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

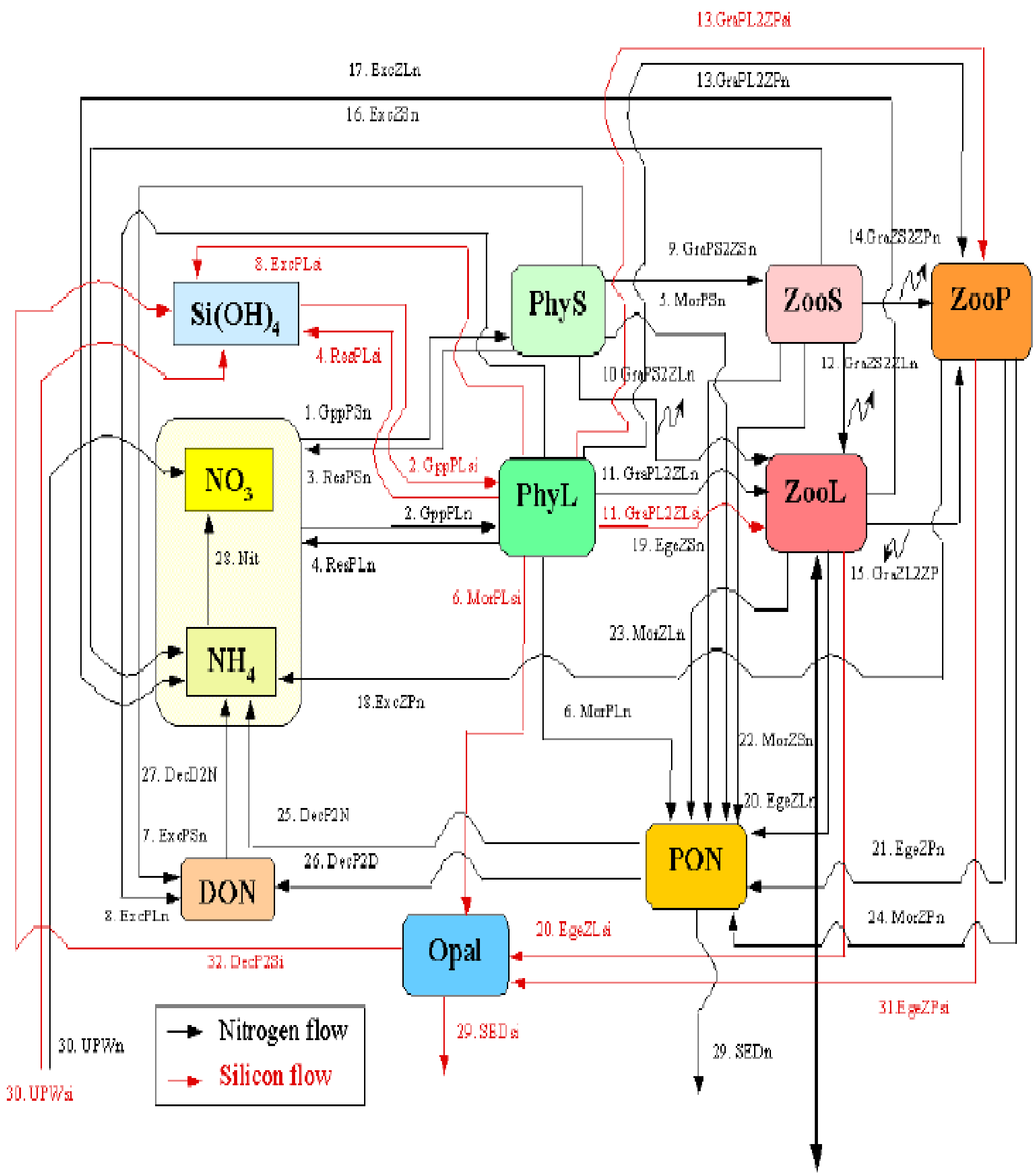

Fig. 1 NEMURO Model (Megrey *et al.* 2000). State variables are the boxes with names, fluxes in black represent nitrogen, fluxes in red represent silicon, thick black line represents vertical migration by large zooplankton.

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.

MONITOR

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.

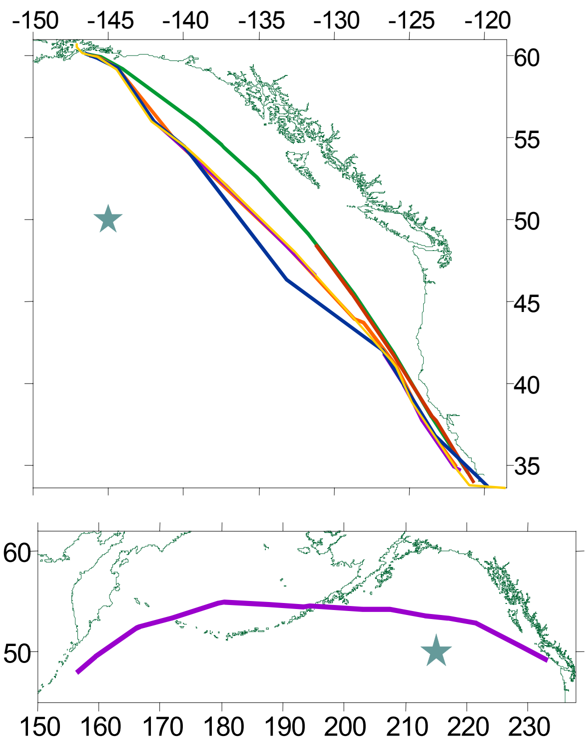

Fig. 2 Continious plankton recorder routes in the North Pacific in 2000: sampling was carried out on five north-south tracks (March-August) and on one east-west track (June-July). Key to colours: March (green), April (red), May (brown), June (violet), July (blue), August (orange). Station Papa is shown 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

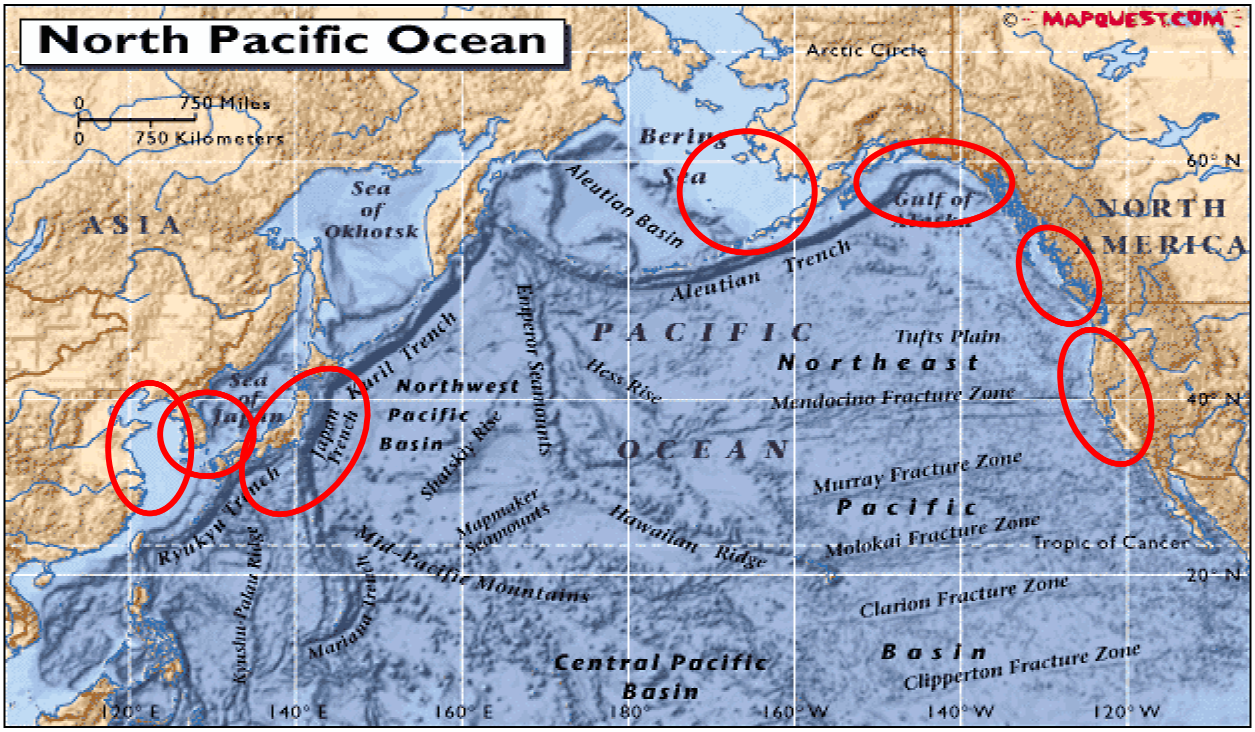

Fig. 3 Schematic map of locations of PICES Climate Change and Carrying Capacity regional programs. Base map courtesy of Mapquest.com.

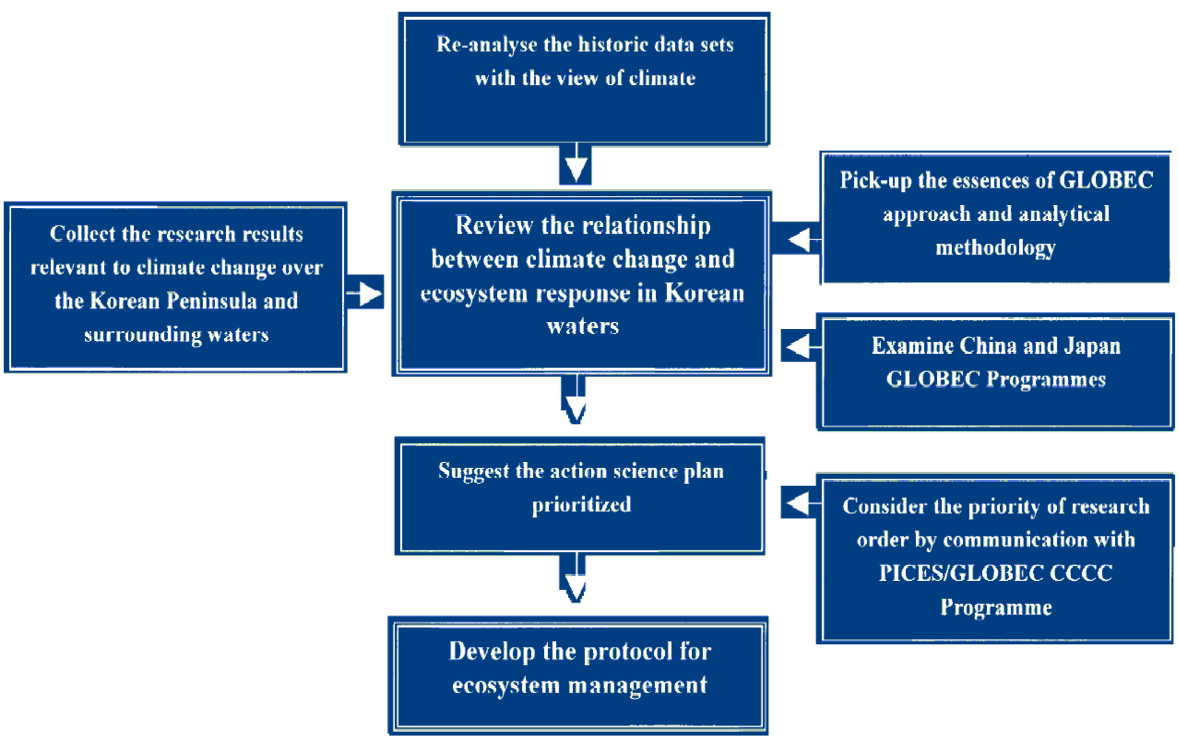

Fig. 4 Diagram of Korea GLOBEC component activities (Kim 2000).

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.

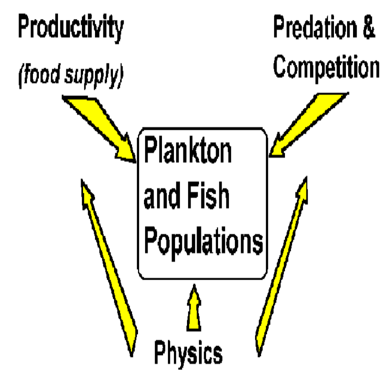

Fig. 5 Conceptual diagram of components for the Canada GLOBEC project (Mackas and Perry, 1999), illustrating forcings on fish populations from direct physical influences to indirect influences through the food web.

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.

References

Anderson, P.J. and Piatt, J.F. 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Mar. Ecol. Progr. Ser. 189: 117-123.

Batchelder, H.P. 2002. Recent achievements/activities of the U.S. GLOBEC Northeast Pacific Ocean program. PICES Press 10(1): 22-26.

Beamish, R.J. and Bouillon, D.R. 1993. Pacific salmon production trends in relation to climate. Can. J. Fish. Aquat. Sci. 50: 1002-1016.

Beamish, R.J., Kim, S., Terazaki, M., and Wooster, W. (Eds.). Ecosystem dynamics in the eastern and western gyres of the subarctic Pacific. Progr. Oceanogr. 43(2-4).

Brodeur, R., McKinnell, S., Nagasawa, K., Pearcy, W., Radchenko, V. and Takagi, S. 1999. Epipelagic nekton of the North Pacific subarctic and transition zones. Progr. Oceanogr. 43: 365-397.

Dodimead, A.J., Favorite, F. and Hirano, T. 1963. Salmon of the North Pacific Ocean, Part II. Review of oceanography of the Subarctic Pacific Region. INPFC Bull 13.

Dugdale, R.C., Hay, D.E., McFarlane, G.A., Taft, B.A. and Yoo, S. (Eds.). 1999. PICES-GLOBEC International program on Climate Change and Carrying Capacity. Summary of the 1998 MODEL, MONITOR and REX workshops, and Task Team reports. PICES Sci. Rep. No. 11, 88pp.

Eslinger, D.L., Kashiwai, M.B., Kishi, M.J., Megrey, B.A., Ware, D.M. and Werner, F.E. 2000. MODEL Task Team workshop report. *In* Megrey, B.A., Taft, B.A., and Peterson, W.T. (Eds.) PICES-GLOBEC international program on climate change and carrying capacity, Report of the 1999 MONITOR and REX workshops, and the 2000 MODEL workshop on lower trophic level modelling. PICES Sci. Rep. No. 15, pp.1-79

Glavin, T. 2000. The Last Great Sea. Greystone Books, Vancouver, 244 pp.

GLOBEC. 1997. Science Plan. IGBP Report Number 40. IGBP Secretariat, Stockholm, 83pp.
Hare, S.R., Minobe, S and Wooster, W. (Eds.). 2000. North Pacific climate regime shifts. Progr. Oceanogr. 47(2-4).
Hargreaves, N.B. and Sugimoto, T. 1993 Subarctic Gyre: Report of WG 6. PICES Sci. Rept. No. 6, pp. 25-130.
Harrison, P.J., Boyd, P.W., Varela, D.E. Takeda, S., Shiomoto, A., and Odate, T. 1999. Comparison of factors controlling phytoplankton productivity in the NE and NW subarctic Pacific gyres. Progr. Oceanogr 43: 205-234.
Helle, J.H. 1999. The Ocean Carrying Capacity research program (OCC) at the Alaska Fisheries Science Center, Auke Bay Laboratory, Juneau, Alaska. PICES Press 7(1): 30-32.
Hollowed, A.B., Ikeda, T., Radchenko, V., Wada, T. 1998. PICES Climate Change and Carrying Capacity workshop on the development of cooperative research in coastal regions of the North Pacific. PICES Sci. Rep. No. 9, 59pp.
Kendall, A.W., Jr., Schumacher, J.D. and Kim, S. 1996. Walleye pollock recruitment in Shelikof Strait: applied fisheries oceanography. Fisheries Oceanography 5(Suppl. 1): 4-18.
Kim, S. 2000. GLOBEC activities in Korea. PICES Press 8(1): 30-32.
Kishi, M.J., Megrey, B.A., Eslinger, D., Rose, K.A., Ware, D.M., Werner, F.E. 2001. Report of the 2001 PICES MODEL Task Team workshop on strategies for coupling higher and lower trophic level marine ecosystem models: status of the LTL model. GLOBEC Newsletter 7(1): 3-6.
Mackas, D.L. and Perry, R.I. 1999. GLOBEC Canada: who we are, what we've been doing, and where we're headed. PICES Press 7(1): 27-29.
Mackas, D. L. and Tsuda, A. 1999. Mesozooplankton in the eastern and western subarctic Pacific: community structure, seasonal life histories, and interannual variability. Progr. Oceanogr. 43: 335- 363.
Macklin, S.A. 2001. Southeast Bering Sea Carrying Capacity (SEBSCC). PICES Press 9(1): 29-30, 34.
McFarlane, G.A., Megrey, B.A., Taft, B.A., and Peterson, W.T. (Eds.). 2001. PICES-GLOBEC international program on climate change and carrying capacity. Report of the 2000 BASS, MODEL, MONITOR and REX workshops, and the 2001 BASS/MODEL workshop. PICES Sci. Rep. No. 17.
Megrey, B.A., Kishi, M.J, Kashiwai, M., Ware, D.M., Eslinger, D.L., Werner, F.E. 2000. PICES Lower trophic level modeling workshop, Nemuro. PICES Press 8(2): 18-22.
Nichol, L. and Heise, K. 1992. The historical occurrence of large whales off the Queen Charlotte Islands. Unpublished report prepared for the South Moresby / Gwaii Haanas National Park Reserve, Canada Parks Service, Queen Charlotte City, B.C.
North Pacific Marine Science Organization (PICES). 1994. Annual Report, Second Meeting, Seattle, WA, 88pp.
North Pacific Marine Science Organization (PICES). 1995. Annual Report, Third Meeting, Nemuro, Japan, 114pp.
Parrish, J. and Litle, K. 2000. PNCERS 2000 Annual Report. Coastal Ocean Program, NOAA.
Parsons, T.R. and Lalli, C.M. 1988. Comparative oceanic ecology of the plankton communities of the subarctic Atlantic and Pacific Oceans. Oceanogr. Mar. Biol. Ann. Rev. 26: 317-359.
Perry, R.I. 1996. Introduction. Fisheries oceanography of walleye pollock in Shelikof Strait, Alaska. Fish. Oceangr. 5 (Suppl. 1): 1-3.
Perry, R.I., Yoo, S. and Terazaki, M. 1997. Workshop on conceptual/theoretical studies and model development, including MODEL Task Team report, PICES Scientific Report No. 7, pp. 1-82.
PICES. 1996. Science Plan, Implementation Plan. PICES Scientific Report No. 4, 64 pp.
Sekine, Y. 1999. On variations in the subarctic circulation in the North Pacific. Progr. Oceanogr. 43: 193-203.
Springer, A.M., Piatt, J.F., Suhntov, V.P., Van Vliet, G.B., Vladimirov, V.L., Kuzin, A.E. and Perlov, A.S. 1999. Marine birds and

mammals of the Pacific subarctic gyres. Progr. Oceanogr. 43: 443-487.
Tang, Q.S. 2000. The new age of China-GLOBEC study. PICES Press 8(1): 28-29.
Terazaki, M. 1997. Japan GLOBEC summary. *In* Perry, R.I., S. Yoo, and M. Terazaki (Eds.) Workshop on conceptual/theoretical studies and model development including the MODEL Task Team report. PICES Sci. Rep. No. 7, pp. 62-63.
Walters, C.J., Christensen, V., and D. Pauly. 1997. Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. Rev. Fish Biol. Fisheries 7: 139-172.
Warner, A.J. and Hays, G.C. 1994. Sampling by the Continuous Plankton Recorder survey. Prog. Oceanogr. 34: 237-256.