic committee and fishery science activities could occur in 4 or more of the standing scientific committees. As a consequence the profile of fisheries matters is much higher in ICES than PICES. ICES also has a distinct advisory role that does not occur in PICES. A review of ICES documents shows that there are 3 advisory committees and much of the working group activity is directed towards specific assessment activities. Another difference between PICES and ICES is that ICES working groups are not limited to a 3-year term, which appears to be the norm for PICES. This restriction, however, is not one specified in the original statutes. Therefore it is clear that the content and profile of fishery science in ICES is substantially greater than that of PICES. In some ways this seems odd, because fisheries matters always appeared to be a prominent justification for the initial developments of PICES (Wooster and Callahan 1994).

In the last 5-6 years, PICES has opted to work closely with GLOBEC, and started the CCCC (four C's) Program (referring to "Climate Change and Carrying Capacity"). Within PICES this consists of 4 Task Teams (REX-Regional experiments), BASS (Basin Scale experiments), MODEL (an oceanographic and biological modelling initiative) and MONITOR. The CCCC Program is represented by two participants on the PICES Science Board, and in that respect, has input to the direction of PICES. We also note that the NPAFC (North Pacific Anadromous Fish Commission) with member countries of Canada, Japan, Russia and the U.S.A., serves as an observer in PICES with respect to international regulation and concern about salmonids.

Present profile of fishery science in PICES

Compared to ICES, the role of fishery science in PICES is not high, although specific concerns about the diminishment of fishery science, relative to that of other Scientific Committees, is not justified. That is, the level of participation of FIS (as measured by the number of hours of scientific presentations, or the numbers of pages of scientific reports) is approximately equal to that of other Committees. Further, there is no justification for concern that contributions of the FIS Committee are declining with time. Indeed, there "appears" to be a relative decline in contribution within scientific meetings, but such a decline has occurred among all Scientific Committees and is mainly related to the incorporation of GLOBEC-like activities into PICES.

Increasing the profile and expanding the role of fishery science in PICES - suggestions

There are a number of ways to increase fishery science profiles and activities in PICES, and we list only a few general suggestions. For instance, the PICES Science Board could add an additional committee, or two, that is focussed on issues of fishery science. One such committee could be an aquaculture committee, a suggestion endorsed informally by several countries, as aquaculture is a topic of major concern to most member nations. Such a committee could also provide strong future linkages to MEQ activities. There are, however, many possible committees that could be added.

An alternate suggestion would be to add a second member, from the Fishery Science Committee, to the Science Board, and proportionally expand (*i.e.*, approximately double) the time given to fishery science issues in Annual Meetings. A concern with this approach, however, is that the Annual Meetings are already long (4-5 days) and packed with concurrent sessions. Perhaps a more viable suggestion would be to increase the support for Working Groups sponsored by the FIS. Further, such Working Groups could be encouraged to hold some smaller, inter-sessional meetings on specialized topics, leading to PICES publications.

PICES should also examine its relationships with the national members to stimulate greater participation. Many participants in PICES meetings use the Annual Meeting as a venue to present and discuss their own research, but the time available to become involved in collaborative PICES activities is limited due to the pressure of work at their own institutions or agencies. PICES should work to impress upon the agencies, and representatives of the member nations, the importance of PICES initiatives such as Working Groups to assure that the scientific manpower required for these efforts can better be met. If successful, this would go a long way towards improving cooperative work in fisheries.

What more should FIS and PICES do?

Finally our general conclusion is that while PICES can be proud of its first decade of life, because in many ways it did a good job, however, it did not fulfil all of the key objectives and visions of the founders of PICES. Overall the activities of PICES were not enough; they were not sufficient to address issues of great concern and misunderstanding on global fisheries issues.

At the operational level, PICES should develop better adherence to the Article V of the PICES Convention. Specifically, three parts of Article V need attention:

(a) to identify research priorities and problems pertaining to the area concerned (i.e., North Pacific) as well as appropriate methods for their solution;
(b) to recommend co-ordinated research programs and related activities pertaining to the area concerned, which shall be undertaken through the national efforts of the participating Contracting Parties;
(c) to promote and facilitate the exchange of scientific data, information and personnel;

Item (a) could be addressed with a working group or other approaches; item (b) is expensive and difficult because many national governments are struggling to support their vital national programs - and may have little sympathy for co-operative international field programs that may jeopardise national activities. Item (c), however, is fundamental and relatively inexpensive. It is not difficult or expensive to develop exchanges of scientific personnel. The results have broad benefits both for the scientists and the host organization and countries. PICES could also play a role in improving fisheries data shortcomings identified in the North Pacific (*e.g.*, Watson and Pauly 2001). This would be particularly valuable because resulting scientific products are expanded into international databases. In this regard, we should point out that PICES fishery science should take a page from our ICES colleagues, who have now presented extensive fisheries databases on the web. Indeed, we might also learn from our oceanographic colleagues who also make their data accessible on web sites. We must begin to do the same with fisheries data. The PICES Secretariat, and PICES web site, are obvious choices for this proposed development. Therefore PICES could consider substantial expansion of its website, to meet some of the original objectives of the PICES founders. Specifically, an expanded PICES website would be an ideal solution to addressing Article 5c - exchange of scientific data and information.

An additional approach would be to develop much stronger links with existing marine science organizations operating in the North Pacific. Specifically, we suggest that there could be much stronger linkages with the North Pacific Anadromous Fish Commission (NPAFC). This organization consists of four member countries (Canada, Japan, Russia and the U.S.A.) that are also PICES members. Stronger linkages could be forged by developing more joint participation (not just representation) at annual and interim meetings. Linkages with NPAFC, and other organizations, could develop into jointly configured standing committees or working groups that would be capable of reviewing scientific information and providing advice. In this regard, if PICES were able to develop the capacity to provide meaningful review, information and advice on the non-salmonid fish species within its mandate area, the way that NPAFC does for salmonids, then it would become a much more useful and meaningful organization. Such issues are of keen interest, not only to scientists, but also to the tens of millions of people who make their living from the sea, throughout coastal regions of the North Pacific Ocean.

Aside from organization modifications, what else could we do? What should we do? In a nutshell, we need to communicate more broadly outside of PICES and broadcast the extent of our collective ignorance - of fishery science in particular and marine science in general. We need to advise those among the non-scientific community and especially the decision- and policy-makers, that we (PICES fishery scientists) do not know the answers to many of the key issues affecting marine fish - indeed we do not even know many of the appropriate questions. Put another way, we need to spend as much energy explaining what we do not know, as what we do know. The systems we study, usually with inadequate resources, are vast and complex. Our understanding is insufficient. We suggest that we need to improve the general understanding about marine systems - including our abilities and limitations.

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Marine Environmental Committee in review

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The history of MEQ and its Working Groups

The North Pacific Marine Science Organization — PICES — was envisaged as long ago as the late 1970s, and an organizational structure was negotiated in 1987. The first scientific plans for the Marine Environmental Quality Committee (MEQ) were outlined at a PICES Scientific Workshop held in December 1991, in Seattle. In a review of that workshop, presented at the PICES First Annual Meeting (PICES I) in 1992, Dr. Usha Varanasi from the U.S.A. identified five research issues of importance:

- nutrient loading and eutrophication,
- chronic and persistent chemical pollutants (all high priority issues and of lower priority),
- the role of the North Pacific in waste disposal,
- large scale environmental impacts, and
- biological community impacts due to exploitation.

Following discussions at PICES I (Victoria, Canada), the MEQ report to the PICES Science Board re-cast these priorities identifying two topics as being particularly important:

- harmful algal blooms (HAB), and
- chemical and biological contaminants.

However, the discussions at PICES I had obviously ranged fairly widely. It was recognized, for example, that the focus of most member countries was on coastal rather than "open ocean" pollution. This issue of whether MEQ should focus its efforts within PICES on coastal or on open ocean is not fully resolved even now. There was also some discussion about need for calibration of environmental assessments under the heading of "common assessment methodology". It had been suggested that MEQ should select:

- suitable species for monitoring of the status and trends in fate and effects of chemical contaminants in the North Pacific, and
- a suite of chemicals or other environmental pollution-related phenomena for the open ocean that would be related to effects on indicator species.

The Committee recommended that a scientific session of MEQ at the next Annual Meeting should focus on "Assessment techniques and methodology in MEQ", with an emphasis on two main issues: HAB and chemical and biological contaminants. Partly in response to these discussions, the PICES Governing Council established a Working Group 2 (WG 2) to formulate approaches to the "Development of common assessment methodology for marine pollution" under the auspices of MEQ.

The "science" activities of MEQ began seriously at PICES II (Seattle, U.S.A.) in 1993, with WG 2's first meeting. Background papers had been solicited from all member countries (at that time, Canada, Japan, People's Republic of China, and U.S.A.), summarising their concerns about marine pollution. "Pollution" had been interpreted to cover a wide range of stresses, not just chemical contamination, but also pathogens, HABs, etc. As noted above, most countries focussed on coastal rather than open ocean concerns, because the coastal zone is where many human activities have their most direct impact. The reports noted that the chemicals of concern were persistent organic pollutants (*e.g.*, PCBs, DDTs, dioxins), metals, oil-related compounds (*e.g.*, polynuclear aromatic hydrocarbons, PAH) and radionuclides, but there was a growing interest in eutrophication and harmful algal blooms.

WG 2 recommended that PICES:

- organize a session to review approaches to assessing the impact of stressors at the ecosystem level, and
- sponsor a practical workshop to address some of these issues.

This recommendation was endorsed by MEQ at PICES II. The approach proposed was to convene a session at PICES III (Nemuro, Japan) to discuss how to measure biological impacts, and to outline the organization of the practical workshop. This was also endorsed by MEQ but with much discussion about where a workshop should (or could) be held, and what problems it would address. Ideally, MEQ would look for a site to hold the workshop where problems existed that were of interest to all member countries. Site selection was important because the location for the workshop needed: (1) to afford the opportunity to have maximum participation by scientists from member countries, (2) have been studied previously so that selection of actual sampling sites would afford the types of samples necessary to test and compare different biological and chemical assessment techniques. The latter was critical, because the longer-term goal was to work towards harmonization of assessment methodologies used by PICES member countries. Harmonization is a key factor in improving inter-comparability among studies. Without the ability to use results from multiple studies with a known degree of confidence, scientists are severely limited in making trans-Pacific assessments of the status and trends in chemical contaminant levels in marine biota, much less assessments of relative magnitudes of biological effects in indicator species.

The MEQ session at PICES III had as its theme "Interdisclipinary methodology to better assess and predict the impact of pollutants on structure and function of marine ecosystems"; 11 papers were presented on various approaches to the subject. Many of these focused on the relationship between the presence of contaminants and their effects on organisms at the biochemical, or whole organism, level or on communities. There was general agreement that chemical analyses and biological effects measurements were each valuable by themselves, but were of considerably more value when combined. A future practical workshop should build upon this theme, and ideally should be held in the western Pacific area. Also at PICES III there was considerable discussion around the issue of the scale at which MEQ should focus with regard to human impacts to marine environmental quality. The discussion centered on the question of what stressors could have the biggest impact on the ecological processes of the North Pacific? The discussion ranged from changes in hydrologic regimes of rivers and their consequences to coastal areas, to climate change and long-range transport of pollutants. The international Arctic Monitoring and Assessment Program (AMAP) was providing solid evidence that long-range transport of certain persistent organic pollutants ("POPs") was the major source of these contaminants to Arctic ecosystems. In addition, there was preliminary evidence of a trans-Pacific transport (west to east) of pollutants associated with combustion of fossil fuels (*e.g.*, NO_x and SO_x), and that they could be affecting relatively pristine forest ecosystems of the Pacific Northwest.

One consequence of these two issues was a major change in the direction of WG 2. Whereas previously it had focused on "development of common assessment methodology", WG 2 now proposed to amend its terms of reference to (a) draft a work plan for a workshop in the East China Sea area (probably focusing on the impact of the Three Gorges project); and (b) to put the workshop in place by 1997. The Three Gorges Project would lead to a major change in the sediment budget to the South China Sea; the impact could be substantial. While this project could have considerable ecological impact on marine waters of the PICES region, conducting a scientific study related to the project was felt by many to be very challenging. Perhaps more than for any other committee in PICES, MEQ, through its scientific work, most directly addresses issues that are controversial and can bring attention to the ecological impacts of human actions. MEQ endorsed this proposal while recognizing the challenges, and WG 2 was re-cast as WG 8 with essentially those terms of reference.

Qingdao, People's Republic of China, was the site for PICES IV. At this meeting, WG 8 consulted with its Chinese members on the feasibility of using the Three Gorges Project as the focus of the workshop. It was concluded that it could be a very lengthy process to get the necessary approvals for a workshop with such a focus. Consequently, WG 8 and MEQ accepted an offer from the Academia Sinica Institute of Oceanology at Qingdao to base the workshop there, with Jiaozhou Bay as the study area, and the focus would be chemical contaminants. Jiaozhou Bay was attractive scientifically, because the Academia Sinica had already accumulated a large body of "baseline" data on the Bay, and good laboratory facilities were available at the Institute of Oceanology. MEQ fully supported this initiative. Throughout the following year, a considerable body of data pertaining to Jiaozhou Bay was assembled (and in some cases translated) and refinements to the operational plan for the practical workshop were developed.

The MEQ scientific session at PICES IV on "Sources, transport and impact of chemical contaminants" provided further background and suggestions for approaches to be used at the practical workshop.

Since one of the first decisions by MEQ was to focus on HABs in addition to chemical pollution, MEQ decided that it should not focus exclusively on the practical workshop. The Committee recommended that PICES V should include a joint session with BIO on HABs as a means to initiate activity on this subject. There was growing evidence that the frequency of HABs appeared to be increasing worldwide and to be having significant ecological (mass die-offs) and economic (depressed shellfish harvests) impacts.

During 1996, there was extensive work by WG 8 on refining plans for the practical workshop, and a detailed work plan with cost estimates was presented to MEQ, approved, and sent to the Science Board at PICES V in Nanaimo, Canada. The workshop was envisaged as involving 2-4 scientists from each member country (now six, since Republic of Korea and Russia had joined PICES), and a detailed list of samples (sediment, water and biota), and analyses (chemical and biological) to be carried out was provided. Since Jiaozhou Bay is a fairly heavily industrialised system, a "reference" site at nearby Laoshan Bay would also be analysed. The workshop was finally scheduled for 2-3 weeks during spring or summer of 1997 (June to October). This was a major step forward for MEQ to bring together what would be the first collaborative scientific effort involving practical field studies by a PICES Scientific Committee.

On the advice of our Chinese scientific colleagues, two formal requests were made to the appropriate Chinese authorities to hold the workshop in Qingdao. However, a formal reply was not forthcoming in time to hold the workshop in 1997, and it had to be postponed for at least a year. At PICES VI (Pusan, Republic of Korea) it was agreed that if no formal approval could be obtained by January 1998 from Chinese authorities to hold the workshop in summer 1998, an alternative study site would be chosen. The general logistic considerations would still apply, but we would clearly have to assemble "background" information about the chemical, physical and biological oceanography of the new site.

In addition to dealing with the planning of the practical workshop, MEQ sponsored a session on "Processes of contaminant cycling" which focussed primarily on processes occurring in the coastal zone; many examples of these processes were based on data from Masan and Chinhae Bays. MEQ also concluded that a new priority area that deserved attention was the issue of aquaculture or mariculture. With the decline in wild fish landings and an increasing global demand for seafood, the culture of fish and shellfish will likely continue to expand and would become a larger portion of the economic base of the seafood industry worldwide. Associated with this growth are increasing concerns about deleterious ecological effects from increased eutrophication and habitat degradation, about antibiotics as a potential chemical pollutants, and about escaped cultured (often "exotic") species.

In early 1998, a reply was received from the Chinese authorities stating that it would not be possible to host the practical workshop at

Qingdao. In light of this decision, and given the amount of work that had gone into planning the workshop, much of the discussion at PICES VII (Fairbanks, U.S.A.) centred on the issue of finding an alternative study area for the workshop. Vancouver Harbour, British Columbia, Canada, was chosen. There were a number of practical reasons for the choice, such as the availability of laboratory facilities at the West Vancouver Laboratory of Canada's Department of Fisheries and Oceans, the availability of appropriate "background" information, and other logistical considerations, which would allow the workshop to proceed without undue delay. This proposal was approved by both MEQ and the Governing Council, and WG 8 revised its work plans accordingly.

The focus of the MEQ sessions at PICES VII was on "Contaminants in high trophic level biota -- linkages between individual and population responses" (jointly sponsored with BIO) and "Science and technology for environmentally sustainable mariculture". This second session indicated a shift in emphasis away from chemical contaminant issues and towards the more biological aspects of marine environmental quality. The recognition of HABs as an area needing additional attention had matured with the establishment of specific national research initiatives (*e.g.*, US ECOHAB), as well as internationally through GEOHAB. These programs were providing support to a number of scientists, which increased the likelihood that they could participate in a PICES-directed effort that would likely significantly improve understanding of HAB events and their ecological impacts.

1999 was a special year in the history of MEQ, because the practical workshop was held in the spring at Vancouver. A full report of the workshop and the data collected are available as PICES Scientific Report No. 16. Briefly, 24 scientists from all PICES member countries participated making a range of measurements including chemical, biochemical, pathological, physiological, anatomical and ecological analyses in Vancouver Harbour over a period of about two weeks. Although the raw data are in the PICES Scientific Report, a more valuable product, in the sense of highlighting internationally PICES' (and MEQ's) environmental studies, is the selection of refereed papers that will appear as a special issue of *Marine Environmental Research*. (At the time of writing, these are being refereed.)

At PICES VIII (Vladivostok, Russia), two sessions were organized by MEQ, one comprising 12 papers on "Ecological impacts of oil spills" (which attracted overflow attendance) and a second (jointly with BIO) on "Coastal eutrophication, phytoplankton dynamics and harmful algal blooms". Following these meetings, and discussions within the Committee, MEQ decided to recommend the formation of a Working Group on "Ecology of hamful algal blooms in the North Pacific" (WG 15); this was approved by the Governing Council.

At PICES IX (Hakodate, Japan), MEQ held topic sessions on "Science and technology for environmentally sustainable mariculture: impacts and mitigation in coastal areas" and on "Enviromental assessment of Vancouver Harbour: results of an international workshop". The quality of the results presented at the last session encouraged planning for a peer-reviewed publication mentioned above.

With the completion of the practical workshop, MEQ turned its attention to the implementation of its Strategic Plan. This identifies several main issues for the next few years:

- coastal pollution/eutrophication and phytoplankton dynamics;
- ecological impact of oil and other chemical spills;
- science and technology for mariculture;
- impacts of climate change on coastal systems;
- biological and physical transport of anthropogenic substances in the North Pacific;
- diseases and their relationship to pollution.

MEQ also recognizes the need to pursue opportunities to work within a broader international framework, *e.g.*, through GOOS, ICES, AMAP, GIWA or a combination of groups.

A broad retrospective view

The foregoing has summarized in some detail MEQ activities over the last decade or so, and it is worth stepping back from this and considering the general evolution of the MEQ programme. PICES' original remit to MEQ was essentially to harmonize approaches to the assessment of pollution by developing a "...common assessment methodology...". It is worth asking if MEQ has reached this objective.

As background, we can consider pollution as one kind of environmental change, which results from a range of "forcing functions"; some of these are natural (such as climate change, perhaps) and some are anthropogenic (introduction of contaminants, over-fishing, habitat destruction). And of course, some of these forcing functions interact among themselves. Their net effects cause changes in the structure and/or function of ecosystems, and it is these changes which we want to record, to relate to causes and, ultimately, to manage. However, at present we are limited in the measurements we can make to indicate ecosystem changes: we can routinely measure the distribution of chemicals in various ecosystem compartments and we can, in a few cases, measure some functional or structural changes in specific ecosystem compartments. These are, however, only "snapshots" of aspects of ecosystem structure and/or function.

Within this generalized conceptual framework, MEQ has gone some way to harmonizing its approaches to assessing pollution. Most countries rely on similar approaches (specifically, contaminant monitoring by analytical chemistry); some extend this to biological effects measurements, which complement the chemical data. Through sessions at the Annual Meetings, MEQ has encouraged discussion of these approaches, and most importantly at the Vancouver workshop, PICES scientists have been able to work together in applying a variety of assessment methods and in seeing their value and relevance. This is not to say that all PICES countries will adopt methods used at Vancouver, but the "hands-on" experience of working collaboratively using these techniques must lead eventually to a better mutual understanding of their value.

In addition to the technical and scientific difficulties of harmonizing approaches to assessing marine pollution, it is worth noting that there are contextual factors of scale, of political objectives, and of technical expertise and economic capacity which govern the evolution of the MEQ programme. As we have noted above, there always has been an element of conflict between PICES' broad --- almost hemispheric --- view of the North Pacific, and individual member nations' focus on local or regional pollution issues. The difference is one of geographic scale: the North Pacific as a system functions on scales of thousands of kilometers, whereas most pollution concerns of member nations (and the programmes to deal with these concerns) occupy scales of tens to hundreds of kilometers. But this difference in geographic scale has implications for the temporal scales on which we operate: changes in ecosystem processes in the North Pacific are likely to occur (or be detected) over intervals of decades, while coastal or regional pollution studies often focus on questions (*e.g.*, about regulation of pollutants) which may be answered (at least, resource managers *hope* they can be answered) over periods of years. MEQ has always been aware of these differences in perspective but national priorities and the practicalities of science funding have probably led us to emphasize local and regional approaches rather than hemispheric ones. This is not to say that MEQ does not recognize the importance, of long-range atmospheric transport of pollutants from industrialized to less contaminated regions (indeed, we have tried to address that issue in previous sessions); rather, our national concerns with local or immediate problems have often pushed these less urgent issues to the background. Only time will tell whether this has been a wise strategy.

"Scale" in the perspective of PICES (as compared to that of its members) also provides a context within which to compare PICES and ICES. PICES structure was modelled largely on ICES, but the geographic scale on which the two organizations operate are quite different. Although Canada and U.S.A. are members of ICES, in the context of MEQ, ICES is much more of a regional organization (Canada and U.S.A. contribute extensively to the "research" aspects of MEQ in ICES, but are involved much less in regulatory affairs). But because ICES is largely an organization of states in close proximity to each other (around the North Sea and the Baltic) pollution concerns or events on scales of tens to hundreds of kilometers have international implications that are virtually absent from PICES. It is therefore not surprising that the ICES Advisory Committee on the Marine Environment has a supra-national advisory role which seems to lead to international co-ordination (within ICES) in dealing with some aspects of marine pollution. Within PICES, there seems to have been no need (so far) for such a PICES-wide group which works towards "managing" the North Pacific; instead, member states have often developed bi-lateral structures to address local or regional pollution issues over scales of tens to hundreds of kilometers. Some examples include the Canada – U.S.A. initiatives in the Straits of Georgia, Juan de Fuca and Puget Sound; the Russia - Japan initiative on MEQ in the Japan/East Sea (Peter the Great Bay) and the Korea - China studies on the Gulf of Bo Hai.

Finally, we should note that PICES membership reflects a wide diversity of cultural approaches to science, and a wide range of technical expertise and economic capacity. This is much less the case in ICES, which comprises nations of mainly northern European stock with roughly similar approaches to science and which are at a generally similar level of technological advancement. Although these considerations should not be important in a purely scientific context, the fact remains that different nations have different outlooks, priorities, and ways of doing things, which inevitably affect the extent to which even general objectives can be reached.

Future directions for MEQ

Although this will be the subject of another paper, it is unavoidable that after reflecting on the past decade we should think a bit about the future. Some trends and remaining issues are obvious.

"Assessment of pollution..." is a moving target. A decade ago we would have assessed pollution largely in terms of the distribution of "classical" contaminants such as POPs, heavy metals and radionuclides (and indeed, those topics were the focus of the background papers prepared for PICES II in which member countries assessed the status of their MEQ programmes); now, we would probably want to consider HABs, eutrophication, introduction of exotic species, habitat destruction, *etc.*, in an assessment of pollution. The obvious response to this has been the formation of WG 15 dealing with the impacts of HABs and related topics. This reflects the general recognition that "pollution" encompasses more than just the distribution and effects of chemicals, and it opens up a new set of problems in "assessing" pollution. These point to the need to develop better indicators of ecosystem change, and while this is not a problem that is unique to PICES, probably the best strategy to deal with it is for PICES to maintain close working relationships with other agencies or individuals working in the area.

A second major area for future MEQ activities is in the context of even larger scale global or hemispheric programmes. Given what we know about the integration of physical processes on a global scale (*e. g.*, the distant effects of ENSO), it would make strategic sense over the next decade or so for MEQ to consider issues such as the trans-Pacific transport of pollutants within the context of structures such as GOOS, which is intended to provide a framework for even larger-scale collaboration than is possible within PICES.

During the last decade, MEQ has developed into a cohesive group, which has collaborated successfully, on problems of common interest, and a measure of its success is the output of the practical workshop, scheduled to be published in a refereed international journal. MEQ has now decided to expand its interests, and while this expansion will undoubtedly raise new (and difficult) scientific questions, the group should be well placed to identify and to address them.

Marine environmental contaminant issues in the North Pacific: What are the dangers and how do we identify them?

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Introduction

A little over a decade ago, Waldichuk (1990) reviewed the state of industrial and domestic pollution of the North Pacific and concluded that interfaces (*e.g.*, air-water, water-sediment, shorelines) and coastal areas, especially those surrounded by dense population and industry, were most at risk. His list of critical contaminants – hydrocarbons and polynuclear aromatic hydrocarbons (PAHs), organochlorine compounds, metals, radionuclides, and persistent solids – remains valid today.

Although toxic effects of contaminants have long been known, it was only during the past decade that we have learned the myriad ways trace quantities of chemicals can produce subtle disruption to endocrine systems every bit as threatening to aquatic animals as outright toxicity (Colborn *et al.* 1996). For this reason, Waldichuk's priority contaminant issues – halogenated hydrocarbons and sewage – were well chosen. During the past decade, expanded industry and increasing coastal populations have escalated the pressure on productive marginal seas (Fig. 1) – the very regions that are being counted on to provide even more protein for future populations. For example, in 1998 an estimated two-thirds of the world's population (3.6 billion) lived within 60 km of the coast (UNESCO 1998), and total population is increasing at about 77 million per year (*U.S.* Census Bureau 2002). In U.S.A., over 50% of the population lives in the narrow coastal fringe and that population is increasing by about 1.3 million per year (Culliton 1998).

In addition to chemical contaminants, these coastal seas are under onslaught from enhanced nutrient and sediment loadings, climate change, over-fishing, habitat disruption and the introduction of exotic species. For the most intensively utilized enclosed seas of East Asia, *e.g.*, the South China Sea, projections are indeed grim (Morton and Blackmore 2001).

Here we discuss the major threats human activities present to North Pacific marine ecosystems with chemical contamination as a central theme. We discuss briefly concurrent issues of climate change, disruption of CNP (carbon, nitrogen, phosphorus) cycles, and predation, because these factors confound chemical contamination, both in terms of its effects and in the way chemical contaminants pass through marine systems. It is not our intention to present a comprehensive review of the literature. Rather, we highlight the contaminant issues facing the North Pacific, drawing suitable examples for the most part from literature of the last decade. Finally, we propose the sorts of observations and research required to mobilize society to reverse its present course, which if unchecked, will lead to the yet further widespread destruction of coastal ecosystems.

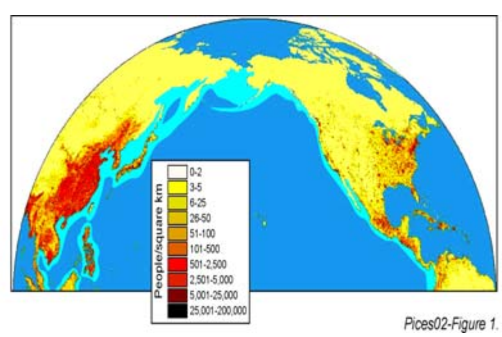

Fig. 1 The North Pacific Ocean, showing the density of human population near coastal seas and the importance of coastal seas for primary production, which, by inference, also represents secondary production.

Pressures on North Pacific marine ecosystems

Climate change

Climate change poses several kinds of risk, including temperature rise through greenhouse gas forcing (IPCC 1995), alteration of the hydrological cycle (Dynesius and Nilsson 1994; Vörösmarty *et al.* 2001), increased exposure from ultraviolet radiation (Weatherhead and Morseth, 1998) and sea-level rise (Ledley *et al.* 1999). These sorts of change, which imply significant effects on aquatic systems and humans, are often difficult to detect at their early stages due to natural variability at time scales from years to decades to centuries (see, for example, Francis *et al.* 1998; Hare and Mantua 2000).

Air temperature in the northern hemisphere has been anomalously high during the past decade (IPCC 1995), as have been the heat content and surface temperature of the North Pacific Ocean (Levitus *et al.* 2000; Ma *et al.* 1995). However, on both sides of the North Pacific, temperature anomalies are associated with El Niño – for example, sea-surface temperatures in northeastern China are lower during summer in El Niño years (Li 1989), whereas those in the eastern North Pacific are higher (Whitney and Freeland 1999). Similarly, the intrusion of Oyashio waters usually causes abnormally cold summers in the northern areas of Honshu, Japan, which, together with the import of nutrients, influences coastal fisheries (Sawada and Hayakawa 1997; Sekine 1996); and atmospheric warming and cooling drive short-term variation in sea surface temperature in the Japan/East Sea (Chu *et al.* 1998). Sub-decadal signals in ocean temperature like these complicate the determination of any temperature trend associated with greenhouse gas (GHG) warming. Ocean warming and ocean-atmosphere disturbance can cause the large-scale re-distribution of species (see, for example, Di Tullio and Laws 1991; Karl *et al.* 1995; Saar 2000; Schell 2000). Anadromous fish may be exceptionally vulnerable to temperature change because threshold temperatures in rivers, once passed, may eliminate spawning. Model projections warn that temperature may increase sufficiently in the Fraser River within a few decades to put at risk the world's largest wild salmon runs (Morrison *et al.* 2002).

Sea level rise (SLR) threatens all coastlines, but especially those with low gradient, poorly-bonded soils, high human population and land subsidence – conditions that frequently converge in deltas. Records suggest that a SLR of perhaps 10-30 cm has occurred during the past century (Anonymous 2000; Wang 1998) and a further 10-25 cm SLR is projected to occur over the next century. Due to overpumping of groundwater and overloading by construction on deltas, the rate of relative SLR is even higher in critical locations like Tianjin on the old Yellow River Delta (24.5-50.0 mm/yr), the modern river delta (4.5-5.5 mm/yr), and the Shanghai area of the Yangtze River mouth (6.5-11.0 mm/yr) (Wang 1996). Assuming a SLR of 30-100 cm in the next century and accounting for land subsidence, Liu *et al.* (1999) estimate that the coastline of the Bohai Sea will retreat by 50-70 km over the next century, involving a marine transgression of 10,000-11,500 km^2, and perhaps as much as 16,000 km^2 if storm surges are taken into account (Zhang and Wang 1994).

The "aliasing" inherent in natural variability at decadal or longer time scales presents what is probably the greatest challenge to detecting recent trends in the ocean produced by human activities. During the last decade, regime shifts have been recognized as a pervasive manifestation of relatively abrupt physical and biological alterations to the upper Pacific Ocean (Hare and Mantua 2000). For example, a restructuring of the mixed-layer depth in the mid to late 1970s (Fig. 2a) (Freeland *et al.* 1997) must have been accompanied by altered nutrient cycling with 'bottom-up' consequences for the ecosystem. At about the same time, it appears that anadromous fish recruitment was affected, probably due to changes in marine survival (Fig. 2b) (Welch *et al.* 2000). It has recently been recognized that, starting with nutrient supply, a large-scale ecosystem restructuring has occurred in the Bering Sea. The associated change in organic carbon cycling was recorded by Bowhead whale baleen (Fig. 3) (Schell 2000) and other wide-spread systematic changes in food-web dynamics (Hunt *et al.* 1999; Niebauer 1998; Rugh *et al.* 1999; Saar

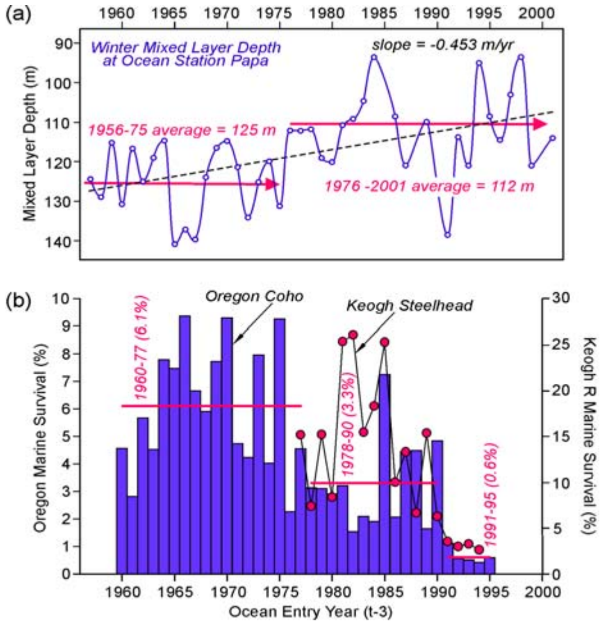

Fig. 2 a) The shallowing of the surface mixed layer at Ocean Station P observed after the regime shift of the mid-1970s (Freeland *et al.* 1997). b) Changes in survival at sea of Oregon and Keogh steelhead between 1960 and 1995, attributed partly to ocean climate conditions (Welch *et al.* 2000).

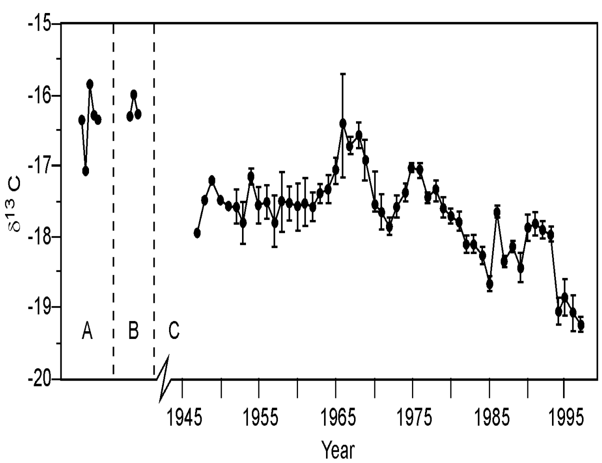

Fig. 3 The change in carbon cycling in the Bering Sea as recorded by δ^{13}C in bowhead whale baleen (Schell 2000).

2000; Stabeno and Overland 2001; Stockwell *et al.* 2000). The wide variety of physical and biological pathways implicated in regime shifts (Hare and Mantua 2000), has significant consequences for the transport and processing of contaminants both regionally and locally – especially for contaminants that concentrate and biomagnify in food-webs (*e.g.*, Hg and organochlorines).

Predation by humans

Over the past decade there has been growing concern that ocean trophic structure can be affected by commercial fisheries. Selective extraction of fish – referred to by Pauly *et al.* (1998; 2001) as 'fishing down the food web' – may lead to a global-scale reduction in marine trophic levels (Fig. 4a), which exerts its influence from the top down (Parsons 1996) (Fig. 4b).

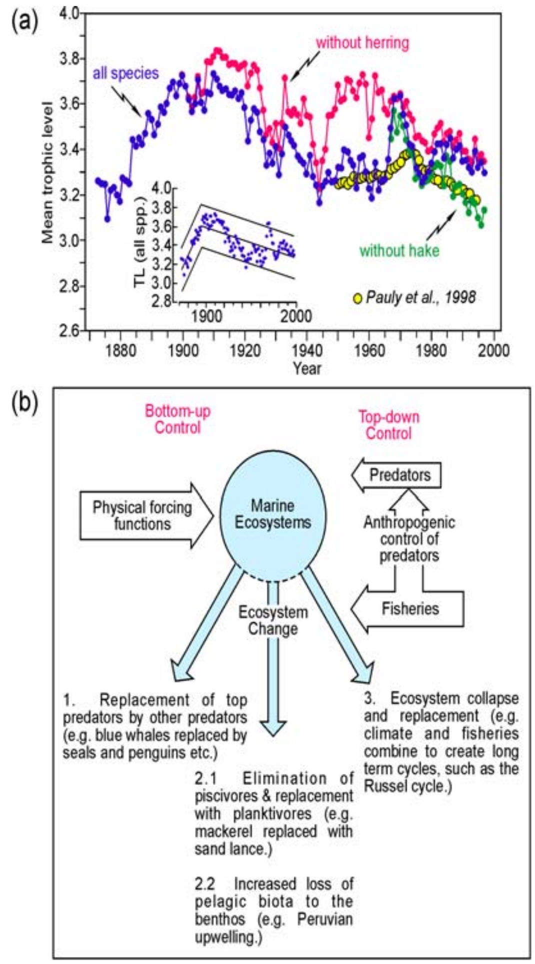

Fig. 4 a) The change in mean trophic level for the Canadian west coast between 1873 and 1996 (Pauly *et. al*. 2001). b) A schemetic showing how trophic structure in aquatic systems can be altered from the bottom-up or from the top-down (Parsons 1992).

All highly-prized species are vulnerable to this impact, but with increasing fishing pressure and dwindling stocks, less desirable species or smaller individuals become targets of commercial and private fisheries, and often, governments prolong un-economical practises which eventually lead to the demise of the resource (Ludwig *et al.* 1993). Destructive fishing methods (blast and cyanide fishing) widely practiced in Asian shelf waters (Morton and Blackmore 2001) exacerbate the problem of over-fishing and undermine the potential for recovery. Driftnet and other "ghost" fisheries have well-known, but perhaps poorly-quantified, effects on non-target species (Dayton 1998).

It is clear that fishing and contamination both provide stresses to coastal ecosystems, but the alteration of trophic structure – either from the top down by fishing, or the bottom up by climate change and coastal eutrophication – has special significance to chemicals that biomagnify (*e.g*., Hg and organochlorines).

Exotic species

Intentional and unintentional release of non-native species plague coastal seas and freshwater systems. The partial list of introduced species for the Northeast Pacific (Table 1) illustrates the extent of the impact and demonstrates that, as in the case of commercial harvesting, aquatic trophic structure can be altered at almost every level.

Harmful algal blooms

Harmful algal blooms (HABs) pre-date human encroachment on marine systems. However, there is concern that the incidence and severity of HABs have increased due to human activities such as coastal eutrophication and contaminant loading, and global change such as warming (see for example Goldberg 1995; Morton and Blackmore 2001; Waldichuk 1990). HABs can present a risk to fish (*e.g.*, Heterosigma Khan *et al.* 1997) or to humans (*e.g.*, PSP, amnesic poisoning: Horner and Postel 1993; IOC 2000) and no corner of the North Pacific may be considered immune from them (Horner *et al.* 1997; Konovalova 1993; Morton and Blackmore 2001). Although HAB-forming algae are widespread, they may in some circumstances be classified as "exotics" since ship's ballast water can transport them (Hallegraeff 1998). In the context of contaminants, HABs can be considered either as a point of leverage where anthropogenic nutrient and trace metal loadings promote a process that produces toxic compounds, or as exotic species with the potential to alter trophic structure either by direct insertion into the food web or by removal of a trophic component through selective toxicity.

Sediment discharge into coastal water

Some 1 billion tonnes of fine sediments are supplied annually to the eastern coastline of China, brought mainly by the Yellow River from the Loess Plateau as a result of soil erosion from human activities since historical times (Wang 1996). Asian rivers have especially been affected by human activities, modern sediment loads being perhaps five times those prior to the development of agriculture (GESAMP 1993). The consequence of these higher loadings is that affected coastal areas may become overly productive and either hypoxic or anoxic (Goolsby 2000). Enhanced sediment fluxes also provide the means to scavenge and bury particle-reactive contaminants in deltas and on the adjacent continental shelves. Recent damming of the Yellow River, however, appears to have reversed the historical trend (Yang *et al.* 1998), with sediment supply now dwindling. The withdrawal of sediment loading alters the balance between sediment supply, wave re-suspension, and coastal transport, with the potential consequence of accelerating the loss of deltaic areas already threatened by sea-level rise.

Chemical contamination

Hydrocarbons and polynuclear aromatic hydrocarbons

Combustion and petrogenesis are the two major sources of hydrocarbons in the environment, and both can occur either naturally or through human activities (Yunker *et al.* 2000). There have not been any major oil spills in the North Pacific since the *Exxon Valdez* incident in 1989, but the effects of that spill were devastating. Marine organisms

Table 1 Non-native aquatic species present in Washington and British Columbia (source Anonymous, 2001).

Fish	Invertebrates	Aquatic Plants
American shad *Alosa sapidissima*	Varnish clam *Nuttallia obscurata*	Japanese weed *Sargassum muticum*
Grass carp *Ctenopharyngodon idella*	Manila clam *Tapes philippinarum*	Japanese eel grass *Zostera japonica Lomentaria hakodatensis*
Striped bass *Morone saxatilis*	Asian clam *Corbicula fluminea*	Purple Loosestrife *Lythrum salicaria*
Common carp Cyprinus carpio	Soft-shell clam *Mya arenaria*	Brazilian Elodea *Egeria densa*
Goldfish Carassuis auratus	Japanese trapezium *Trapeziium liratum*	Parrotfeather Milfoil *Myriophyllum aquaticum*
Largemouth bass *Micropterus salmoides*	Japanese little neck clam *Venerupis philippinarum*	Fanwort *Cabomba caroliniana*
Smallmouth bass *Micropterus dolomieui*	Pacific oyster *Crassostrea gigas*	Eurasian Watermilfoil *Myriophyllum spicatum*
Bluegill, Green sunfish *Lepomis* spp.	Eastern oyster *Crassostrea virginica*	Hydrilla *Hydrilla verticillata*
Black Crappie *Pomoxis* spp.	Japanese or green mussel *Musculista senhousia*	Spartina/Cordgrasses Spartina alterniflora, anglica, patens
Walleye *Stizostedion vitreum*	Slipper shell *Crepidula fornicata*	Yellow Iris *Iris pseudacorus*
Yellow Perch *Perca flavescens*	Mud snail *Nassariuis obsoletus/Ilyanassa obsoleta*	Agar weed *Gelidium vagum*
Channel Catfish *Ictalurus* spp.	Eastern oyster drill *Urosalpinx cinerea*	
Flathead Catfish *Pylodictis olivaris*	Japanese oyster *drill Ceratostoma inornatum*	
Black Catfish Brown Bullhead *Ictalurus* spp.	Red beard sponge *Microciona prolifera*	
Northern Pike *Esox* spp.	Boring sponge *Cliona* spp.	
Atlantic salmon *Salmo salar*	Bowerbank's halichondria *Halichondria bowerbanki*	
Brown trout *Salmo trutta*	Asian copepod *Pseudodiaptomus inopinus*	
	Bivalve intestinal copepod *Mytilicola orientalis*	
	Mud worm *Polydora ligni*	
	Wood-boring gribble *Limnoria tripunctata*	
	Shipworm *Teredo navalis*	
	Green crab *Carcinus maenas*	

from barnacles to seals were killed, including about 250,000 sea birds (Piatt and Anderson 1996). Long-term effects include depressed populations and the lowered reproductive success of most of the oiled species, although in many cases it is difficult to distinguish between effects of the oil spill and those of decadal-scale environmental change. For example, the unusually low flow of the Alaskan Coastal Current in the years following the spill may have contributed partly to the low murre population during that time (Piatt and Anderson 1996), and the number of seals killed by the spill is disputed, due to limited observations over their natural range (Hoover-Miller *et al.* 2001). A definite link has been made in one case: Brown pelicans that had been oiled, cleaned and released were marked and compared over the course of several years with marked control birds (Anderson *et al.* 1996). The oiled birds disappeared much more quickly than control birds, and they failed to reproduce, whereas the controls continued to behave normally.

Lowered reproductive success of animals that have been exposed to oil is not surprising, given that PAHs are known endocrine-disrupters (Carls *et al.* 1999). Oil from the *Exxon Valdez* spill remained under the stones and mussel beds of nearby beaches five years after the spill (Spies *et al.* 1996), although the sediments of the intertidal zone had lost their toxicity to oysters and amphipods after two years (Wolfe *et al.* 1996).

Increasing pressure to find oil on continental shelves will probably increase the risk of hydrocarbon pollution to the North Pacific: Canada (British Columbia), the U.S.A. (California), Republic of Korea and Japan have all indicated that they intend either to begin or to expand exploration on the continental shelves of the Pacific, and drilling already occurs off Alaska and California and in the East China Sea. The environmental risks posed by offshore exploration and production are well known. They include the loss of hydrocarbons to the environment, smothering of benthos, sediment anoxia, destruction of benthic habitat, and the use of explosives (Patin 1999). Oil released from offshore operations may contain other harmful components like the endocrine-disrupting alkylphenols (Lye 2000). The generally high seismic activity of the Pacific Rim may further enhance the risk of spills (for comments regarding the South China Sea, see Zhang 1994).

Despite the high media and public interest in catastrophic oil releases, the predominant sources of hydrocarbons to coastal seas are either land based (*via* rivers) or derive from intense shipping activity as exemplified by studies in Peter the Great Bay (Nemirovskaya 1999), around Vladivostock on the Russian coast of the Sea of Japan (Tkalin 1992), and the Georgia Basin of the British Columbia coast (Yunker *et al.* 2000).

Halogenated hydrocarbons

Organochlorine compounds (OCs) have been released to the global environment in a number of ways, including industrial applications (*e.g.*, PCB), incineration (*e.g.*, dioxins, furans), chlorination in pulp mills (dioxins, furans, PCBs) and pesticide application (*e.g.*, DDT, HCH, chlordane). As a result, for any coastal sea in the North Pacific there will be a long-range, global source component for these compounds which is then augmented to a lesser or greater degree by local sources, either through the air or through runoff. Waldichuk (1990) noted that winds in the North Pacific would tend to transport volatile contaminants from Asia eastward to North America. Recent work has clarified this general transport scheme and provided further evidence of its efficacy in spreading volatile and particulate contaminants from Asia across the ocean to North America (Fig. 5) (Bailey *et al.* 2000; Jaffe *et al.* 1997; Li *et al.* 2002; Macdonald *et al.* 2000a; Wilkening *et al.* 2000).

Despite bans or restrictions during the 1970s and 1980s in most of the countries surrounding the North Pacific, PCBs, DDT and other organochlorine pesticides remain in soils and in aquatic environments. In the latter, they biomagnify to especially high concentrations in apex feeders such as marine mammals (Muir *et al.* 1999; Ross *et al.* 2000). In the early years following bans, the concentrations of PCBs and DDT decreased rapidly in the Pacific Ocean (Waldichuk 1990), but that seems no longer to be universally true. For example, between the late 1970s and early 1990s, there has been no trend in PCB concentration in particulate and dissolved fractions of San Francisco estuary water (Jarman *et al.* 1996). According to Iwata *et al.* (1994a), the concentrations of DDT, PCBs, HCH and HCB (hexachlorobenzene) have not been decreasing rapidly in the Bering Sea, because atmospheric deposition exceeds the sedimentation rate. However, decreased atmospheric concentrations of HCH following the elimination of technical HCH use in China and India during the 1980s and 1990s (Li *et al.* 2002), have reversed the net exchange of α-HCH, such that the Bering Sea has now become a source to the atmosphere (Jantunen and Bidleman 1995). The long-range atmospheric and/or oceanic transport of HCHs together with large changes in emissions have made them (*i.e.* α-, γ-, β-HCH) useful tracers of transport processes in the Bering Sea and into the Arctic Ocean (Li *et al.* 2002; Rice and Shigaev 1997).

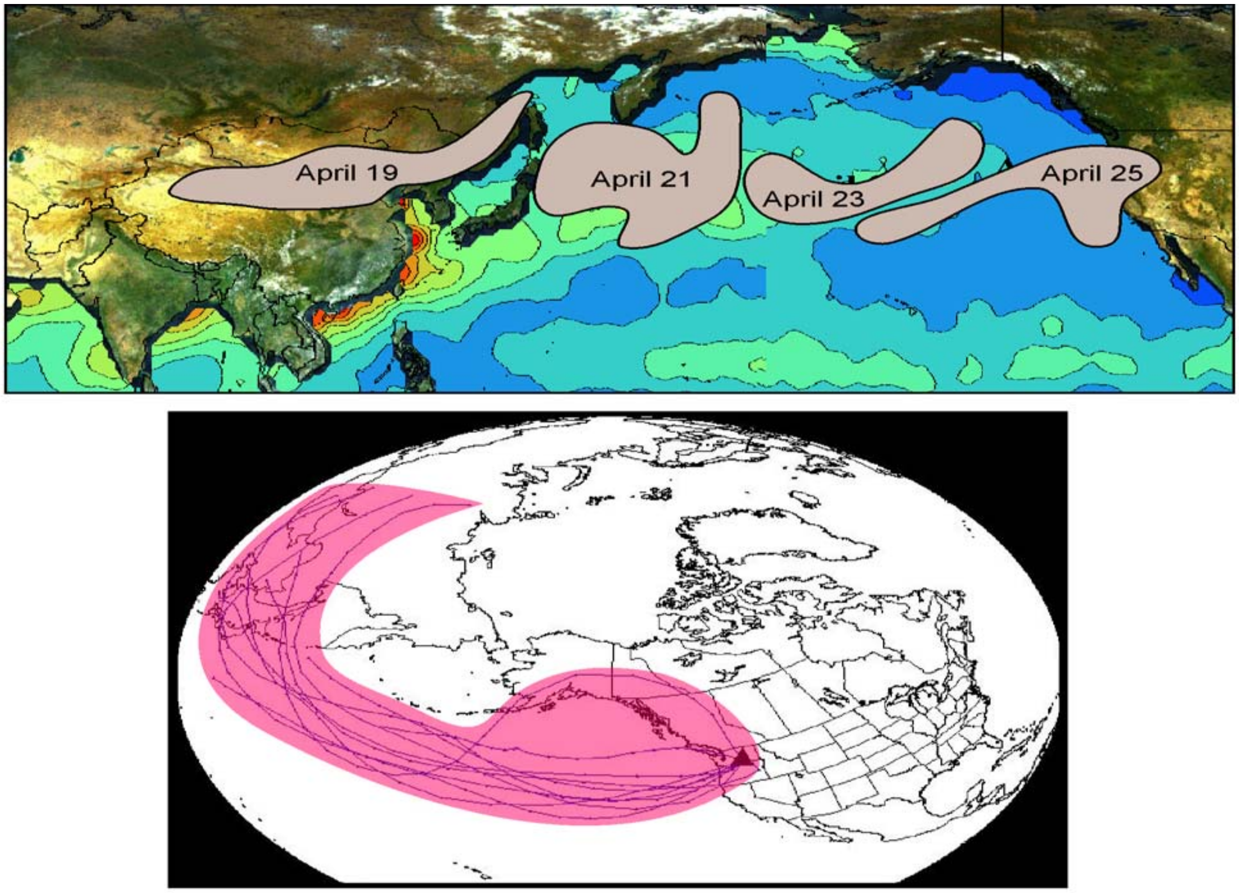

Fig. 5 Trans-Pacific atmospheric transport from Asia to North America as shown by a) dust from the Gobi Desert (Wilkening *et al.* 2000), and b) back trajectories from an air monitoring site in Canada's Yukon Territory (Bailey 2000 # 179).

The Bering Sea illustrates that long-range transport together with physical and biological processes (Chernyak *et al.* 1996; Hoekstra *et al.* 2002; Sokolova *et al.* 1995) can produce significant concentrations of pesticides in apex feeders far from local sources. Furthermore, the animals themselves may then become significant vectors of OC contaminant transport as exemplified by anadromous fish in Alaska (Ewald *et al.* 1998).

Local sources of OCs support high sediment concentrations in some locations. For example, DDT and HCH in the sediments of Peter the Great Bay probably reflect a continuing local source of those contaminants near Vladivostok (Tkalin *et al.* 2000), and high concentrations of DDT, DDD and DDE in the sediments of Lianyungang Harbour in China suggests continuing use of these compounds in local agriculture (Zhu and Tkalin 1994). There appear to be a number of local sources of DDT in some areas of the South China Sea (probably local industry or illegal dumping), as evidenced by variability in the ratio of DDE/ ΣDDT in the sediments (Morton and Blackmore 2001).

Marine mammals are particularly vulnerable to OCs due to biomagnification. Whales (Aono *et al.* 1997; Hayteas and Duffield 2000; Jarman *et al.* 1996; Ross *et al.* 2000), dolphins (Jarman *et al.* 1996; Minh *et al.* 2000), porpoises (Jarman *et al.* 1996; Minh *et al.* 2000; Zhou *et al.* 1993), seals (Nakata *et al.* 1998), sea lions (Lee *et al.* 1996) and humans (Morton and Blackmore 2001) are all contaminated. The degree of contamination and specific pollutants in each case depend on geographic location and trophic level.

Temporal trends in the concentration of organochlorines in marine mammals also vary among species and with organochlorine type. In Minke whales, the concentration of DDT is decreasing, while PCB concentration is not, suggesting a continuing source of them to the North Pacific (Aono *et al.* 1997). The concentration of PCBs and other organochlorines in Killer whales varies with age and gender (Ross *et al.* 2000) and, off the coast of British Columbia and California, is generally higher than in dolphins and porpoises (Jarman *et al.* 1996). British Columbia Killer whales (and seals) exhibit high concentrations of dioxins and furans (Jarman *et al.* 1996; Ross *et al.* 2000), but for these compounds, local sources (pulp mills) have clearly made a substantial contribution (Bright *et al.* 1999; Macdonald *et al.* 1992). Elimination of chlorine bleach and pentachlorophenol- (PCP) contaminated feed stock after 1987 has led to substantial declines in PCDD/F concentrations in sediments and crabs (Yunker and Cretney 1996) and in seals (Fig. 6). Source controls, which have all but eliminated the pulp mill PCDD/Fs, however, have made no inroads on the PCBs which derive predominantly from other sources – local, regional and global (Addison and Ross 2000).

Juvenile Pacific salmon accumulate immunosuppressive OCs as they develop in estuaries (Arkoosh *et al.* 1998), which may make them especially susceptible to the pathogens common in these environments. Sea birds are similarly affected. At Port Alberni, on the west coast of Vancouver Island, Canada, fish-eating grebe and seaduck were heavily contaminated with dioxins and furans from a nearby pulp mill (Elliott and Martin 1998). Those compounds also present the main pollution threat to Marbled murrelets along the British Columbia, Washington and California coasts. Eggshell thinning due to organochlorine pesticides is no longer considered a threat to seabirds off California (Pyle *et al.* 1999), and in herons the threat is mainly restricted to those that live near agricultural areas (Speich *et al.* 1992). Amphipods, sea urchins, bioluminescent microbes (Long 2000) and squid (Shibata, pers. comm.; Sato *et al.* 2000) also accumulate OCs although toxic effects are as yet unclear. Oysters off Taiwan are so contaminated with DDT that there is a high lifetime risk of cancer for people who consume them (Han *et al.* 2000). The concentrations of HCH and PCB ($Cl_{5\text{-}9}$) in squid livers correlate well with those in nearby sea water, lagged by 1-2 years, suggesting a reasonably dynamic equilibrium rather than progressive accumulation with age (Sato *et al.* 2000).

Metals

The waters off Hong Kong (Parsons 1998) and the sediments of the Japan/East Sea (Shulkin and Bogdanova 1998; Vaschenko *et al.* 1999), the South China Sea (Morton and Blackmore 2001)

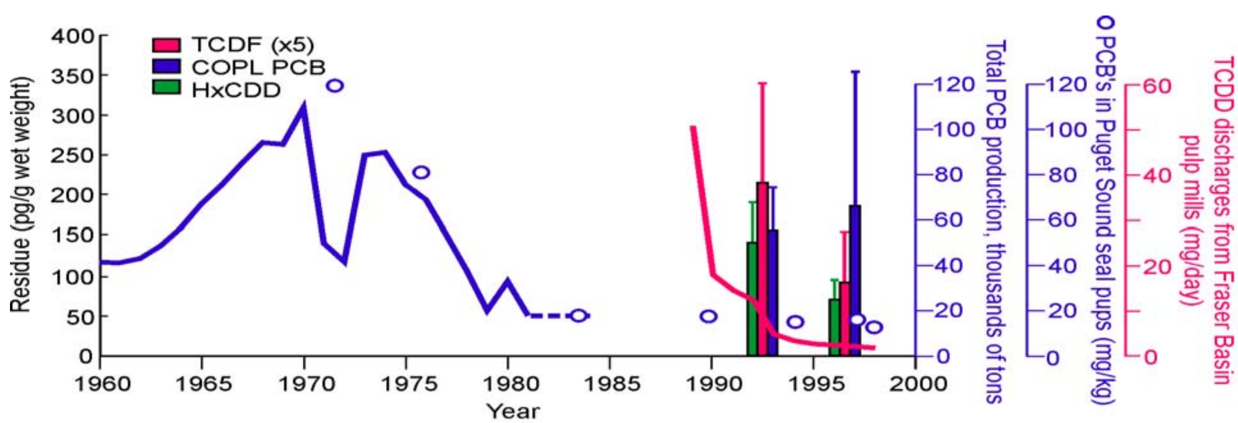

Fig. 6 An example of trend data from the west coast of North America showing PCB production (solid blue line) and TCDF discharge from Fraser basin pulp mills (solid red line) compared with residues in Harbour seals (Addison and Ross 2000) and in Harbour seal pups (blue circles, Calambokidis *et al.* 1991).

and the Yellow Sea (Shao *et al.* 1995; Yu *et al.* 1996; Zhang *et al.* 1998) are highly contaminated with metals, especially near farmed shrimp ponds (Cui *et al.* 1997), and the problem is increasing. Long-range transport of some metals (Pb: Lin *et al.* 2000; Cd: Patterson and Duce 1991*)* from Asia has been observed in the North Pacific, and some particulate trace metals cross the shelf from the East China Sea to enrich the intermediate layer of the Kuroshio Current (Hung and Chan 1998). But the main effect of metal pollution remains close to the source. A pronounced increase in anthropogenic lead loading to the Yangtze River during the 1980s and 1990s has been inferred from sediment cores collected from the East China Sea continental shelf (Huh and Chen 1999). These trends probably reflect the rapid economic growth and the lack of waste control in China. Contaminant metals in the marginal seas derive mainly from untreated sewage and industrial wastes (Parsons 1998; Shao *et al.* 1995) that either washes off the shore or enters rivers. Resuspension (Fichet *et al.* 1998) and deposition of dissolved and particulate matter by rain (Gao *et al.* 1997; Zhang *et al.* 1999; Zhang *et al.* 1992) are also major sources of metal pollution in Asian marginal seas.

As a consequence of the sediment and water pollution, much of the marine life in Asian marginal seas exhibits metal contamination. In Zhifu Bay in the Yellow Sea, for example, increased benthic pollution between 1986 and 1998 caused a change in dominant species from non-pollutant-resistant echinoderms to pollutant-resistant polychaetes (Zhang *et al.* 1998). Oysters (Cheung and Wong 1992; Han *et al.* 2000), scallops (Vaschenko *et al.* 1999) and fish (Parsons 1998) are also contaminated.

The shelves of the northwest coast of North America appear to be almost pristine compared to Asia (Macdonald and Pedersen 1991; Naidu *et al.* 1997). However, metal contamination can certainly be identified in enclosed embayments (Flegal and Sañudo-Wilhelmy 1993; Macdonald and Crecelius 1994; Paulson *et al.* 1993; Sañudo-Wilhelmy and Flegal 1992).

Of the metals, mercury and tributyltin (TBT) cause particular concern due to their toxicity and endocrine-disrupting characteristics. Furthermore, mercury biomagnifies by factors of 1000-3000 from particulate organic matter to apex predators (Atwell *et al.* 1998), and its rate of cycling in the global environment appears to have increased by perhaps a factor of three since pre-industrial times (Mason *et al.* 1994). Mercury, therefore, provides a problem not unlike that of the OCs, in that the upper ocean has globally-enhanced mercury concentrations (Mason *et al.* 1994), which are then augmented locally (usually from land). Furthermore, enhanced global cycling together with biomagnification can create biotransport vectors (Zhang *et al.* 2001) as was shown for OCs (Ewald *et al.* 1998).

Symptoms of Minimata disease were detected during the 1980s in fishermen who relied heavily on fish from the Songhua River in China, a river that had been polluted by mercury in the 1970s (Gao *et al.* 1991). The intake of methyl mercury was estimated to be between 0.17-0.34 mg/day and the average mercury contents of the hair and urine were 13-58 and 10-33 times higher than normal, respectively. In the Japan/East Sea the concentration of mercury is increasing in water, sediments and the tissues of molluscs (Luchsheva 1995). In the most affected area in Alekseev Bight in Peter the Great Bay, the concentration of mercury in molluscs exceeds pollution guidelines. Indo-Pacific humpbacked dolphins off the coast of Hong Kong also contain dangerous levels of mercury (Parsons 1998). On the eastern side of the Pacific, problems arose during the 1960s, but the sources of mercury have since been controlled (Waldichuk 1990). This is reflected in the sedimentary records of the Strait of Georgia and Puget Sound, Washington (Macdonald and Crecelius 1994). The common sources of mercury (*e.g.*, dental and medical offices, light industry (Nriagu and Pacyna 1988)) imply that municipal outfalls are probably important local conduits for this metal to coastal environments.

Tributyltin is prevalent in the sediments, water and biota in the North Pacific and the South China Sea (Iwata *et al.* 1994b; Morton and Blackmore 2001) but it is the manifestation of imposex in shellfish at extraordinarily low TBT concentrations (< 0.5 ng l^{-1}, Ronis and Mason 1996) that has engendered the greatest concern in the literature.

In 1989, the use of TBT to prevent biofouling on hulls was restricted to ships > 25 m long; TBT is now found mainly in heavily-used ports, especially those with dry-dock facilities (Evans *et al.* 1995; Morton and Blackmore 2001). In two such areas - the Strait of Malacca and Tokyo Bay - the concentration of TBT in seawater is high enough to cause imposex in gastropods and damage to other marine life (Hashimoto *et al.* 1998). In areas with less ship traffic, TBT restrictions have been successful at reducing imposex in gastropods and shell-thickening in oysters (Evans *et al.* 1995).

In British Columbia's coastal waters there is some evidence that the gastropod population in the Strait of Georgia is recovering since TBT restrictions have been implemented (Tester *et al.* 1996). However, imposex in female whelks continues near Victoria, and in Vancouver Harbour there are still no animals to study. Although TBT is highly toxic, its use persists on large ships (and probably illegally on many smaller boats) because of its effectiveness and the tremendous saving in fuel that it allows (Morton and Blackmore 2001). A related compound, triphenyltin (TPT), has been detected in water and mussels from Osaka Bay, but levels appear to have declined between 1989 and 1996 (Harino *et al.* 1999).

Other bioactive metals may threaten marine life (Bruland *et al.* 1991; Waldichuk 1990). Manganese and copper have been reported in snow geese off British Columbia and California (Hui *et al.* 1998). Manganese can cause neurological damage in seabirds and copper can cause anemia (Hui *et al.* 1998). The birds that feed off agricultural land in California are more contaminated than those that feed on British Columbia's pastures and marshes, probably because agricultural fungicides and fertilizers contain both metals (Hui *et al.* 1998). Edible seaweed in British Columbia and Japan is contaminated with arsenic, but the human health risk is unknown, because its bioavailability in seaweed has not been determined (van Netten *et al.* 2000).

The Bering Sea is less polluted with metals than are Asian marginal seas and the coast of North America. In contrast to the Yangtze River that feeds the East China Sea, the Anadyr River, the second-largest to flow into the Bering Sea, is not measurably contaminated with either metals or radionuclides (Alexander and Windom 1999). The concentrations of zinc, copper, cadmium and lead in Bering Sea fish (pollock, hake, whiting and mackerel) are low (Polak-Juszczak and Domagala 1993) as are the concentrations of such metals in sediments (Naidu *et al.* 1997).

Placer mining, tailings disposal and the collection of polymetallic nodules from the deep sea are likely to be sources of contaminant metals into the future. Placer gold mining in Norton Sound in the northeastern Bering Sea from 1986 to 1990 appears not to have affected the concentration of metals in King crabs because they were only in the area in the winter, which was the off-season for mining (Jewett 1999; Jewett *et al.* 1999; Jewett and Naidu 2000).

The Rudnayu River discharges mining wastes into the Japan/East Sea from Russia contaminating coastal sediments with lead, cadmium, copper and zinc in a 25 km long plume southward of the river's estuary (Shulkin and Bogdanova 1998). Disposal of metal-rich mine tailings in coastal fiords of British Columbia creates a combined impact from smothering and metal contamination, which may persist for decades due to instability of sub-sea tailings deposits (Burd *et al.* 2000).

The technology for mining polymetallic nodules and crusts in the Pacific Ocean has advanced sufficiently to allow serious prospecting for large-scale mining by Japan (Nakao 1995) and China (Xu *et al.* 1994). Deep-sea mining of nodules would bring with it the risks of physical disruption to benthic habitats, spills of toxic leaching fluids and smothering by sediment plumes and degradable organic matter (Ahnert and Borowski 2000).

Radionuclides

Waldichuk's (1990) conclusion, that artificial radionuclides from atmospheric weapons testing posed little risk to marine environments in 1990, can be repeated with the comment that radio-decay will have further reduced inventories of the predominant radioactive contributors (^{137}Cs, ^{90}Sr –

$t_{½}$ ~30 years) by 20% over the past decade. However, in the early 1990s, it was revealed that the former Soviet Union had disposed of liquid and solid radioactive wastes at a number of sites including the Northwest Pacific (Yablokov 2001). Extensive studies during the 1990s concluded that, despite the size of the releases both in the Arctic and North Pacific, there was actually little radiological risk (Layton *et al.* 1997). For example, Hong *et al.* (1999b) reported that the concentration of $^{239,\ 240}$Pu in zooplankton in the Bering Sea was similar to that of zooplankton found in the rest of the Pacific Ocean and represented long-range transport of radionuclides. In the Sea of Okhotsk, as of 1995, most of the ^{90}Sr, ^{137}Cs and ^{138,139,140}Pu was still in the water column (Pettersson *et al.* 2000). The concentration of these elements was consistent with previous measurements, but the total inventory in water and sediments represented more radionuclides than expected from global fallout (Pettersson *et al.* 2000). Measurements of $^{239,\ 240}$Pu and ^{137}Cs in fish, shellfish, cephalopods, crustaceans and algae in the Japan/East Sea and off the Pacific coast of Japan showed no evidence of pollution from dumping by Russia or the former U.S.S.R. (Yamada *et al.* 1999), even immediately after 14GBq of liquid radioactive waste was dumped into the Japan/East Sea in October 1993 (Hong *et al.* 1999a). The ratio of ^{239}Pu/^{240}Pu in the sediments was consistent with global fallout (Yamada *et al.* 1999).

Persistent solids

Waldichuk (1990) reported that entanglement by plastic driftnets, other fishing gear and other plastic objects, such as grocery bags, was estimated to be responsible for killing two million sea birds and 100,000 marine mammals each year. Entanglement was considered to be a particularly significant problem for endangered species. There have not been many studies on the prevalence and effect of plastics in the North Pacific in the last ten years, but the research that is available supports the seriousness of the problem and demonstrates that plastics affect different species to different degrees. Sea birds (Blight and Burger 1997; Robards *et al.* 1995) are particularly strongly affected, since they tend either to ingest the plastic or become entangled by it. Benthic communities can be smothered by the plastics, which are slow to break down (Uneputty and Evans 1997). California sea lions, however, although many of them do become entangled in plastic, are seven times more likely to be shot than entangled, according to data from a rehabilitation centre in California (Goldstein *et al.* 1999).

Domestic pollution

Domestic pollution consists of sewage and some industrial wastes that end up in the municipal treatment system (from hospitals, dentists, photographic processors and other industries). Many of the industrial wastes are toxic, and some bioaccumulate or biomagnify. Nutrients from sewage can cause eutrophication, bacterial pollution and harmful algal blooms, whereas other components are known to disrupt endocrine processes (Goldberg 1995; Kramer and Giesy 1995; Shang *et al.* 1999). Waldichuk (1990) described sewage-related problems in coastal British Columbia and commented that the situation was worse in Asia, where there was a much larger human population. The impact of sewage discharge is site-specific, depending on, among other things, cumulative loadings, rate of coastal flushing and mechanism of discharge (*e.g.*, deep, shallow, diffuse). In western North America, untreated and secondarily-treated sewage is still discharged to coastal waters by some cities (*e.g.*, Victoria and Vancouver) (Thomson *et al.* 1995), but upgrades are proceeding in many areas, and it seems likely that the impact of municipal outfalls on shallow coastal waters has been declining despite population increases. Widely-distributed poorly-maintained septic systems continue to contaminate shorelines in many places, however.

In the Asian marginal seas, domestic pollution is especially severe: less than 10% of China's domestic and industrial waste is treated before it flows into rivers or the ocean (Morton and Blackmore 2001). The degree of nutrient pollution and eutrophication varies geographically (Ma *et al.* 1997). In the Japan/East Sea, between 1982 and 1995, domestic pollution of water and sediment increased, changing the availability of a substrate for barnacle larvae to settle on and causing an increased mortality of young barnacles and decreased growth rate where the temperature had risen above 18°C and dissolved oxygen concentrations were critically low (Silina and Ovsyannikova 2000).

In Tokyo Bay, organic pollution is so severe that benthic organisms decline in summer when a thermocline is formed in the water column (Hisano and Hayase 1991). Over a period of 15 and 18 years respectively, Hirota (1979) and others (Anakubo and Murano 1991; Nishida, 1985; Nomura and Murano 1992; Uye 1994) recorded that for the Seto Inland Sea and Tokyo Bay, Japan, as eutrophication problems grew, there were zooplankton community structure shifts from a calanoid copepod to a cyclopoid-dominated one. In Tokyo Bay, the copepod community became dominated by *Oithona davisae*. These authors also recorded a shift in phytoplankton community structure towards small dinoflagellates and diatoms. Pollution thus seems to favour dinoflagellate feeders, such as *O. davisae*. Furthermore, the anoxic bottom-water formed in Tokyo Bay from organic enrichment and stratification acts selectively to advantage or disadvantage plankton life cycles. Copepod eggs that are spawned freely into the water column may sink onto the seabed where they are adversely affected by oxygen-deficient water, resulting in heavy recruitment loss. Inseminated *O. davisae*, however, which carries its eggs in egg sacs, can complete its life cycle by avoiding anoxic habitats. Recruitment of egg-carrying copepods would thus be favoured and *O. davisae* comes to dominate the resident community. Formation of oxygen deficient bottom water might also be detrimental to copepods with no flexible vertical distribution. For example, male *Parvocalanus crassiroustris* and species of Acartia remain in deeper waters, especially late in the day (Ueda 1987).

In the Yellow Sea the concentration of inorganic phosphorus is increasing (Ma *et al.* 1997), and eutrophication is thought to be responsible for more frequent HABs (Jiao and Guo 1996; You *et al.* 1994). In the East China Sea, human deaths have resulted from ingestion of toxic bivalves and gastropods; the HABs responsible for the toxicity of the shellfish are thought to have been caused by eutrophication in combination with physical processes, including coastal upwelling and climate events (Chen and Gu 1993).

Twenty to fifty percent of the “new” nitrogen in the Yellow Sea comes from atmospheric deposition and groundwater (Paerl 1997). Urban and agricultural discharges to groundwater are increasing (Paerl 1997), and rain over the Yellow Sea has a high concentration of nutrients from air pollution (Zhang *et al.* 1999). Groundwater and rain bypass the estuarine filters and can cause eutrophication and HABs at a considerable distance from the source. Atmospheric deposition of nitrate varies seasonally, with higher concentrations in the winter, when there is less precipitation (Zhang and Liu 1994); the episodicity of the high atmospheric delivery of nutrients corresponds with HABs in the nearby Pacific Ocean (Zhang 1994; Zhang and Liu 1994).

Due to increasing population and a relatively small land base, Korean bays have become sinks for a variety of domestic and industrial wastes. In Chinhae Bay, oxygen deficient conditions due to organic pollution perturbated the resident marine benthic communities in 1989 (Lim and Hong 1994; Yang 1991). In the early 1990s, Shihwa Lake was formed by impounding a marine bay on the west coast of Korea with a 12.7 km long barrier. The bay, which became stratified by salt and temperature, then went eutrophic and the sea bed became anoxic. Sea bed levels of nutrients and industrial wastes increased and macrobenthic diversity collapsed with blooms of *Polydora ligni* and *Capitella capitata* in winter (Lee and Cha 1997).

Aquaculture, a source of organic carbon, nutrients, and industrial chemicals (antifoulants, pharmaceuticals, contaminants in feedstock), is an expanding industry. Although total amounts of materials from any one operation may be small, there is the potential for impacts close to the operation and, with sufficient density in poorly-flushed coastal waters, there could be regional impacts. For example, fish culture in meshed cages in a bay in southern Japan resulted in an azoic sea bed with summer defaunation followed by recolonization the following spring (Tsutsumi 1995). Molluscs were progressively replaced by polychaetes as the dominant macrobenthos below the cages.

Components of a warning system

The multiple stresses briefly reviewed here provide an enormous and increasing challenge to North Pacific coasts and shelves. These stresses do not operate independently but, rather, interact with one another in a manner that varies among locations (Fig. 7). If we survey the Pacific Rim, we see that the Asian coasts are most immediately threatened on a large scale by over-fishing, destructive fishing practices, nutrient loadings and inputs of contaminants from large populations undergoing industrial transition (Morton and Blackmore 2001). To the far north, local sources dwindle in importance and climate change and long-range transport of contaminants become leading causes for concern (Alexander and Windom 1999; Rice and Shigaev 1997; Shaporenko 1997; Vaschenko 2000). Finally, for the temperate west coast of North America, climate change, over-fishing and long-range contaminant transport remain important issues, with contaminant loadings to enclosed seas (Strait of Georgia, Puget Sound, San Francisco Bay) assuming high local profiles (see for example, Macdonald and Crecelius 1994; Parsons 1996; Ross *et al.* 2000; Sañudo-Wilhelmy and Flegal 1992).

The challenge that ocean scientists must meet if we are to avert the demise of coastal ecosystems is: (1) to produce observations that forewarn us (trends); (2) to understand ocean processes sufficiently to associate ecosystem response with cause (human or natural) and; (3) to assign the order of importance of stresses put upon coastal seas by human activities. Clearly, for this scientific effort to be of benefit it must be translated into action, for example, either to reduce or to eliminate contaminants at local, regional and international scales. One strategy widely promoted to conserve biological resources is the development of a network of Marine Protected Areas (MPAs). If carefully chosen, MPAs provide undisputed benefits for conservation (Roberts *et al*. 2001). However, they allow us little room for complacency as they provide no protection against coastal eutrophication, chemical contamination, introduction of exotic species, over-harvesting of free-ranging biota, or climate change – the majority of the stresses that threaten our oceans (Fig. 7). To recognize and prioritize threats to coasts from these disparate stressors will require coherent observations and research, which we suggest should include at least the following elements.

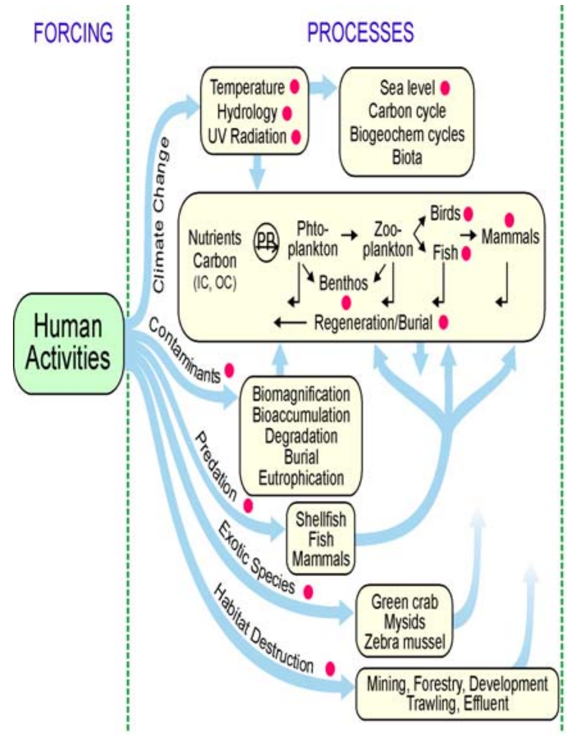

Fig. 7 A schematic diagram illustrating how human activities may affect marine ecosystems at multiple points. Points at which the marine systems are monitored for contaminants (dots) may be influenced by other confounding factors.

Box models, other models and case studies

Box models are especially useful in enclosed seas where inputs and outputs can in principle be tightly constrained, but they may also be applied to open shelves (Chen *et al*, 2002; Johannessen *et al.* 2002; Liu *et al.* 2000). Beginning with water, salt, and nutrients (Gordon *et al.* 1996), budgets can be scaled up to include sediments, organic carbon and contaminants. These budgets then allow a preliminary assessment of human loadings compared with fluxes and budgets in the undisturbed system. From such an assessment, an estimation can be made of the likely scale (local, regional) of impact, and human loadings can be ranked to allow for a logical approach to mitigation. An example from the Seto Sea (Fig. 8) illustrates that human loadings dominate the zinc and copper budgets and that most of the contaminant load of these metals ends up in its sediments. Box models provide a schematic understanding, which can help to validate the output of more sophisticated ones.

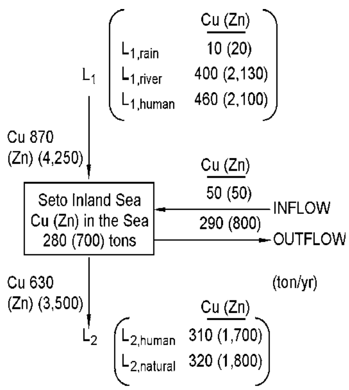

Fig. 8 An example of the application of a box model to an enclosed sea. Mass balances are given for copper and zinc in the Seto Island Sea (tons/yr). L1 identifies load into the sea, L2 identifies load into sediment, and zinc loadings are given in parentheses (Hoshika *et al.* 1988).

Box models provide a solid foundation upon which to build case studies (Macdonald *et al.* 2000b). Case studies can be applied to a relatively constrained environmental impact such as the disposal of mine tailings to a coastal fjord (Ellis *et al.* 1995), to a specific chemical like PCB, HCH or toxaphene (Macdonald *et al.* 2000b) and may provide the basis to initiate appropriate environmental action (Lindstrom and Renescu 1994).

Time-series observations

The observation of change is one of the most powerful means to initiate action. The difficulty, however, is to recognize it early enough to avert irreversible change, and to be able to draw clear inference from observations to causes so that appropriate action can be taken. As shown in Figure 7 (dots), time series can be assembled at many points of the ocean system. However, the meaning of such time series varies from point to point and, in many cases, multiple components of change act simultaneously, so that a simple observation (declining PCB levels with time) can be produced by more than one factor (*e.g.*, reduced global emission, reduced local emission, change of atmospheric or ocean pathway through regime shift, changes to the food web structure (top-down or bottom-up)). Generally, time series have been collected *ad hoc* without worrying about confounding factors or comparability with other time series. It is time for the scientific community to develop coherent, intercomparable time series of sufficient sophistication to guide administrators toward appropriate action.

Sediment cores

Sediments provide well-recognized archives of the history of particle reactive contaminants and, as such, will remain a key resource to understanding current loadings of contaminants in the context of pre-industrial loadings (see, for example, Huh and Chen 1999; Macdonald and Crecelius 1994). Finney *et al.* (2000) have demonstrated elegantly that in certain circumstances, sediment can record both the forcing (anadromous fish return) and effects (lake eutrophication), allowing a more secure inference of how climate change and human predation work together to affect fish escapement. Such insights are not available in the instrumental observation record. This study certainly points the way to more powerful application of sediment cores to sort out combined stresses; for example, the findings of Finney *et al.* (2000) could be further expanded to consider the effects of fish on lake contaminants and, potentially, the effects of contaminants on fish (see, for example, Ewald *et al.* 1998; Zhang *et al.* 2001).

Monitoring components of the food web

A food web provides an enormous scope for monitoring, from filter feeders (Beliaeff *et al.* 1997) to apex predators (Addison and Smith 1998; Ross *et al.* 2000) to HABs (Yanagi 1988). Presently, time series data for any component of the food web in the North Pacific are extremely rare, and where there is such information, it often comprises few time series points, several or more years apart, and well after contaminants began to be released into the environment (for example see Fig. 6). It is now recognized that contaminant burdens recorded by aquatic animals depend on their life histories and cycles they may exhibit (age, sex, size, season, prey). With research, many of these factors can be taken into account through, for example, sampling strategy. However, the food web itself is a dynamic system (Fig. 7) subject to alteration in a number of ways, as discussed earlier.

The problem with monitoring individual components in the food web, therefore, is that a change in contaminant burden with time may have non-unique causes. For example, a shift in a single trophic level produced by over fishing or eutrophication can produce a change in mercury concentration by a factor of 10 (Fig. 9). The same problem exists for the organochlorines, which also biomagnify. In the latter context, a particularly apt example was provided in the Great Lakes where the invasion of an exotic species, the zebra mussel (*Dreissena polymporpha*), led to a fundamental change in lake trophic structure and, presumably, to contaminant pathways (Morrison *et al.* 1998; Whittle *et al.* 2000). Given the varied pressures on the aquatic food webs of the North Pacific reviewed here, it seems clear that we need to institute a monitoring programme that incorporates all trophic levels. Furthermore, support data (stable isotope composition) must be assembled to help interpret changes in trophic level together with changes in contaminant burdens.

Sample archives

Tissue archives provide a safety net for ongoing monitoring. We cannot hope to anticipate all future chemicals, nor can we predict accurately the sorts of changes that might occur in our ecosystems. We can be sure, however, that new and better techniques will be developed with time to apply to problems of chemical contamination and ecosystem change. For example, the change in trophic structure due to zebra mussel invasion of the Great Lakes would not have been identified without such archives (Kiriluk *et al.* 1999), nor would the relationship between this change and

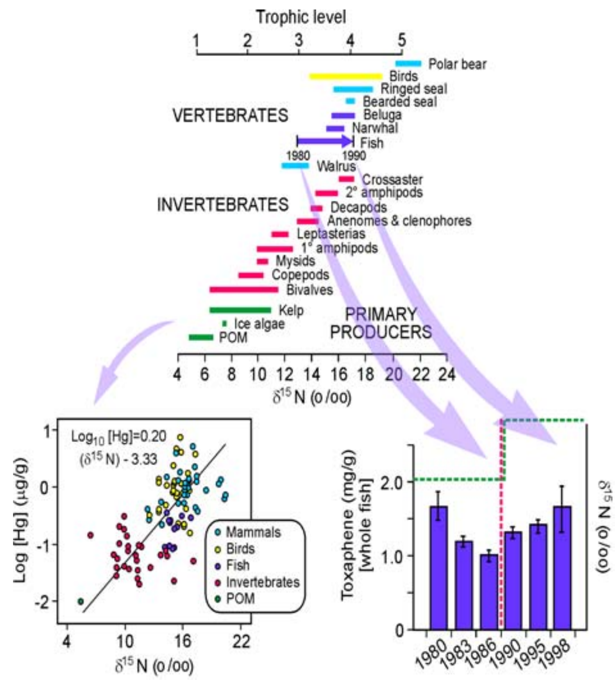

Fig. 9 A schematic diagram showing trophic organization of a marine food web based on $\delta^{15}N$ measurements (top panel, Hobson and Welch 1992), and how biomagnification increases mercury concentration as trophic level is increased (bottom left, Atwell *et al.* 1998). Alteration of the food web resulting in, for example, a change in the trophic level of fish can accordingly alter contaminant burdens observed in time series (after Whittle *et al.* 2000).

contaminant burdens. It is astonishing to note that the tissue archive applied to understanding what had occurred in this system was maintained unofficially with soft funding. Recognizing the importance of tissue archives, we should institutionalize immediately the collection, cataloguing and storage of appropriate samples.

Ecological indicators

Monitoring environmental quality using chemical measurements tends to be prejudiced either toward chemical analyses for which we have developed skill, or toward chemicals known to cause environmental problems (the usual suspects). As a consequence, one detects only those chemicals that have been sought, and unexpected chemicals are likely to go unrecognized. Biological measurements are required, therefore, to alert us to the presence of unidentified chemicals that require the development of new analytical methods (the research to isolate and identify domoic acid, following shellfish poisoning of humans on Canada's East Coast provides an excellent example (Addison and Stewart 1989)). Although marine pollution is often presented as a chemical problem, our ultimate interest is not in the chemicals themselves, nor of their burdens in environmental media. Rather, we would like to be able to relate chemical loadings to harmful effects on the structure and functioning of ecosystems (Addison 1996). To do this requires the development of ecological indicators, the science of which is in its infancy. The difficulty we face is that many of the relatively simple and affordable measurements (*e.g.*, PCB burden in seal blubber) cannot be related confidently to animal health, and even less so to population health (Fig. 10), even though we suspect that certain clinical toxic thresholds may have been exceeded. On the other hand, monitoring community structure and relating changes to chemical and other stresses is not only beyond our present understanding but also beyond our financial means. A crucial task remains therefore, to develop indicators that exhibit reliability, robustness and specificity but which also are affordable.

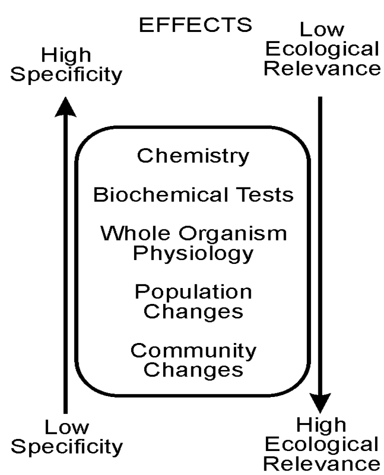

Fig. 10 A schematic diagram relating the cost of ecosystem monitoring with the complexity and relevance of the measurements (modified from Addison 1996).

Conclusions

Like Waldichuk (1990), we conclude that continental shelves and near shore areas of the North Pacific are under the greatest stress from chemical contaminants. Increasing population and industrialization will increase that stress. With either their restriction or elimination (PCBs, OC pesticides), global cycling of some of these contaminants have decreased; however, it is likely that they will continue to cause concern for some time (Ross *et al.* 2000). And we will discover new chemical problems to replace old ones (*e.g.*, see Betts 2001; Kramer and Giesy 1995; Paasivirta 1998).

The problem we face is not just chemical contamination, but assault on coastal systems from multiple stressors. Presently, we lack coherent observational networks, reliable inventories for contaminants, and an understanding of processes that would unequivocally distinguish real threats from perceived threats. Given the degree of concern that pervades much of the literature cited here, it is surprising that the scientific and political communities of the North Pacific have not collaborated to conduct a regional assessment. The Arctic Monitoring and Assessment Programme (AMAP 1998) provides an apt example where international hurdles were overcome to produce a well-founded, science-based review that led to action. We therefore suggest that the highest priority for PICES should be to produce, within the next five years, an International North Pacific Assessment Programme.

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The PICES Climate Change and Carrying Capacity Program: Why, how, and what next?

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Introduction

The Climate Change and Carrying Capacity (CCCC) Program is the first major inter-disciplinary initiative undertaken by the North Pacific Marine Science Organization (PICES). Planning for this program began one year after the First Annual Meeting of PICES, and it has continued to be the major scientific integrating activity of PICES. This report describes the CCCC Program, its objectives, activities, accomplishments and problems, and provides suggestions for future directions of the Program.

This paper asks the central question: how has the PICES CCCC Program contributed to the present understanding of the ecosystems of the North Pacific, and their potential responses to climate changes? An underlying theme to this review is identification of those factors, which have either contributed to the success, or lack of success, of such a large multi-national and inter-disciplinary initiative, as a guide to developing other large scientific programs.

Historical views of the North Pacific marine system

In the mid-1500s in Japan, and the mid/late 1700s in North America, when Europeans were first exploring the North Pacific, they encountered highly maritime-adapted peoples and an ocean rich in resources, in particular salmon and marine mammals. Estimates of the abundances of marine mammals in the North Pacific prior to industrial exploitation are necessarily sketchy, but range from tens of thousands to millions (Table 1).

Table 1 Abundance estimates (numbers) of marine mammals in the North Pacific prior to industrial exploitation (Glavin 2000; Nichol and Heise 1992).

Whales	Blue	5,000
	Sei	63,000
	Humpback	15,000
	Sperm	1,250,000
	Gray	15,000
	North Pacific Right	?
Sea otters		300,000
Fur seals (Bering Sea)		3,000,000

These resources spurred discovery of the North Pacific, fueling commerce with Asia and greasing the wheels of the industrial revolution in Europe (Glavin 2000). Nothing is known, however, about the productivity or structure of the marine ecosystems that supported such large abundances of high trophic level species.

Two hundred years later, in the 1960s and 1970s, understanding of the North Pacific marine system was firmly on a scientific basis. Different domains were recognized in the physical and biological oceanography of the region (*e.g.*, Dodimead *et al.* 1963). However, the approaches to studying these domains differed: offshore studies in the western Pacific emphasised a real coverage along transects, whereas offshore studies in the eastern Pacific focussed on time series and process studies at a few locations (*e.g.*, Station PAPA). It had also been recognized that the marine ecosystem, at least in the eastern oceanic subarctic North Pacific, appeared to function differently from that in the North Atlantic. These differences were explained largely on the basis of the life cycle and vertical migratory behaviours of the large copepods in the North Pacific (*e.g.*, Parsons and Lalli 1988).

Twenty years later, in the 1990s, the scientific view of the North Pacific had changed again, with a different understanding of three key features:

- the roles of iron and the microbial loop in explaining why the subarctic North Pacific is a high-nutrient but low-chlorophyll region (*e.g.*, Harrison *et al.* 1999);
- the extent to which North Pacific marine ecosystems are coupled to larger basin-scale oceanographic and atmospheric processes (teleconnections), such as tropical forcing (El Niño – Southern Oscillation), high latitude forcing (Arctic Oscillation, Thompson and Wallace 1998), and east-west Pacific basin oscillation (Pacific Decadal Oscillation, Mantua *et al.* 1997);
- the connections between environmental changes and marine population fluctuations (*e.g.*, Beamish and Bouillon 1993; Anderson and Piatt 1999).

Therefore, the major question is: how has the PICES CCCC Program contributed to this recent view of the structure and functioning of the marine ecosystems of the North Pacific?

Origin and structure of the CCCC Program

The seeds of the CCCC Program were planted by PICES' Working Group 6 (Subarctic Gyre), which was established at the First Annual Meeting of PICES in 1992. Based in part on the activities of this Working Group (Hargreaves and Sugimoto 1993), and recognizing that the Scientific Committees of PICES were established mostly along traditional disciplines (such as physics, biology, etc.), the Governing Council of PICES approved the development of a CCCC Program at its Second Annual Meeting (North Pacific Marine Science Organization 1994). The scientific program was elaborated at the Third Annual Meeting to include (North Pacific Marine Science Organization 1995):

- a strategy for determining the carrying capacity for high trophic level carnivores in the subarctic North Pacific; and
- a plan for a cooperative study of how changes in ocean conditions affect the productivity of key fish species in the subarctic North Pacific and the coastal zones of the Pacific Rim.

These issues embodied the two major themes of the Program: carrying capacity and climate change. It was also noted at this Third Annual Meeting that member countries were developing national programs affiliated with the emerging Global Oceans Ecosystem Dynamics (GLOBEC) program (GLOBEC Science Plan 1997), and that it was therefore desirable for the PICES–CCCC/GLOBEC science plan to be developed in a timely manner to guide coordinated planning among PICES member nations.

The Science Plan for CCCC was developed during a large workshop held prior to the Third Annual Meeting in 1994, and the Implementation Plan was developed a few months later at a smaller workshop in 1995 both published as PICES Scientific Report No. 4 (PICES 1996). At about this time, the PICES CCCC Program was accepted as a Regional Program of the evolving International Geosphere – Biosphere Program (IGBP) GLOBEC core project which greatly broadened the affiliation of the CCCC Program with global environmental change research networks and provided integration with the global comparisons being conducted by these networks.

The ultimate goal of the CCCC program was set:

"to forecast the consequences of climate variability on the ecosystems of the subarctic Pacific"

and the general question was framed as:

"how do interannual and decadal variation in ocean conditions affect the species dominance, biomass, and productivity of the key zooplankton and fish species in the ecosystems of the PICES area?"

(PICES 1996, p. 22 and 61). The Science Plan identified eight Key Scientific Questions, which were "re-mapped" into four Central Scientific Issues in the Implementation Plan (PICES 1996, p. 61):

Physical Forcing: What are the characteristics of climate variabilty, can interdecadal patterns be identified, how and when do they arise?

Lower Trophic Level Response: How do primary and secondary producers respond in productivity, and in species and size composition, to climate variability in different ecosystems of the subarctic Pacific?

Higher Trophic Level Response: How do life history patterns, distribution, vital rates, and population dynamics of higher trophic level species respond directly and indirectly to climate variability?

Ecosystem Interactions: How are subarctic Pacific ecosystems structured? Is it solely through bottom-up forcing, or are there significant intra-trophic level and top-down effects?

Consistent with other GLOBEC programs, the CCCC Science and Implementation Plans described five key research activities:

- retrospective analyses
- development of models
- process studies
- development of observational systems
- data management

The approach to study of the general question and its scientific issues was to pursue investigations on two broad spatial scales: Regional and Basin (Table 2). Regions were defined in general terms as including continental shelf and national waters, whereas the Basin spatial scale included the open oceanic waters.

In 1997, the Terms of Reference for the CCCC Program were revised to:

- integrate and stimulate national activities on the effects of climate variations on marine ecosystems of the subarctic North Pacific;
- determine how the PICES Scientific Committees and Working Groups can support the Program;
- identify national/international research programs with which CCCC could coordinate;
- provide scientific direction.

Table 2 Regions defined for CCCC studies. Numbers 1-10 include national waters (REX) and numbers 11 and 12 are open ocean waters (BASS).

1.	California Current system – south
2.	California Current system – north
3.	South east and central Alaska
4.	Eastern Bering Sea
5.	Western Bering Sea / Kamchatka
6.	Okhotsk Sea
7.	Oyashio / Kuroshio
8.	Japan Sea / East Sea
9.	Bohai, Yellow Seas
10.	East China Sea
11.	Western Subarctic Gyre
12.	Eastern Subarctic Gyre

To put the CCCC Program into action, and to involve as many people as possible, the Implementation Panel proposed establishing three "Task Teams" to integrate the key research activities and the two spatial scales of the Program. These were:

MODEL – to advance the development of conceptual / theoretical and modelling studies;

BASS (BASin Scale) – to develop the basin scale component of CCCC;

REX (Regional EXperiments) – to develop inter-comparisons among regional (national) studies.

A fourth Task Team, "MONITOR", was established in 1997 to:

- review and suggest improvements to monitoring by PICES Nations;
- consult on designing a PICES monitoring system (calibrations, standardisation, etc.);
- assist with development of a coordinated monitoring program to detect and describe events that strongly affect the subarctic Pacific;
- report to CCCC on the montoring needs in the subarctic Pacific to be implemented in GOOS (Global Ocean Observing System).

Each Task Team had two appointed Co-Chairmen, representing opposite sides of the Pacific. A larger oversight body, called the Implementation Panel of the CCCC Program, was established. It consisted of at least two members appointed from each PICES member countries plus other members from the Task Teams. Its role was to provide coordination of the CCCC Program and input from the member countries. As this Panel was relatively large (~27 members), an Executive Committee (EC) of the Implementation Panel was formed to provide oversight of the Implementation Panel; this EC was composed of the two CCCC Co-Chairmen and the Co-Chairmen of each of the Task Teams. The Chairmen of the CCCC Program since its inception are identified in Table 3.

Table 3 CCCC Program Co-Chairmen.

Warren S. Wooster	1995 - 1997
Daniel M. Ware	1995 - 1996
Patricia Livingston	1996 - 1998
Yutaka Nagata	1997 - 1998
Suam Kim	1998 - 2000
David Welch	1998 - 2001
Makoto Kashiwai	2000 - present
Harold Batchelder	2001 - present

Highlights of major accomplishments

The CCCC Program has produced significant accomplishments. The following represents some of the highlights for each Task Team.

MODEL

The major task of MODEL is to develop the modelling components of the CCCC Program. In its early meetings, MODEL identified the modelling needs of the CCCC scientific community (Perry *et al.* 1997). It was concluded that the development of lower trophic level models, and their coupling with physical models and with higher trophic level models, lagged behind development of physical models for the North Pacific basin. This led to a significant effort to develop a lower trophic level model that would serve the needs of the CCCC research community.

Development of this model is described by Megrey *et al.* (2000), Eslinger *et al.* (2000), and Kishi *et al.* (2001). It was named "NEMURO" for **N**orth Pacific **E**cosystem **M**odel for **U**nderstanding **R**egional **O**ceanography. The model (Fig. 1) consists of 11 state variables, defines fluxes of both nitrogen and silicon, and includes the seasonal vertical migrations of the large copepods (*e.g.*, *Neocalanus* spp. in the NE Pacific). It was initially developed as a diagnostic tool, and applied to one western Pacific and one eastern Pacific location. The model appeared to get results "in the right ballpark", and it is being used to investigate the effects on upper trophic levels of shunting a large fraction of primary productivity through a microbial loop rather than directly through the autotrophic phyoplankton. Recent activities have involved refinements to, and further testing of, the model. There have also been collaborations with the BASS Task Team to couple the NEMURO model to upper trophic level models such as ECOPATH and ECOSIM (Walters *et al.* 1997l; McFarlane *et al.* 2001), and collaborations with the REX Task Team to use the NEMURO model to explore time series of growth variability in pelagic fishes such as herring.

BASS

The major task of BASS was to develop CCCC activities in the deep basins of the North Pacific. These regions were expected to need multi-national support for research. Outstanding questions early in the CCCC Program were:

- To what extent are the processes and structures in the eastern subarctic Pacific gyre like those in the western subarctic Pacific?
- Do they respond similarly to similar forcings and disturbances?

To address these questions, BASS hosted a very successful Science Board symposium in 1997, which resulted in a dedicated volume of papers in the primary literature (Beamish *et al.* 1999).

This symposium was extremely important for enhancing east-west collaboration as each paper was authored by at least one Asian and one North American scientist. Papers in this volume identified teleconnections between atmospheric processes in the central and eastern subarctic Pacific with oceanographic conditions in the Oyashio current area (Sekine 1999); determined that plankton (Mackas and Tsuda 1999) and marine bird and mammal productivity (Springer *et al.* 1999) is higher in the western subarctic gyre than in the eastern gyre; but, in contrast to the

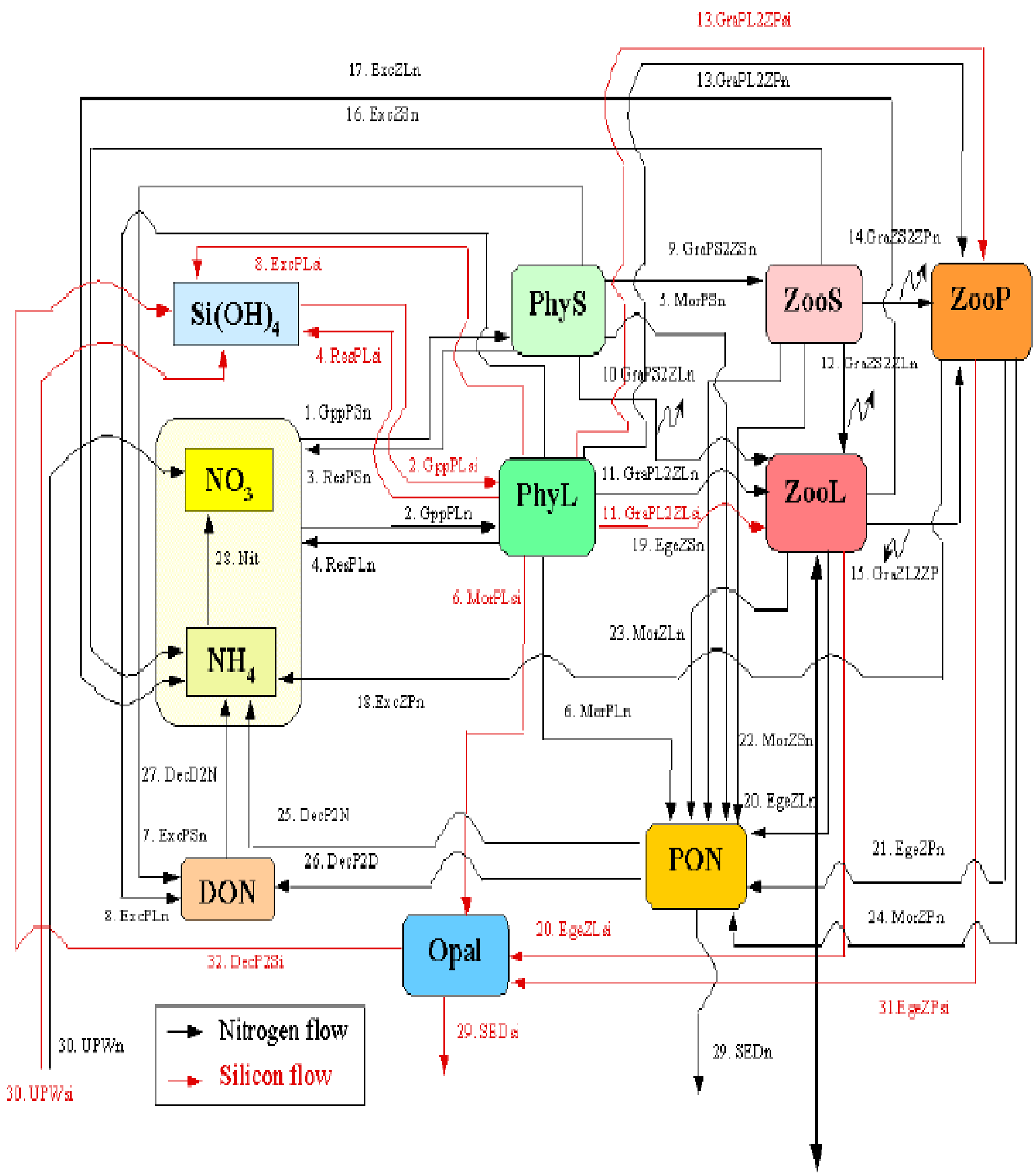

Fig. 1 NEMURO Model (Megrey *et al.* 2000). State variables are the boxes with names, fluxes in black represent nitrogen, fluxes in red represent silicon, thick black line represents vertical migration by large zooplankton.

previous findings, fish species diversity is greater in the eastern subarctic gyre (Brodeur *et al.* 1999). Outstanding research questions were also identified, such as the role of iron in plankton production, and why the western gyre should be more productive than the eastern gyre (Harrison *et al*. 1999).

Considering the questions and potential significance relating to the role of iron on productivity processes in the subarctic North Pacific, an Advisory Panel on an Iron Fertilization Experiment in the subarctic Pacific (IFEP) was formed in 1999 under the BASS Task Team.

The objective of this Panel is to oversee and coordinate an experimental fertilization of iron in the subarctic North Pacific, in order to examine the details of the responses of the lower trophic levels (*e.g.*, Harrison *et al.* 1999). The Panel plans to identify similarities and differences in the responses of the planktonic ecosystems in the eastern and western subarctic gyre to the addition of iron (*e.g.*, differences in species composition, export flux rates, *etc.*). There are strong linkages of this Panel with the emerging IGBP core program on Surface Ocean Lower Atmosphere Studies (SOLAS).

Significant efforts have also been made between BASS and the MODEL Task Team to compare lower trophic level processes with upper trophic level responses, by integrating the NEMURO model with an ECOSIM model of the subarctic North Pacific (McFarlane *et al.* 2001). Details of this have been noted in the previous section on the MODEL Task Team accomplishments.

<u>MONITOR</u>

The youngest Task Team, MONITOR, has both backward-looking and forward-looking components, by being responsible for retrospective analyses of past changes in the subarctic Pacific, and designing observational systems to detect future changes.

In 1999, MONITOR hosted the Science Board symposium on the "Nature and impacts of North Pacific climate regime shifts" which was subsequently published in the primary literature (Hare *et al.* 2000). Papers in this symposium provided further evidence from around the North Pacific for a major shift in 1976/77, and provided evidence to suggest that additional changes may have occurred in 1989 and in 1999, although the mechanisms remain obscure. Other papers found evidence for persistent changes at specific locations at other times.

The MONITOR Task Team is also the contact point within PICES for a North Pacific monitoring program (Dugdale *et al.* 1999; McFarlane *et al.* 2001). As one component of this, MONITOR has been successful at obtaining independent sources of funding for an in-water observational program. They established an Advisory Panel on the Continuous Plankton Recorder (CPR) survey, and initiated a pilot project to sample plankton and oceanographic properties using commercial ships of opportunity. Five north-nouth transects were conducted through spring and summer 2000, and one east-west transect across the northern Pacific in June-July 2000 (Fig. 2).

These sampling programs use methods that are well-developed in the Atlantic Ocean (Warner and Hays 1994), and which provide an along-track spatial resolution of 18 km. Funding from the Exxon Valdes Oil Spill Trustee Council has been secured to continue the North Pacific CPR Program in 2002, and the data from existing surveys are being prepared for publication.

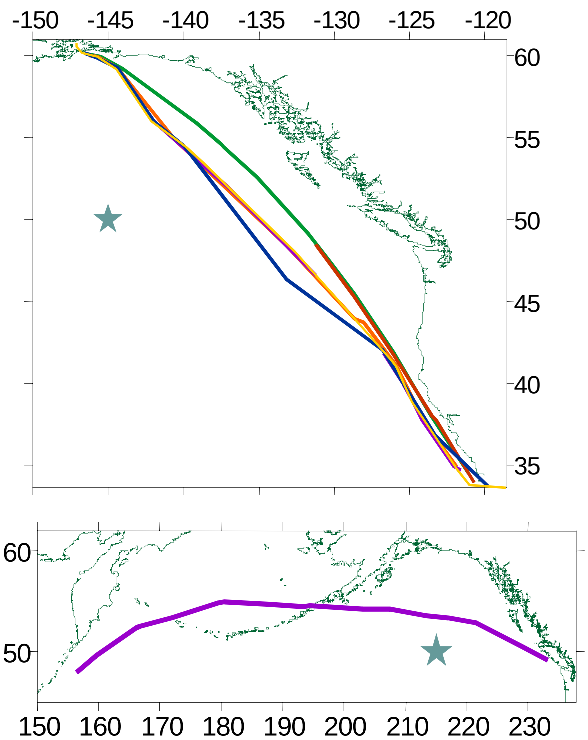

Fig. 2 Continious plankton recorder routes in the North Pacific in 2000: sampling was carried out on five north-south tracks (March-August) and on one east-west track (June-July). Key to colours: March (green), April (red), May (brown), June (violet), July (blue), August (orange). Station Papa is shown for reference (star). Figures courtesy of S. Batten (Sir Alister Hardy Foundation for Ocean Science, UK) and D. Welch (Pacific Biological Station, Nataimo, B.C., Canada).

REX

The REX Task Team was initially expected to encourage the development of "regional experiments" among the 10 identified regions of the Pacific continental margins (Table 2). The role of REX in the CCCC community differed from other programs because it relied on national programs for development and design of research studies. The REX Task Team worked to identify data gaps within the PICES regions and communicated the potential for international co-operation in support of comparison of results across large geographic regions (Hollowed *et al.* 1998). More recently, however, most PICES member nations have established GLOBEC programs, and the synergy during early planning appears to have been lost. REX has developed a workshop series on small pelagics, herring in particular, and has been assembling data on life history patterns of these fishes across the Pacific basin (McFarlane *et al.* 2001). REX has also been examining temporal variations in size-at-age for fish species in coastal areas around the North Pacific rim, and is working to couple this information to the NEMURO model.

The REX Task Team assisted national programs by providing a forum for discussion of project design and research goals and objectives. Once national programs were established, REX established an annual scientific session within PICES to provide a forum for exchanges of results and innovations. This session has attracted participation of researchers from a variety of academic disciplines.

The major accomplishment of the REX Task Team has undoubtedly been the initiation of CCCC GLOBEC, and GLOBEC-like, programs around the North Pacific (Fig. 3):

China

The title of the Chinese GLOBEC program is "Ecosystem dynamics and sustainable utilisation of living resources in the East China and Yellow Sea" (Tang 2000). Its program goals are to:

- identify key processes of ecosystem dynamics, and improve predictive and modelling capabilities in the East China Sea and the Yellow Sea; and
- provide the scientific underpinnings for sustainable utilisation of marine ecosystems and the rational management of fisheries and other marine life.

It consists of 12 projects.

Korea

The overall program goal is defined as providing a long-term science and strategic plan for Korean waters to establish effective and reasonable conservation and sustainable measures for fisheries and ecosystem management (Kim 2000). This program has developed several Task Teams, including retrospective data, scientific program development, capacity building; and fisheries and ecosystem management approaches (Fig. 4). Note one of the specific relationships includes "Consider the research priorities of the PICES CCCC Program".

Japan

The Japan GLOBEC program has several research activities (Terazaki 1997):

- the dynamics of the food chain through zooplankton and micronekton, which examines how changes in ocean physics resulting from global climate changes affect the structure and dynamics of marine food chains;
- the dynamics of the responses of marine ecosystems to climate change, which examines variability of fish stocks in major marine systems as a response to global changes; and
- the development and application of new technologies for measurement and modelling in marine ecosystems.

The program has been supported by the Ministry of Education, Science, Culture and Sport; the Japan Fisheries Agency of the Ministry of Agriculture, Forestry and Fisheries; the Japan Meteorological Agency and the Japan Oceanographic Data Center of the Ministry of Transportation; and the Science and Technology Agency of Japan.

The Fisheries Research Institute of Japan has been conducting GLOBEC-like programs over the period of 1997-2002 with VENFISH (Variation of the oceanic ENvironment and FISH production in

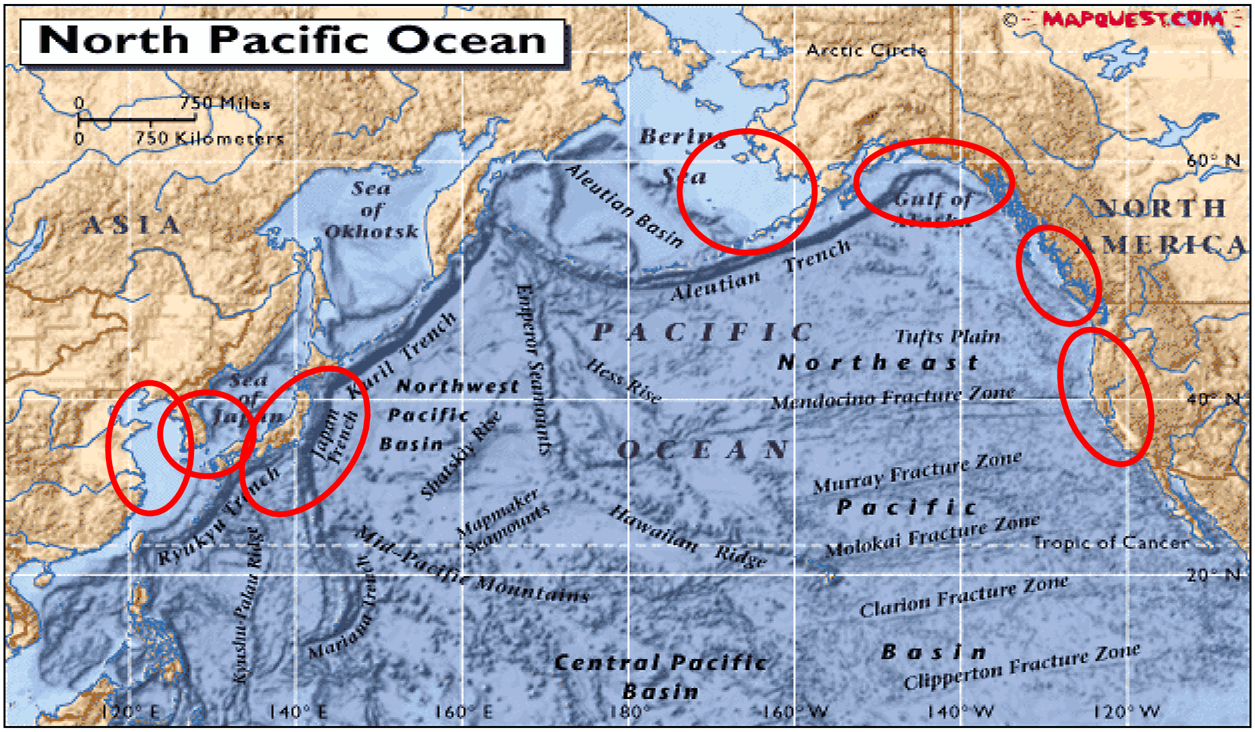

Fig. 3 Schematic map of locations of PICES Climate Change and Carrying Capacity regional programs. Base map courtesy of Mapquest.com.

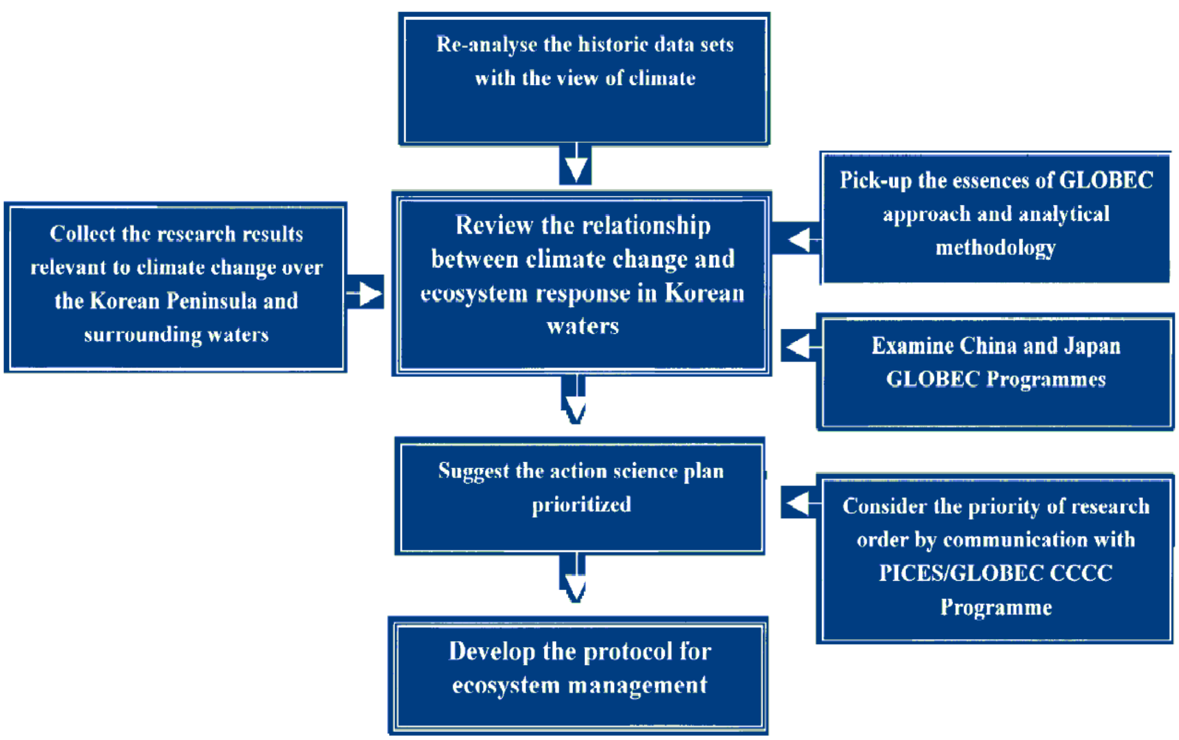

Fig. 4 Diagram of Korea GLOBEC component activities (Kim 2000).

the northwestern Pacific) and the FRECS program, which is scheduled for 2000-2005 (FRECS: Fluctuation of Recruitment of fish eggs and larvae by changes of spawning grounds and transport patterns in the East China Sea). The main subject of VENFISH is bottom-up control processes from phytoplankton and zooplankton production to the recruitment of fish, in particular the Pacific saury (*Cololabris saira*). The FRECS program aims to understand the mechanisms of environmental impacts on the spawning grounds and their linkages to recruitment; the mechanisms by which eggs and larvae are injected into the Tsushima and Kuroshio Currents and are carried to coastal areas; and factors affecting survival during growth processes. Target species are jack mackerel (*Trachurus japonicus*) and the Japanese common squid (*Todarodes pacificus*). The findings of these programs are expected to improve estimations of Allowable Biological Catches for these species.

United States

United States activities conducted by GLOBEC in the North Pacific are extensive; U.S. GLOBEC programs are described by Batchelder (2002). The U.S. GLOBEC Northeast Pacific program (NEP) has research nodes in the central Gulf of Alaska and the Calofornia Current System. The NEP GLOBEC program is jointly funded by National Oceanic and Atmospheric Administration's (NOAA) Coastal Ocean Program (COP) and the National Science Foundation (NSF).

The principal goal of the U.S. GLOBEC program is understanding how changes in the atmospheric forcing and circulation affect the productivity of the coastal ecosystems, and the survival of juvenile salmon after they enter the ocean. A central hypothesis is that the spatial and temporal variability in mesoscale circulation is a dominant physical forcing that impacts production, biomass, and distribution of plankton. The U.S. GLOBEC research team consists of 34 funded projects and 90 investigators from 26 institutions. In addition, several GLOBEC-like programs were funded in the United States.

The COP supported programs in the Bering Sea and west coast. The Bering Sea programs (Bering Sea FOCI and Southeast Bering Sea Carrying Capacity Regional Study) are described by Macklin (2000). The COP study on the west coast (Pacific Northwest Coastal Ecosystems Regional Study) is described by Parrish and Litle (2000). The National Science Foundation also funded GLOBEC-like research programs including the Arctic Research Initiative in the Bering Sea, and the Coastal Ocean Processes (COOP) program off the coast of Oregon. The National Marine Fisheries Service (NMFS) supported two GLOBEC-like programs in the Gulf of Alaska: the Ocean Carrying Capacity program that targeted responses of salmon to climate shifts, and the Fisheries Oceanography Coordinated Investigations (FOCI) which is described by Kendall and Schumacher (1996).

The Southeast Bering Sea Carrying Capacity Study (Macklin 2001) has components on monitoring, process studies, modelling, and retrospective analyses. The program has the following central scientific issues:

- How does climate variability influence the Bering Sea ecosystem?
- What limits population growth on the Bering Sea shelf?
- How are forage and apex fish species linked through energetics and life history?
- How do oceanographic conditions on the shelf influence biological distributions?
- What influences primary and secondary production regimes?

The principal field seasons were from 1996 to 1998, and results are now being analysed. During this period, the Bering Sea appears to have undergone a significant shift in production characteristics and species composition, and the SEBSCC program is well-placed to help understand these shifts.

The Ocean Carrying Capacity program (Helle 1999) in coastal Alaska is addressing the impacts of changes in the productivity of the North Pacific Ocean on Pacific salmon. Specifically, the program is examining the effects of ocean productivity on salmonid carrying capacity, and changes in the biological characteristics of Pacific salmon in the Alaska region. It has three major components:

- distribution and migrations of juvenile, immature, and mature salmon and associated species in coastal waters;
- distribution and migration of immature and maturing salmon in offshore waters; and
- understanding the influence of marine climate change on the abundance, age, and sizes of Pacific salmon in the past, so as to understand present and future changes.

Canada

The major objectives of the Pacific component of the Canada GLOBEC program were to determine how physical and biological processes affect the ecosystem structure off the west coast of Canada. The key issues for the Canadian program (Fig. 5; Mackas and Perry 1999) are:

- seasonality and timing matches between physics and biology;
- freshwater inputs, and effects on mixing and transport;
- advective coupling among continental shelf, margin and the deep ocean;
- interactions between zooplankton and fish populations.

Research was conducted at three spatial scales: the west coast of Vancouver Island, examining shelf-scale processes; the coast of British Columbia, examining regional scale events; and the deep NE Pacific, examining large-scale events and how they are coupled to the coastal and shelf regions of British Columbia.

The project had a mix of *in situ* observational and process studies, retrospective analyses, and modelling. The active phase of the program is now over, and results are being prepared for publication.

As a conservative estimate, these GLOBEC and GLOBEC-like programs, inspired and coordinated in large part by the PICES CCCC Program, have contributed in total over US$6 million per year to marine ecosystem research in the North Pacific over the past decade. Most of these programs are still on-going, and it will be the challenge for REX and the CCCC, in collaboration with IGBP GLOBEC, to integrate the findings from these programs over the basin and global scales.

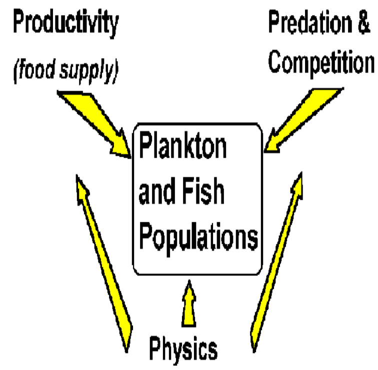

Fig. 5 Conceptual diagram of components for the Canada GLOBEC project (Mackas and Perry, 1999), illustrating forcings on fish populations from direct physical influences to indirect influences through the food web.

Problems

The PICES CCCC Program has experienced its share of problems, which is not surprising in a large international program spanning an entire ocean basin. A major problem has been the heavy administrative structure. While it is desirable to have places for many people to become involved, the structure of the CCCC Program has become too large (Table 4). The consequences have been a reduction in the flow of information and ideas, redundancy in meetings, lack of true participation, and difficulty in filling all these positions.

Table 4 Structure and numbers of positions involved in the components of the PICES Climate Change and Carrying Capacity Program.

	Number of members
CCCC Executive Committee/ Implementation Panel	≥ 10
CCCC Implementation Panel	27
BASS Task Team	12
IFEP Panel	16
MODEL Task Team	16
MONITOR Task Team	17
CPR Panel	14
REX Task Team	13
Total "Positions" (not people, as some people have >1 position)	≥ 125

A second problem is lack of direct funding, since program elements are funded separately by each nation. Even though there is coordination of programs through REX, each nation also has its own priorities for research. The result is that while the CCCC Program identifies an overall structure and over-arching questions, each element is actually assembled from the nationally-funded programs, which can leave gaps and missing pieces from the overall CCCC Program design.

The program has also not integrated as well with other PICES Scientific Committees as was expected at the outset, and it still needs much work on coodinating data management issues and creating a data legacy from the Program. Despite these issues, however, the CCCC Program has encouraged a tremendous infusion of new resources to be devoted to the marine sciences in the North Pacific Ocean.

Overall assessment of the CCCC Program

How has the CCCC program contributed to the changed view of the North Pacific Ocean, as outlined at the beginning of this paper? Development of the NEMURO model and its connections with upper trophic level models, and the iron fertilization experiment, are providing further understanding of what drives lower trophic level productivity and its consequences in this ocean. The BASS symposium and publication and the regional programs developed because of CCCC, have improved understanding of the similarities, differences, and connections among the eastern and western subarctic Pacific basins and with atmospheric forcing. The MONITOR symposium and publication on climate shifts, the CPR program, and the recent REX workshops have provided understanding of the large (basin) scale synchrony of marine populations and how they are connected to atmospheric and oceanographic processes.

Has the CCCC Program been a success or failure? The answer depends to some extent on how one interprets the principal objective of the Program. If one believes the goal was to stimulate and integrate programs on climate variations and marine ecosystems in the North Pacific, the answer must be that the CCCC Program has been an outstanding success. If one believes the goal was to initiate a co-operative study with its own observational program of how changes in ocean conditions affect lower and upper trophic levels (as some have suggested the CCCC should have done as the Program developed), then the answer might be somewhat less successful.

As we have pointed out at the beginning of this review, the initial objectives for the Program clearly centered around developing and coordinating research activities under a GLOBEC umbrella, and we believe the CCCC Program has far exceeded these goals.

Perry (1996) identified key features leading to the success of a large inter-disciplinary, but regionally-based, fisheries oceanography project, FOCI. These included a focus on a single region (Shelikof Strait, Alaska), a single species (walleye pollock, *Theragra chalcogramma*), and a focussed hypothesis (centred on the early life stages). These allowed coordinated planning and simplified the logistics of observational projects. Another key point was consistent institutional involvement and stability of program management and administrative personnel.

The CCCC Program has none of these characteristics. The CCCC includes many different regions (12), many different species from all trophic levels, and many different nations, institutions, and administrative personnel. This resulted in the funding for GLOBEC programs in some nations terminating before funding in other nations started. The CCCC Program, however, was initially envisaged to identify issues, to initiate and facilitate planning, to coordinate programs once begun, and to integrate and synthesize analyses and conclusions on the scale of the North Pacific Ocean. In this context, PICES and its CCCC Program have provided an on-going forum for presentation and discussion of hypotheses, issues and results, even if these have not always been translated into national programs or action.

Future directions

The CCCC Program is at a cross-roads, where it must move towards integration and conclusion of its existing activities, or move in new directions. One of the most pressing needs is to revise the administrative structure of the Program. This might include disbanding the Implementation Panel in favour of plenary meetings of all Task Team members as needed, and combining the REX and BASS Task Teams – a process which is already taking place to some extent in practice. The Program must also improve synthesis and coordination, perhaps with a re-focusing of its objectives. The emerging Ecosystem Status Report project of PICES could serve as a means to summarize what is known about the North Pacific marine system, and to identify the key unknowns that need further study, perhaps coordinated by the CCCC Program. The developing Global Ocean Observing System may also provide similar focus and questions. The Program could also be terminated, and PICES could begin a new and different initiative. However, this would leave several important problems unresolved, which would need some follow-up to complete adequately. Such issues include coordination of monitoring the North Pacific, how changes in lower trophic levels affect the upper trophic levels, and early detection of regime shifts and their impacts.

PICES should serve as a source of scientific information on issues related to the North Pacific marine system. One model that might be considered is that of the Intergovernmental Panel on Climate Change (IPCC), which provides scientific assessments of significant environmental issues, in this instance on climate change. The CCCC Program could be the start of this for climate impacts in the North Pacific, and could define and develop our ability to distinguish these from more direct human forcing.

In conclusion, we wish to reflect back to the changing understanding of the nature of the North Pacific that was outlined at the beginning of this report, in particular as represented by the large populations of marine mammals. Is the structure and function of the North Pacific marine system different now than it was 200 years ago? Considering the significant declines in marine mammal populations, what has happened to the "excess production" that used to fuel these large upper trophic level populations? What can we learn from these events that will help us understand future responses of the North Pacific to change? These are the continuing tasks of the CCCC Program.

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LIST OF ACRONYMS

AMAP	Arctic Monitoring and Assessment Program
Argo	International Program for deployment of profiling floats
BASS (TT)	Basin Studies (Task Team)
BIO	Biological Oceanography Committee
CCCC	Climate Change and Carrying Capacity Program
CLIVAR	Climate Variability and Predictability Program
COOP	Coastal Ocean Processes Program
COP	Coastal Ocean Program
CREAMS	Circulation Research of the East Asian Marginal Seas
ECOHAB	The Ecology and Oceanography of Harmful Algal Blooms Program
EEZ	Exclusive Economic Zone
FAO	Food and Agriculture Organization
FIS	Fishery Science Committee
FNMOC	Fleet Numerical Meteorology Oceanography Centre
FOCI	Fishery Research Oceanography Coordinated Investigations Program
GEOHAB	Global Ecology and Oceanography of Harmful Algal Blooms Prpgram
GESAMP	Group of Experts on Scientific Aspects of Marine Pollution
GIWA	Global International Waters Assessment program
GLOBEC	Global Ocean Ecosystem Dynamics Programme
GODAE	Global Ocean Data Assimilation Experiment
GOOS	Global Ocean Observing System
HAB	Harmful Algal Blooms
IATTC	Inter-American Tropical Tuna Commission
ICES	International Council for the Exploration of the Sea
IFEP	PICES Advisory Panel on Iron Fertilization Experiment in Subartic Pacific Ocean
IGPB	International Geosphere Biosphere Programme
INPFC	International North Pacific Fisheries Commission
IOC	Intergovernmental Oceanographic Commission
IPHC	International Pacific Halibut Commission
ISCTNP	Interim Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean
JCOMM	Joint Commission on Oceanography and Marine Meteorology
JGOFS	Joint Global Ocean Flux Study (IGPB)
LOS	Law of Sea
MBM	PICES Marine Birds and Mammals Advisory Panel
MEQ	Marine Environmental Committee
MIRC	Marine Information Research Center
MODEL (TT)	Conceptual / Theoretical and Modeling Studies (Task Team)
MONITOR (TT)	Monitor (Task Team)
MPA	Marine Protection Area
NEAR-GOOS	North East Asian Regional GOOS
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration (U.S.A.)
NPAFC	North Pacific Anadromous Fish Commission
NRC	National Research Council
NSF	National Science Foundation

OOSDP	Ocean Observing System Development Panel
PICES	North Pacific Marine Science Organization
POC	Physical Oceanography and Climate Committee
REX (TT)	Regional Experiments (Task Team)
SCOR	Scientific Committee on Oceanic Research
SEBSCC	Southeast Bering Sea Carrying Capacity Program
TCODE	Technical Committee on Data Exchange
TOGA	Tropical Ocean Global Atmosphere
UNESCO	United Nations Educational, Scientific, and Cultural Organization
WESTPAC	Sub-Committee for the Western Pacific Intergovernmental Oceanographic Commission
WMO	World Meteorological Organization
WG	Working Group
WOCE	World Ocean Circulation Experiment