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WORKSHOP ON CONCEPTUAL/THEORETICAL STUDIES AND MODEL DEVELOPMENT
INCLUDING THE MODEL TASK TEAM REPORT

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BASS TASK TEAM REPORT

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REX TASK TEAM REPORT

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PICES-GLOBEC INTERNATIONAL PROGRAM ON CLIMATE CHANGE AND CARRYING CAPACITY

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EXECUTIVE SUMMARY

A workshop was convened by the MODEL Task Team and held June 23-28, 1996, in Nemuro, Japan, to develop the modeling requirements of the PICES Climate Change and Carrying Capacity (CCCC) Program. It was attended by over 40 scientists from all member nations of PICES. The principal objectives of the workshop were to

- review the roles and limitations of modeling for the CCCC program;
- propose the level of modeling required; and
- provide a plan for how to promote these modeling activities.

Secondary activities at the workshop included organisational meetings of the Regional comparisons (REX) and Basin-scale experiment (BASS) Task Teams, and a symposium by Japan-GLOBEC on "Development and application of new technologies for measurement and modeling in marine ecosystems."

This report serves as a record of the proceedings of this workshop. It includes the texts of the invited state-of-the-art overviews of atmosphere-ocean modeling, lower trophic level models, upper trophic level models, and model integration and management issues. Discussion groups were formed on each of these overview topics to consider the status of relevant models, identification of boundary conditions and interactions, model evaluation, and roles in process and observational studies; reports from each of these groups are included in these workshop proceedings. Also included is a report of MODEL Task Team meetings at the end of the workshop and just prior to the fifth Annual PICES meeting, in which the workshop results are distilled into a plan for action regarding CCCC modeling activities. Summaries of the Japan-GLOBEC symposium and reports of national GLOBEC activities in member nations are included as appendices.

The workshop underlined the central role of models in the CCCC program. Models serve to extrapolate retrospective and new observations through space and time, assist with the design of observational programs, and test our understanding of the integration and functioning of ecosystem components. Clear differences were identified in the level of advancement of the various disciplinary models. Atmosphere-ocean and physical circulation models are the most advanced, to the extent that existing models are generally useful now for CCCC objectives, at least on the Basin scale. Circulation models in territorial and regional seas are presently more varied in their level of development, and may need some co-ordination from PICES. Lower trophic level models are advancing, and examples of their application coupled with large-scale circulation models are beginning to appear. There is a need for comparisons of specific physiological models, and for grafting of detailed mixed layer models into the general circulation models. With upper trophic level models, there are several well-developed models for specific applications, but workshop participants felt there were as yet no leading models available for general use within the CCCC program. This is an area that needs particular attention and encouragement from PICES.

Participants at the workshop strongly endorsed the view that modeling for the CCCC program should take place as distributed activities at several locations rather than be a highly centralised effort. This introduces problems of co-ordination and capabilities for integration of component sub-models, which need to be resolved by the CCCC program. There was no support for efforts to standardize models or model approaches within the CCCC program at this time, believing that diversity in assumptions and techniques will lead to faster advances in the North Pacific region. There was strong support for the need to compare and contrast models for similar areas to understand the reasons for possibly different results.

As a result of the workshop, the MODEL Task Team proposed the following plan for action over the next 1-2 years:

- make published circulation models results for the North Pacific widely available to the scientific community, preferably representing conditions before and after 1977; and provide a meta-analysis of available circulation models in the regional seas;
- compare specific lower trophic level physiological models and conduct a meta-analysis of upper mixed layer models suitable for grafting into general circulation models;
- encourage awareness and comparative applications of upper trophic level models for the North Pacific, and work to identify potential leading models;
- develop recommendations for facilitating linkages among component sub-models;
- interact with the developing retrospective and observational programs of the BASS and REX Task Teams of the CCCC program.

1. INTRODUCTION

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Background

Inspired by recent scientific findings on the climate variability in the North Pacific, PICES has established a science program on climate variability and its consequences in the North Pacific area in conjunction with International GLOBEC. The program was named Climate Change and Carrying Capacity (CCCC). In 1994, during the Third Annual Meeting of PICES, a workshop was organized to develop a Science Plan. The Science Plan was approved at the PICES Fifth Annual Meeting in 1995. In 1995, an Implementation Panel was established, which reviewed the Science Plan and developed it into an Implementation Plan (PICES Scientific Rep. No. 4, 1996).

The Goal of PICES/CCCC is to address how climate variability affects ecosystem structure and the productivity of key biological species at all trophic levels in the open ocean and coastal North Pacific ecosystems (PICES Scientific Rep. No. 4, 1996). The relevant time scales are seasons-to-centuries, i.e., quasi-biennial, ENSO, bi-decadal, and near-centennial. The studies will be conducted at two spatial scales: basin-scale studies, which include the open, deep waters of the North Pacific, and regional-scale comparative ecosystem studies. Two basin ecosystems and ten coastal ecosystems are defined in the North Pacific.

In the Implementation Plan, four Central Scientific Issues are identified, which is a restatement of the eight Key Scientific Questions addressed in the Science Plan:

- *Physical forcing*: What are the charac-teristics of climate variability, can inter-decadal 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, distributions, 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? Do higher trophic levels respond to climate variability solely as a consequence of bottom-up forcing? Are there significant inter-trophic level and top-down effects on lower trophic level production and on energy transfer efficiencies?

To answer the Central Scientific Issues, five Key Research Activities are planned: retrospective analysis, model studies, process studies, observation systems, and data management. Of these, model studies play a central role in that they draw upon the findings of retrospective analyses and guide the process studies and observation systems (Fig. 1.1). As such, model activities are expected to be initiated in the early phase of the CCCC implementation.

In 1995, three task teams were formed to pursue the goals specified in the Implementation Plan: MODEL (modeling studies), BASS (basin scale studies), and REX (regional experiments). Of these, the MODEL task team is concerned with advancing the development of conceptual/ theoretical and modeling studies needed for both regional and basin scale components of CCCC. During the Fourth Annual Meeting it was approved to hold a workshop on the conceptual/theoretical studies as an initiating activity to implement the CCCC program.

The Objectives and Organization of the Workshop

The major objective of the workshop was to develop the MODEL-related requirements of the

CCCC Implementation Plan and, as an outcome, to produce a work plan that will further the goal of the CCCC Program. In addition, other activities relevant to the CCCC program were conducted during the workshop. One was to review the present GLOBEC plans and activities in each of the PICES member nations. Another was to develop work plans for BASS and REX. A symposium organized by the Japan-GLOBEC committee was also held to review new technologies relevant to observational studies and model development.

For the MODEL workshop, four focal topics were defined corresponding to the Central Scientific Issues: Physical Forcing, Lower Trophic Level Responses, Higher Trophic Level Responses, and Model Integration/Management. The fourth focal topic was an amalgamation of ecosystem response and data management topics from the Implementation Plan.

Based on this division, a review of the state-of-the-art of modeling activities in each of the four topics was made by invited experts, after which the participants were grouped into four discussion groups based on these four topics. During the discussion group deliberations, each group reviewed the role and nature of modeling activities relevant to its topic. Some of the common questions considered were:

- What would be the appropriate level of modeling?
- What kind of models are to be used?
- What is the limitation of models?
- How should we define boundaries?
- What are the requirements for BASS and REX studies?
- What will be the common strategy for regional study models?
- What is the relation of MODEL with other activities? In other words, what is needed from retrospective studies? How to aid the process studies?
- What kind of observation system is needed for validation and data assimilation?

Each group also discussed scientific, technical, and methodological issues. These included:

- Structure of models, e.g., important factors and processes
- Crucial processes and parameters that need most attention
- Required information flow between model components
- Development, integration and management of models
- Data assimilation
- Exchange and sharing of software

As a result, recommendations were made for requirements and priority of action for the MODEL Task Team. Although not fully completed at the time, these discussion group comments and recommendations formed the basis for a meeting of the MODEL Task Team members towards the end of the workshop, which produced an initial plan of action.

This report serves as a record of the proceedings of this workshop. It includes the invited state-of-the-art reviews, the discussion group reports, the report of the MODEL task team meeting, synopses of the national GLOBEC reports, and the report of the Japan-GLOBEC symposium.

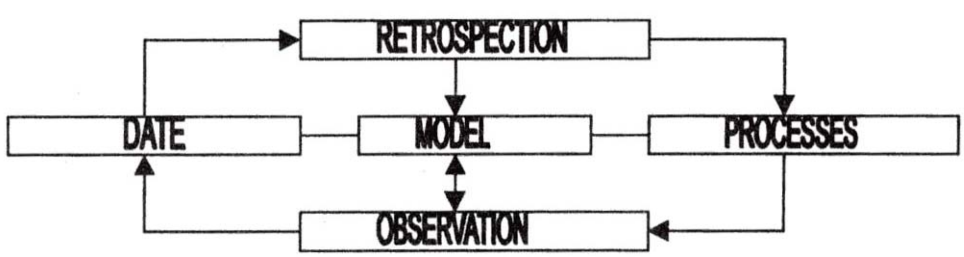

Fig. 1.1. Relationships among the research activities of PICES-GLOBEC CCCC (from PICES Scientific Report No. 4, 1996).

2. AN OVERVIEW OF ATMOSPHERE-OCEAN MODELING OF THE NORTH PACIFIC

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Abstract

Background information on numerical models of the circulation of the North Pacific has recently been presented in the report of PICES Working Group 7. This presentation highlights some of the more important points of that report and draws attention to some features of particular relevance to the CCCC program.

Introduction

The physical and chemical properties of the ocean affect all aspects of life in that medium. These properties vary with time as they are subject to atmospheric forcing and redistribution of the ocean's waters. A description of the ocean's properties, and particularly of their changes in time and space, is fundamental to an understanding of changes in the oceanic ecosystem. This presentation reviews some of the highlights of models which describe and explain oceanic variability in the North Pacific, while commenting on some of their successes and limitations and drawing attention to their sensitivity to initial and boundary conditions.

Model features

Models are simplified formal representations of nature. They use simple rules (in our case, the equations of fluid motion), consider a limited selection of variables, and have only limited resolution. They are used as tests of understanding, providing a comparison between their predictions and observations. They may also be used to assess the impact of changes in conditions and, when reliable enough, as predictors of future states.

Atmospheric and ocean circulation models share a number of features. They usually discretize spatial variations in terms of vertical layers (or levels) and cut up the horizontal plane into squares or triangular elements. Effects taking place on scales smaller than these grids may have an effect on larger scales which is represented by parametric approximations. For example, mixing by various kinds of eddying motions is commonly approximated in this fashion.

Initial and boundary conditions have a strong influence on the solutions of numerical models, as should be expected. Models are run for long times to try to eliminate the effects of uncertainties in their starting conditions. Boundary conditions for ocean models include forcing by the wind and other surface fluxes, as well as flow in and out of model boundaries from other parts of the ocean. Efforts to minimize the effects of boundary conditions lead to global models, where there are no other parts of the ocean to consider, and to coupled ocean-atmosphere models, wherein both fluids are included.

Model performance must be evaluated against observations. Numerical models however yield much more information than is available from data. That discrepancy between what we can calculate theoretically and what we really know is always a difficulty!

Model performance

The most sophisticated model of North Pacific circulation is probably at this time the Navy Research Laboratory's high resolution model as described by Hurlburt et al. (1996). The realistic computations of the Kuroshio-Oyashio region, including the double front structure and the presence of numerous warm-core eddies (described most lately by Talley et al. 1995) between them is an encouraging result (cf. PICES Report No. 5, 1996). Similarly, the close comparison of sea-levels predicted by the NRL model and observations of sea-level at Sitka, on the other side of the North Pacific, is also enheartening (Melsom et al., 1995; cf also PICES 1996).

On the other hand, comparisons of model results with observed WOCE drifters are not quite as satisfying. A NRL simulation of the path of a WOCE drifter is no better than the much simpler OSCURS model described in Fig. 31 of PICES 1996. Very complicated, and physically more complete models of the North Pacific circulation are not more successful at predicting surface circulation than a semi-empirical model...a sobering result!

Time-scales of predictability

As outlined in Table 1 of PICES 1996, predictability of oceanic phenomena depends on the physical properties of the feature of interest. Features directly related to weather-scale atmospheric forcing will, of course, be no more predictable than the weather itself. Other features, associated perhaps with El Niño or other long-period phenomena may have longer prediction scales. Decadal or longer scales of ocean variability are identifiable in nature as well as in model output (Yukimoto et al., 1996). The inertia of property transfers by diffusion or drift controls many longer scale processes related to water-mass formation.

Scales of variability in the North Pacific are first of all seasonal, and then interannual at the time scale of the ENSO. Relations between tropical and higher latitude phenomena are prominent in models and in observations at the ENSO time-scale as well as at longer time scales (Yukimoto et al., 1996). Whether the decadal variations described by Trenberth and Herrell (1994) are best interpreted as "regime shifts" as Francis and Hare (1994) and others have proposed, or as less abrupt long-period variations, remains a matter of interpretation. Genuine oceanic regime shifts certainly deserve more explicit documentation. A regime shift seems to imply an inner change, perhaps in the detailed dynamics of a system, and not just a shift in some of its properties. It is encouraging to find that long period variability in sea surface temperature produced by the Yukimoto et al. (1996) model shows a similar pattern to that observed by Thomson and Tabata (1989) at Station P.

The variability of oceanic conditions, as mirrored by model output, presents serious problems for observational verification. Even integrated quantities, such as meridional heat flux, show factor-of-two interannual variations. For example, the global coupled model of Russell et al. (1995) gives an average northward heat flux of about 1.5 petawatts across 16°N, but at least nine years of model output must be averaged to obtain a stable estimate. Will a meaningful comparison with observations then require an observational time series of comparable duration? If so, will the WOCE observational program have been sufficient?

Sensitivity to initial and boundary conditions

A number of examples presented in PICES 1996 illustrate the dependence of model results on boundary conditions and model structure. Fig 11 in that report illustrates the differences in the path and meandering of the Kuroshio in different types of models. Fig. 30 shows the sensitivity of model results in the same region to the particular wind-stress field used to drive the ocean.

The major concern of the PICES CCCC program is the response of the North Pacific ecosystem to climate change. Beyond natural long-term variability, climate change is also linked to the increase in atmospheric CO_2 concentration. Simulated changes in surface temperature due to a doubling of CO_2 are largest in high northern latitudes. Boer (1996) shows increases of up to 8°C in the Bering and Okhotsk Seas. The extensive ice cover in these regions may be strongly modified by a warming trend. Interannual variability in the extent of ice cover may in turn affect global warming trends. There remains some doubt as to the magnitude of the expected warming.

The lesson is that one must remain careful in using results of climate models and refrain from drawing apocalyptic conclusions about their potential effects on the oceanic ecosystem.

Model development and ecosystem applications

One may distinguish four stages in the development and improvement of models. These stages apply just as well to ecosystem as to hydrodynamic models. The first stage is the identification of significant variables and essential processes, followed by the formulation of a simple model. The second stage consists of a first comparison of the results with observations, identification of discrepancies and refinement of the model. At the next stage, observations and model results are linked through a thorough statistical analysis which allows optimal control of model parameters. Finally, error analyses are performed and the model is analyzed for its predictive capacities.

Atmospheric circulation models have progressed through all these stages, driven by the high quality requirements of practical weather prediction. Except for models strictly restricted to tides, oceanic circulation models are generally less advanced. Because biological and chemical effects usually do not significantly affect the dynamics of the ocean, it is appropriate to develop ocean circulation models independently of subsequent applications to ecosystem modeling.

Conclusions

There continues to be rapid progress in ocean circulation modeling. The impetus for better models of coastal areas derives from a variety of concerns, e.g., water quality, fish migrations, navigation. Ocean-wide models and deep circulation models are mostly of concern to climate studies. Model development will proceed regardless of PICES interests and it would seem most effective to devote PICES efforts towards its own specific objectives of developing ecosystem models.

The best models have been developed in areas rich in observations. Model verification and testing against real data is the surest road to reliability. Model results must be made understandable and unambiguously clear to all who are interested in their applications. Visualization methods and other ways of enhancing the impact of the results should be strongly encouraged.

Finally, the most effective way to hasten model development and improvements may be to apply them to real problems, where there are people and organizations who are likely to benefit personally from model results. Effort should be made to disseminate model results beyond the scientific and government community to those (fishermen, environmentalists, etc...) who may have an emotional commitment to the nature of the results.

Acknowledgements

I wish to thank fellow members of Working Group 7, and particularly M. Endoh and V.Kuzin, who provided direct input to this report.

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3. SOME COMMENTS ON LOWER TROPHIC LEVEL MODELING

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Many kinds of numerical models have been proposed in order to investigate models for understanding the processes that govern the cycling of biological material in the ocean. However, most of them are based on Fasham's JGOFS model (Fasham et al., 1993) and focused on the ecosystem of Atlantic.

We (Kawamiya et al., 1995) made a numerical model to simulate the trophodynamics of ocean station Papa, which includes a 1-D physical model with Mellor and Yamada's closure scheme (level 2) for the vertical diffusion coefficient. The results showed good agreement with the time series of observations of biological and physical compartments, especially of the spring bloom, fall bloom, and yearly primary production (about 130 g C m^{-2} y^{-1}) in 1980.

This kind of 1-D model has been investigated by, e.g., Radach and Moll (1993), Franks and Marra (1994) and Doney et al. (1996). Doney et al.(1996) applied their model to the BATS data set. So, our model was also applied to BATS data and the results were satisfactory.

Generally speaking, any ecosystem model can follow the time evolution of chlorophyll concentration if the physical model in which the ecosystem model is involved is made to follow the mixed layer mechanism. So, the ecosystem model must follow the time series of nutrients, new production, and/or yearly production.

I want to comment that the small differences in the equations which describe the material flows among compartments (for example, Fasham *et* al. (1993) and Kawamiya *et* al. (1994) use the same formulation for nitrogen uptake but different ones for the P-I curve, Kawamiya *et* al. (1994) and Doney *et* al. (1996) use the same formulation for the P-I curve but different ones for nutrient uptake, etc.) cause the giant differences in the results of the calculations. It is well known that zooplankton equations define the steady state solution of phytoplankton (not the phytoplankton equations) if we use a linear formulation for zooplankton mortality. These kinds of mathematical problems (what is effective on steady state solutions, uniquenes of solutions, existence of solutions, stability of solutions and so on) must be taken into consideration when we construct ecosystem equations as there are no exact formulations (like Newton's equations in dynamics) in ecosystems.

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4. A REVIEW OF MODELS FOR PREDICTING THE EFFECTS OF CLIMATE CHANGE ON UPPER TROPHIC LEVEL SPECIES

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Introduction

When considering what types of models to include in this review, it seems critical to examine models that explicitly consider the mechanisms by which climate can affect upper trophic level species. There are possibilities for direct and indirect pathways through which climate change effects are transferred to upper trophic level species. One conceptual model of these pathways is that of Francis et al. (1995) wherein the main effect of physical change is through a bottom-up path starting at primary production and working its way up through the trophic levels. This conceptual model also explicitly recognizes that temperature change will directly affect process rates and distribution and availability of prey at all trophic levels. These are the pathways and physical variables that can influence change but what are the mechanisms for change?

A conceptual model that contains the main biological processes to be considered when trying to understand climate change effects on any upper trophic level species is depicted in DeAngelis et al. (1991). Although their model was developed specifically for understanding density-dependent effects on a population, the main processes of reproduction, growth (and consumption), survival, and movement are all potentially affected directly or indirectly by climate change. A detailed conceptual diagram of climate variables and their connections to biological processes for a fish population (DOE, 1985 in Glantz, 1992), illustrates how many different variables and processes can be involved in an explicit model of climate change effects on an upper trophic level species. There are no existing models that include all of these linkages between physical factors and biological processes for even a single marine species. There are many models, however, that contain some explicit detail of one or more important processes for one or more life stages of an upper trophic level species.

The following review summarizes models which include some of physical and biological factors thought to influence the important biological processes of reproduction, growth, consumption/ predation, movement, and ultimately the survival of upper trophic level species. Because different mechanisms may regulate the survival process at different life history stages, models which could be considered state-of-the-art for a given life history stage are reviewed first, then models which include all life history stages and even multiple species.

Although there is definitely a role for minimal (or strategic) models (Scheffer and Beets, 1994) in identifying climate change effects on upper trophic level species (e.g., Collie and Spencer, 1994; Pascual and Adkison, 1994; Butterworth and Thomson, 1995; York, 1995), these models are more of a first step in the model-building process. Also, on the other end of the spectrum, some of the large-scale simulation models developed mainly in the 1970's may have contained too many processes and parameters to be estimated from admittedly sparse data (e.g., Parrish, 1975; Andersen and Ursin, 1977; Laevastu and Larkins, 1981). The current state-of-the-art upper-trophic levels models are somewhere in the middle of these two extremes and are strengthened by the existence of more data for parameterization and validation. These recent models being developed might be called tactical models (Figure 4.1) and are usually designed to answer specific questions using a mechanistic approach (DeAngelis, 1988). Those taking this approach believe that in order for a model to be predictive it must include the correct mechanisms operating in a system. Therefore, this review is limited to population models that explicitlyconsider at least one or more of the mechanisms affecting recruitment, growth, consumption/predation. Also not included here are models with longer-time scales where genetic change and evolution of species-level traits are considered, although development of these types of models would be important. Finally, upper-trophic level species are considered to be those above the second trophic level. I will attempt to use examples of models that consider the stereotypical marine upper trophic level species: larval, juvenile and adult fish, and marine birds and mammals.

Early-life history models

Early-life history models, particularly for larval marine fish, tend to focus on the transport process as a way of testing Hjort's (1914) critical period hypothesis. This hypothesis assumes that most larval fish mortality is due to starvation and that factors that lead to successful larval feeding and growth are important for survival. Because advection of eggs and larvae to areas of favorable temperature and food availability is considered a primary mechanism determining successful larval feeding and growth in a marine environment, most early life history models of fish center on predicting larval transport via wind-driven currents.

Several early life history survival models have been developed for various North Pacific species including English sole, *Parophrys vetulus*, (Kruse and Tyler, 1989; Walters et al., 1992), walleye pollock, *Theragra chalcogramma*, (Walsh and McRoy 1986; Hinckley et al. 1996), sardine, *Sardinops melanostictus*, (Kasai et al., 1995), and red king crab, *Paralithodes camtschatica*, (Hsu and Armstrong, 1988). Some of these (e.g., Kasai et al., 1995) apply differential survival rates to larvae depending on their location. Others include more detail about temperature-dependent growth processes and vertical movement (Hinckley et al., 1996) and food availability (Walsh et al., 1981; Walters et al., 1992). The effect of variability in the timing and location of reproduction on larval transport and resulting survival can also be explored. Models that explicitly included food availability (e.g., Walsh and McRoy, 1986) concluded that this was the key factor influencing survival. Others that included details on events prior to spawning (Kruse and Tyler, 1989), however, found that those factors were also very important. Most state-of-the-art models of early life history survival tend to be individual-based models (IBM's), where the characteristics of each individual animal are tracked through time (Van Winkle et al., 1993). The planned additions to the model of Hinckley et al. (1996), such as prey abundance from a nutrient-phytoplankton-zooplankton model and a turbulence/ feeding success rate relationship will make it a state-of-the-art model for early life history survival of marine fish.

Although I was unable to find any detailed models specifically of early life history survival of marine mammals and birds, processes that influence food availability to lactating female marine mammals or to adult birds caring for chicks would be important. Also, thermal budget analysis of northern fur seal pups (*Callorhinus ursinus* L.) by Trites (1990) indicated that low birth weight pups would be susceptible to certain environmental extremes in air temperature, wind speed, and humidity during the first week of life. Marine bird chicks would also be susceptible to exposure mortality in early life history stages. Aside from larval transport, many of the other processes (e.g., timing of adult migration for reproduction, climate during the first few weeks of life, and temperature and food dependent growth) included in larval fish growth and survival models could be used to model early life history survival of marine mammals and birds.

Juvenile and adult upper trophic level models

Most models that consider climate effects on juveniles and adults of a single upper trophic level species tend to focus on consumption, growth, and migration processes, either singly or in concert.

The effects of surface currents on salmon migration rates and return times are being investigated with an ocean surface current model in which salmon are included as passive drifters during their non-directed ocean phase and as active drifters during their return migration phase

(Thomson et al., 1994). It was concluded that interannual variability in surface currents could affect the return times of Fraser river sockeye by up to 1.5 weeks, an amount more than three times the standard deviation around the peak return dates of several Fraser river stocks.

Another salmon model in progress relates to developing a measure of available thermal habitat for each North Pacific salmon species (Welch, 1995). This appears to be similar to the work of Stefan et al. (1995), in which the amount of lake habitat available for good fish growth is estimated under the present temperature regime and under a climate warming regime. In addition to a global warming model, this estimation requires species-specific estimates of lower and upper temperatures for good growth, upper lethal temperature, and optimum temperature. These models predict large decreases in the area of good growth habitat for cold-water fish which would presumably result in decreases in actual growth rates. However, these models do not actually show how much of the good growth area is currently being used and there is no direct linkage to predicting changes in fish growth.

A more explicit model of climate change effects on sockeye salmon growth has been developed by Hinch et al. (1995). Salmon are assumed to achieve their temperature-dependent maximum daily ration and move through fixed monthly positions in the Northeast Pacific Ocean. This model predicts a 14% reduction in average final ocean weight if sea surface temperatures increase by 3.5°C when atmospheric CO_2 doubles.

A model of salmon migration and consumption that takes into consideration salmon active migrations as a function of currents and temperature and migrations due to food availability and temperature limits, is the model of Favorite and Laevastu (1979). This model also considers growth as a function of temperature and food availability. It was able to reproduce the offshore distribution of salmon. However, more complete validation and refinement of the model never proceeded any further.

These above models are approaching some of the complexity used in spatial models of freshwater salmon and other pelagic fish growth potential (Goyke and Brandt, 1993; Mason and Patrick, 1993). Included in these models are more detailed bioenergetics relating to direct temperature effects on growth, prey availability effects on growth and vertical movements based on minimizing predator encounter rate and maximizing feeding rate. Combining these spatial models of fish growth potential with a more detailed model of salmon migration, perhaps similar to that of Thomson et al. (1994), and information on prey availability would provide a state-of-the-art model of juvenile and adult growth of salmon.

It is apparent that a state-of-the-art model of the effects of climate change on juvenile and adult upper trophic level predator growth may require a model of bioenergetics that describes how juveniles and adult metabolic requirements and growth change as a function of temperature and food intake. These models range from those that predict growth changes directly as a function of temperature (Stevens, 1990) to those that include detailed equations for different components of metabolism such as standard metabolism, activity, and digestion of food (e.g., Hewett and Johnson, 1992 for fish; Oritsland and Markussen, 1990 for mammals).

Feeding migrations may also need to be a significant component of models developed for juvenile and adult upper trophic level predators. Presently, most of the feeding migration models do not explicitly include temperature or currents as a factor influencing movement. Those for mammals and birds tend to include a directional and distance component from the colony or rookery (Ford et al., 1982; French et al., 1989; Agnew and Phagan, 1995). Although pattern-matching movement rules are easiest to implement, they limit the type of questions that models with those rules can address (Tyler and Rose, 1994). The simulation of fish migrations developed by Laevastu and Larkins (1981) includes a predetermined migration speed and direction for seasonal migration and a diffusion component for movement away from areas of unfavorable temperature and food availability. This model was able to qualitatively reproduce observed summer distribution patterns of some Bering Sea groundfish species in cold and warm years (Pola, 1985). This effort is a movement toward more process-based movement rules that appear to be needed in spatial models that address the effects of climate change on upper trophic level species.

Full life cycle models

There is an apparent scarcity of full life cycle models for upper trophic level species, particularly in marine environments. There are some models that simulate the bioenergetics of all life-history stages of a population (e.g., Wiens and Innis, 1974; Ford et al., 1982; Swartzman et al., 1982), but only through one year or feeding season. The scarcity of full-life cycle models that include a feedback loop of adult life history events including reproduction through to early life history survival events is perhaps due to the different modeling strategies used for modeling early life history stages versus juvenile and adult stages. Individual-based models where the state of each individual is tracked through time, i-space configuration models, tend to be used most frequently for early life history models of growth and survival (Van Winkle et al., 1993). However, for juvenile and adult life history stages where multiple generations are often being modelled and the data may take the form of average values and variances, an i-space distribution model may be more appropriate (DeAngelis and Rose, 1992). Instead of tracking attributes such as size for each individual, an i-space distribution model might specify a size-frequency distribution for individuals within a certain age or size class. Some other models may aggregate even further, considering only the total number or biomass within an age group or of the whole adult or juvenile population. Thus, it may be more appropriate to link outputs of separate early life history models and juvenile/adult models than to attempt building a single model for the full life cycle of an organism.

Multiple-species models

Most of the recent efforts incorporating multiple upper-trophic level species in a single model have taken a step back from the multispecies models developed in the late 1970's and 1980's (e.g., Parrish, 1975; Andersen and Ursin, 1977; Laevastu and Larkins, 1981). The latter two models each contained over ten upper-trophic level species. In these earlier models and in most of the multispecies models now being developed, such as Bogstad et al. (1992), Robinson and Ware (1994), Bryant et al. (1995), and Stefansson and Palsson (1995) the focus has been on fish as the main upper trophic level species. If marine mammals and/or birds are included, they are modelled less dynamically and the focus has been on some of the main spatial and trophic interactions of commercially important fish resources in an area.

Three of the recent modeling efforts are relatively similar in approach: the fish population module of the European Regional Seas Ecosystem Model (ERSEM) (Bryant et al., 1995) of the North Sea, the boreal migration and consumption model of the oceanic region around Iceland (BORMICON) (Stefansson and Palsson, 1995), and the multispecies model of the Barents Sea (MULTSPEC) (Bogstad et al., 1992). Each modelled region has been broken into several spatially defined areas and one or two main fish species have prescribed seasonal movement among the subareas. The models include or plan to include a full-life cycle model for at least one small pelagic fish species (herring or capelin) and static or dynamic predators (mammals and cod) on the small pelagic species. Individual growth is dependent upon availability of food and temperature and there is some attempt to prescribe a seasonally varying zooplankton abundance. The authors of these models discuss the possibility of including variable migration rates, depending on temperature and/or other factors such as prey availability, but have not yet implemented such a modification.

A somewhat different approach has been taken by Robinson and Ware (1994) in their model of pelagic fish and plankton trophodynamics on the continental shelf off Vancouver Island. A lower trophic level model of nutrients, phytoplankton and zooplankton has been linked to an upper trophic level model of herring, hake, dogfish, and salmon. Thus, zooplankton are modelled more dynamically than in the models discussed above. Fish migration rates in and out of the one model area, with the exception of dogfish, are fixed and there is no age structure or detailed growth model of the fish components. Instead of focusing on details of fish population response to food availability, temperature, and predation, this model directs attention to the effects of fish predation on zooplankton dynamics. They conclude that the migratory behavior of upper trophic level predators is an important process to include in trophodynamic models.

Summary

Almost all of the recent modeling efforts of upper trophic level species exhibit a recognition of the need to include spatial resolution and more detailed descriptions of upper trophic level species behavior and bioenergetics. The modeling efforts in progress appear to be taking a more incremental approach to model-building than models built twenty years ago. As noted by Sklar and Costanza (1991), there appears to be an inverse relationship between model complexity and the degree of use of a particular model. Thus, many models are being built to answer more specific questions about a system than to address many, broad ecosystem level questions. Although recent models are reduced in scope, there still are many uncertainties about the behavior and bioenergetics of upper trophic level predators (Ney, 1993). Nevertheless, the iterative nature of the modeling process involves the continual re-evaluation of the status of our knowledge, the design of experiments to improve our knowledge, and the revision of our models. With each iteration, we can refine our knowledge of the system and hopefully converge to a better understanding of ecosystem processes.

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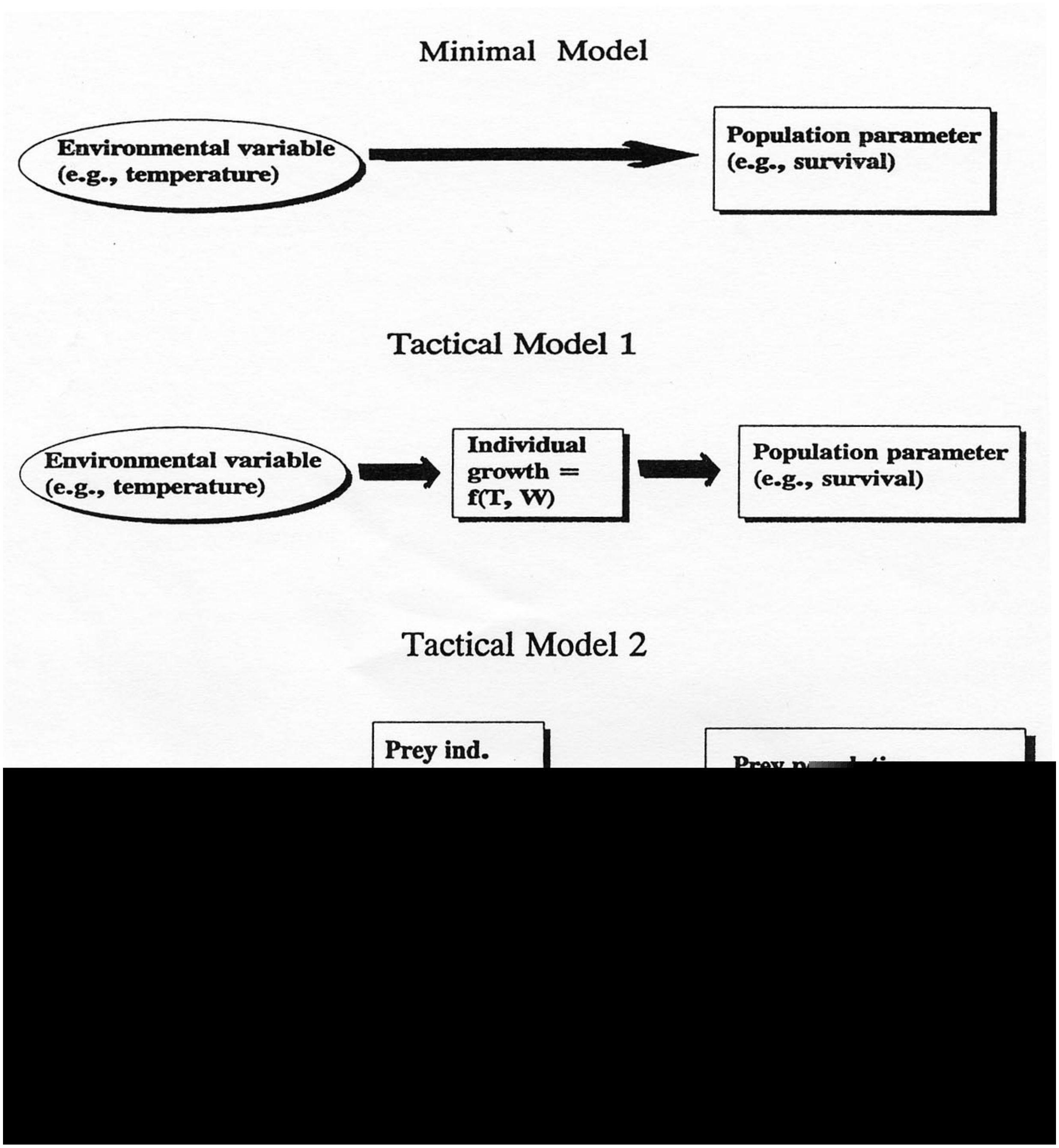

Fig. 4.1. Stages of the model-building process, beginning with a minimal model and moving to more complex mechanistic models. (T-temperature, W-weight, N-number).

5. MODEL INTEGRATION AND MANAGEMENT

Jerry Blackford, Plymouth Marine Laboratory, Plymouth, U.K.

Introduction

This paper derives from the experience of constructing the European Regional Seas Ecosystem Model (ERSEM). This European Community funded project ran in two phases between 1990 and 1996 and involved nine institutes from six different countries (Fig. 5.1). About twenty people have made significant contributions to the model during the course of the project. The aim was to construct a generic ecosystem model that included representations of those processes thought to be of importance to the ecology of temperate shelf seas, without becoming incomprehensibly complex. Thus ERSEM combines physical, chemical and biological descriptions of both the pelagic and benthic systems, modeling the cycling of carbon and the nutrients: nitrate, phosphate, ammonium and silicate. It covers the full trophic range from primary production to higher predators (Fig. 5.2) including four types of phytoplankton, the microbial loop, zooplankton and the zoobenthos.

The model may be coupled to a variety of hydrodynamic box models and forcing functions that describe a region of interest (Fig. 5.3). The main developmental application has been a model of the North Sea, employing various spatial resolutions. Other applications include a high resolution model of the Humber river plume and the simulation of a water column as it passes through the Orkney-Shetland gap. The long term objective of the ERSEM project is to provide a tool for the management of the marine environment.

The computational structure of ERSEM

A number of concepts, protocols and packages combined to make the ERSEM project possible. Firstly, a decision was made to equip each participant with identical hardware and software. Although computer environment differences should only produce tiny variations to model results, it can be shown that, however infrequently, even minute quantitative differences can qualitatively affect model behaviour. Identical hardware and software then ensures that inter-site comparisons are valid.

ERSEM was developed with a modular structure and consists of a series of inter-linked modules each describing one particular part of the system. It is a hierarchical structure in that modules for the higher trophic levels can be stripped off and replaced with say constant mortality without necessitating any change to the modules describing lower trophic levels. This creates a high degree of flexibility by allowing modules to be added or removed depending on the level of detail required for the particular task in hand. The development of each module, within a series of rules and protocols, was the responsibility of an expert in that particular field. The collation of modules into a coherent whole was the responsibility of one of the institutes involved in the project.

The set of state variables - those variables that we take to define the state of the whole system at any one time - was another important initial decision. These variables are the only method by which the modules communicate. It is possible to add or re-define this set, but everyone must be aware of the implications for the rest of the trophic structure. Although with the style of coding used in the project, adding new state variables is not hard, it is at the same time not a trivial task. It is important to get the initial decisions fairly correct. The definition of state variables also implies the definition of the units used throughout the model.

With probably about a dozen people at any one time actively developing their modules there is a great possibility for divergence and chaos. To prevent this, whilst at the same time allowing the individual modellers the freedom work in the way they wish, the project has used the concept of the standard model. This is an important component of the ERSEM modeling philosophy. Each partner at any one time possessed the exact same standard version of the model. All improvements to their own modules were developed in the context of the standard version, but in a separate test directory. Thus there is no need to alter the standard in the course of modules development. This new or improved module is embedded in the standard for the purposes of testing. The concept of the standard model also allows for the rigorous cross comparison of results between sites.

The standard model includes the requisite code for one or more of the applications. Embedded within the standard model is the generic model, i.e. those elements (essentially the ecology) that are common to all applications.

Apart from the model itself, two other, elements combine to enable model development and simulation; a modeling tool SESAME, and lately a visualisation package which assists with the interpretation of model results. The model itself consists of a series of FORTRAN subroutines (the modules) which communicate via a common block which defines the set of state variables only. The model routines are responsible only for calculating the rates of change for each state.

SESAME encodes some of the concepts detailed above and perhaps even more importantly it provides the mathematical algorithms used to solve the model's system of parallel differential equations. SESAME is thus responsible for the integration of these rates, along with model compilation, common block creation and the coupling of development modules to the standard. A number of parameters supplied to SESAME control the method of integration, maximum allowable rate of change and hence the time step. Although all processes in the model are defined with daily rates, SESAME will decrease the time step in response to potentially numerically unstable conditions. SESAME also provides some simple graphical interfaces to the model results.

The directory structure (Fig. 5.4) for the current version of the model illustrates some of these principles. There is a directory containing the generic model and a number of parallel directories containing code for the different applications (humber, adriatic, north sea). One of these has been expanded to show the standard model directory. This contains subdirectories of forcing functions (force), initial conditions (initial) and hydrodynamics (fcm). The standard directory itself contains code specific to the application, box definitions, boundary conditions and river inputs etc. When compiling the standard, which is one of SESAME's menu driven functions, the generic directory is referenced and the standard produced in conjunction with the application specific code.

Model development takes place in the separate 'test' directories. These are the only part of the directory structure with write permission.

Finally, whilst the state variable names and units are mandatory and must be common to all sub-routines, a number of other variable naming conventions have been developed. Although not essential to the integrity of the model, they serve to give a unified feel to the programming and more importantly serve to make each sub-module readably accessible to all the project participants (Fig. 5.5).

The development of ERSEM

The concept of the standard model only makes sense if it has a reasonable degree of longevity. The standard provides a solid base from which to work and can't be constantly updated in response to each module improvement. However neither can there be too long between issuing new standards as this would slow down model development.

The compromise that the ERSEM group used, was to adopt a six monthly development cycle in conjunction with the twice yearly project workshops (Fig. 5.6). New or improved modules were expected to be delivered to the model co-ordinating laboratory by a deadline approximately 6-8 weeks prior to the workshop. These deliveries were expected to include not only the new module but also relevant documentation and a sample set of results. Each new module would be individually quality assured by establishing that the delivered results could be reproduced, thereby performing an indirect check on the status of the standard model at the other sites, and by checking that the intention as stated in the documentation was in fact carried out by the code. When these checks had been successfully completed the new modules were combined into a new draft standard and a mass balance check performed. This ensured that all process fluxes defined were correctly transferred between the relevant states. The overall model performance would then be initially assessed and compared against the previous version. Should the models performance be acceptable it would then be released to the partnership for a more thorough and detailed assessment which would be reported on at the workshop. The workshop provided a discussion forum in which the pros and cons of each module were discussed. There would usually be one or two problem areas identified which were never the less tractable in the short term. There would usually be a short period after the workshop set aside for these problems to be solved. This would lead to a mini submission and verification process and eventually an official new standard release.

This two or three tier process of verification is very important. Although at the outset, with simple water column models the model was realisable, with the move to higher resolutions and more complex ecosystems it is certainly not possible for one individual to check the entire model within a reasonable amount of time. It is the experience that individuals tend to judge models from different perspectives, and it is certainly very constructive if at least some in the group are familiar with the details of other group members modules.

Validation of any complex model is unavoidably problematic. With about fifty principal state variables in each of up to 360 boxes for the most detailed application to date, there is simply not enough data available to perform a full validation. Further at the spatial scales employed by the ERSEM project, measured data tends to a high degree of variability. The data set assembled to validate ERSEM ranged from relatively comprehensive data sets for nutrients and chlorophyll to very sparse or highly derived indicative measurements for some of the other trophic groups. Qualitative decisions are to some extent unavoidable when assessing the relative merits of one model version over another.

Visualisation of model results

With an ever growing complex model, a comprehensive method of examining results and validating the model is of great importance. Although SESAME initially provided a simple graphical interface to the model, enormous impetus was given to the modeling process by the development of a front end tool (MOVIE) which utilises *pv-wave* macros to visualise the model output. This gave the possibility of complex graphical output, quick overview and animations as well as validation plots and numerical output.

Summary

In conclusion, the recipe for modeling success comprised of a consistent hardware and software base throughout the partnership; a modular approach to ecosystem functionality; coding rules and conventions; protocols describing model development and submission; quality assurance and the concept of the standard model.

During the six year lifetime of the project it became apparent that over complex coding styles were not advantageous, nor where attempts to perform serious modeling exercises within the context of a workshop. Such activities were better left to smaller workshops convened around single issues.

The generic model has proved to be very versatile and capable of simulating much of the essential behaviour of the marine system in a number of applications. These have included vertically resolved water column models of the northern Adriatic, 2D models of river plumes and 2D stratified models of the European North Sea. Work is now beginning on coupling the generic ERSEM with fully 3D hydrodynamic models.

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Netherlands Journal of Sea Research 1995, Vol 33 (3/4). This special issue collects the papers describing the first phase of the ERSEM project which culminated in 1993.

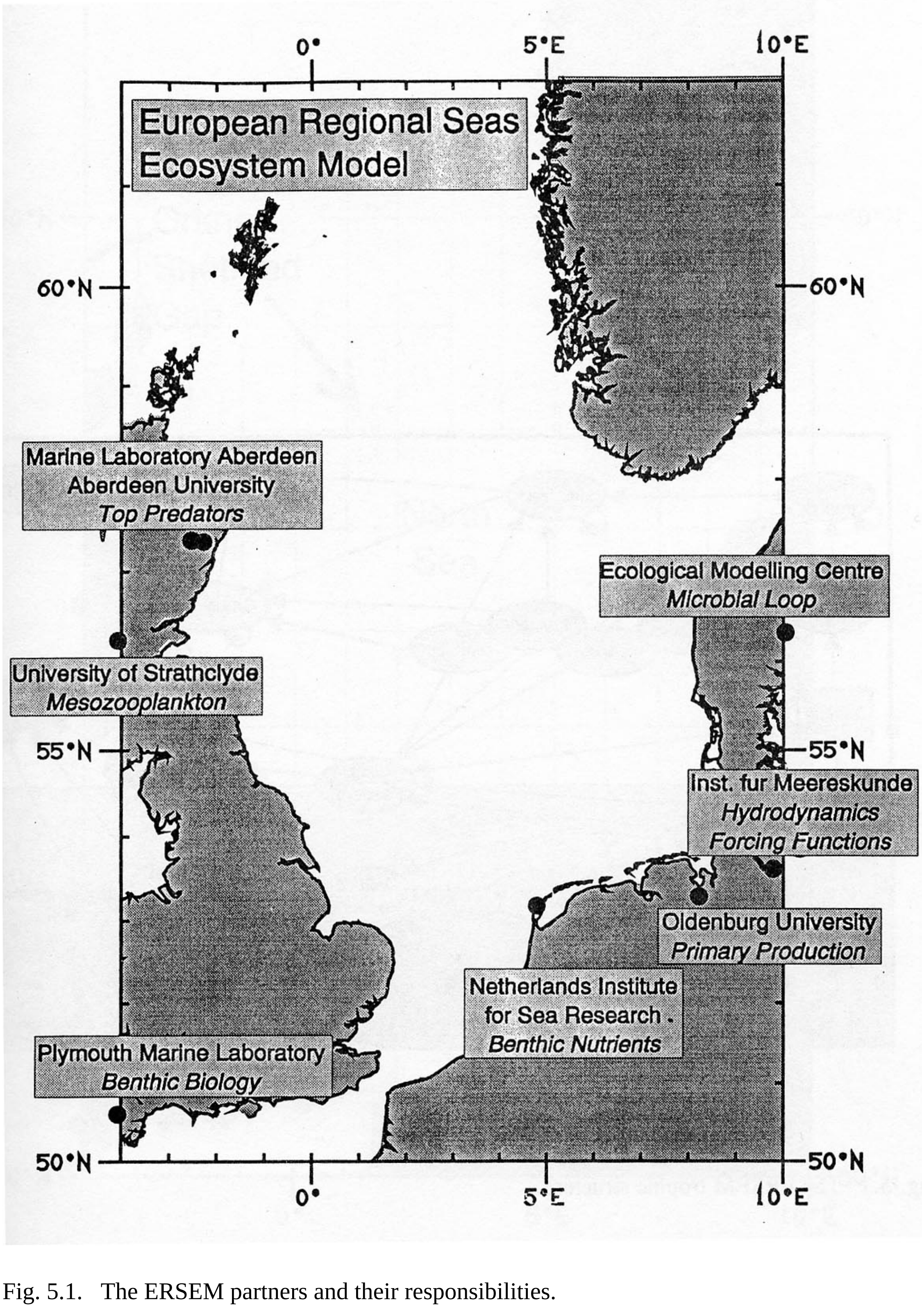

Fig. 5.1. The ERSEM partners and their responsibilities.

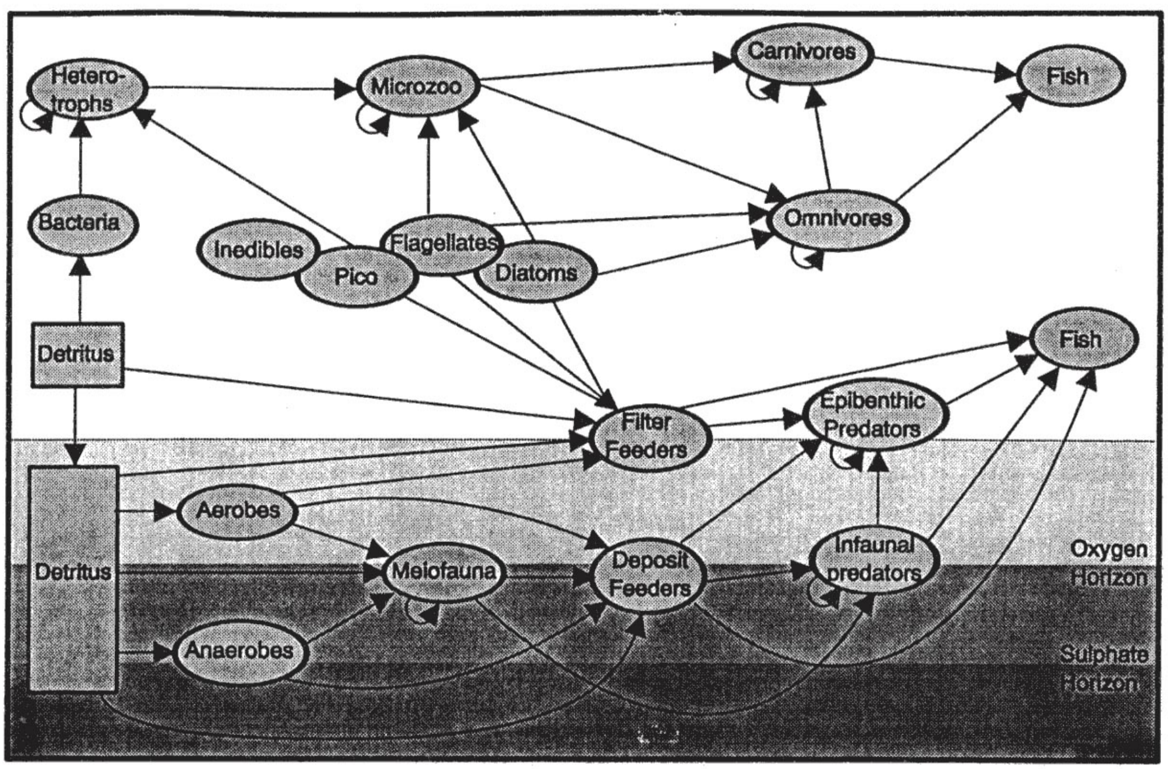

Fig. 5.2. The ERSEM trophic structure.

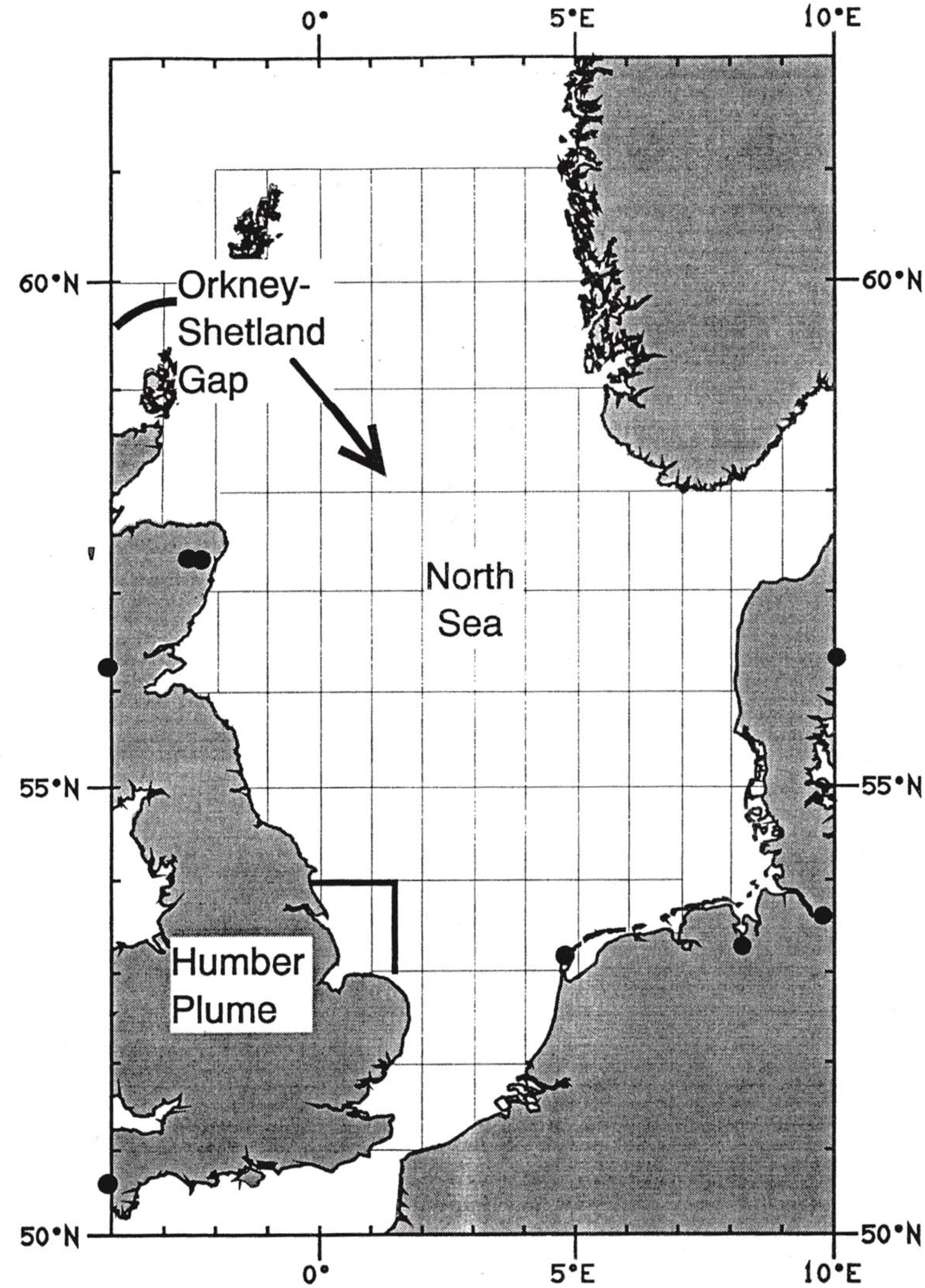

Fig. 5.3. ERSEM applications.

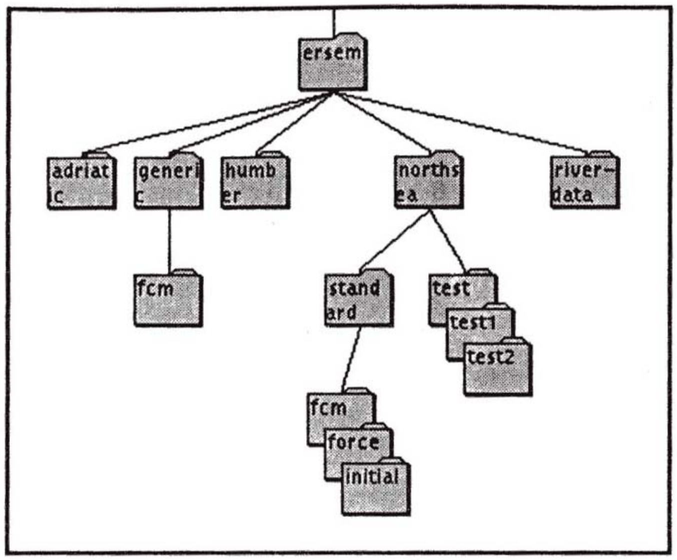

Fig. 5.4. The ERSEM directory structure.

Rules:

i) The first character must be one of the identifiers (table 5.)
ii) This may be followed by one or more of the Process/Description/Magnitude characters (table 6.)
iii) One or two state variable (table 2.) acronyms may follow, finishing with the composition code (table 3.)
iv) Parameters must end with a "$".

Identifier		Process		Description		Magnitude		to/for	State	Comp	Param
c	concentrations	d	death	a	active	g	gross	'-'	P1	c	$
e	environmental	e	excretion	s	standard	h	half sat.		Z3	n	
p	proportions	r	respiration	o	other	l	lowest		.	p	
q	quotients	u	uptake	t	total	m	maximum		.	s	
q10	Q10 values					n	net		etc.	o	
r	rates									e	
s	specific rates										
t	temperatures										
u	unit conversions										
v	volume rates										
x	all others										

Fig. 5.5. Variable naming conventions.

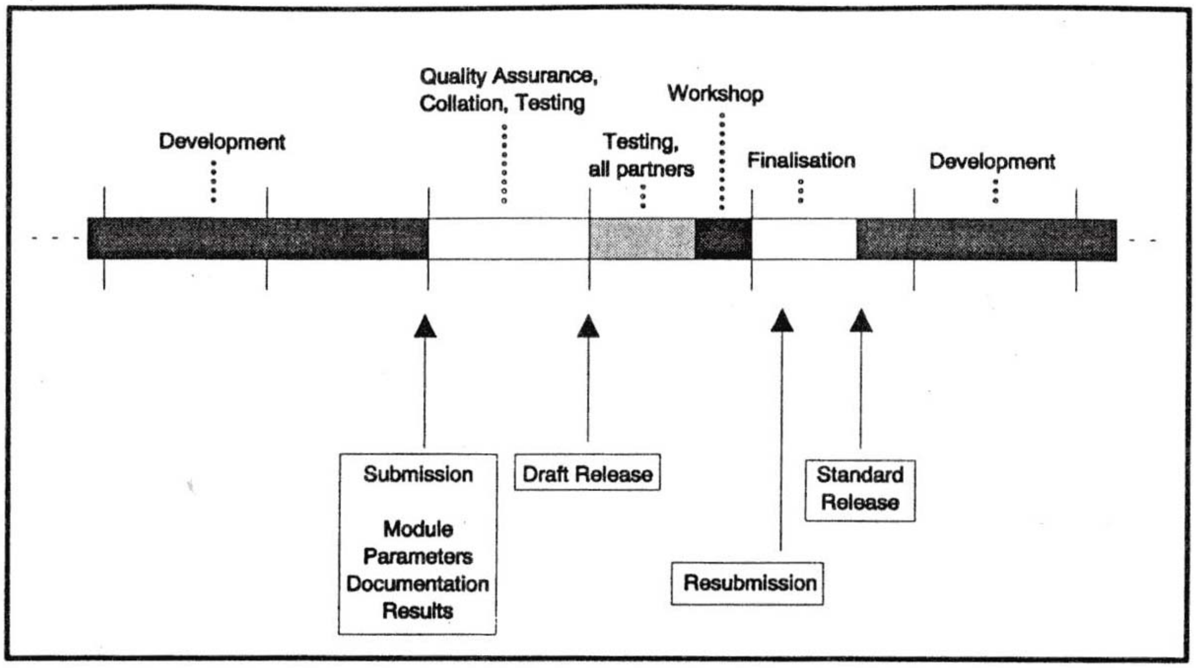

Fig. 5.6. The model development cycle.

6. INTRODUCTION TO THE DISCUSSION GROUPS

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The ultimate goal of the PICES Climate Change and Carrying Capacity program is to "... forecast the consequences of climate variability on the ecosystems of the subarctic Pacific" (PICES/GLOBEC Implemen-tation Plan, PICES Scientific Rep. No. 4, 1996, p. 22). The objective of the MODEL Task Team is identified as "... advancing the development of conceptual, theoretical and modeling studies needed for both regional and basin scale components of CCCC" (PICES Annual Rep. 1995, p. 25). At the end of this workshop, the MODEL Task Team must propose a work program to further the goals of the CCCC program, for discussion and approval by PICES Governing Council in October, e.g.:

- review the roles and limitations of modeling for the CCCC program;
- propose the level of modeling required,
- provide a plan for how to get there.

The goal of the Discussion Groups is to develop the model-related requirements of the CCCC Implementation Plan:

- to identify scientific, technical, and methodological issues in development and application of models;
- to identify requirements for model and theoretical studies to guide the process and observation studies, and to integrate the results, of the CCCC program.

Proposed modeling activities may range from development of a fully coupled, spatially-explicit ecosystem model; to simpler models which provide a framework for monitoring activities and comparisons of field studies; to models developed specifically to support individual monitoring or process studies. To help focus the Discussion Groups, and to provide common elements to the discussions of all groups, the Workshop Scientific Steering Committee developed specific themes and sets of related questions that each Discussion Group might consider. The themes are:

- the use of models for designing and comparing process and monitoring studies;
- identification of system boundaries and specification of boundary conditions;
- coupling of model components with other sub-models
  - e.g. requirements by Lower Trophic Level sub-models for Physics and Upper Trophic Level model outputs
  - different time and space scales
- model verification and comparisons with observations.

The specific questions are:

Discussion Group 1: Atmosphere / Ocean circulation modeling

1.1. How can a model be used for guiding/designing process studies in physical oceanography?
  - identification of important factors
  - identification of missing processes
  - identification of methods for validation of hypotheses

1.2. What are the criteria for defining ecosystem boundaries from the view point of physical modeling?

1.3. How can a model be used as a common apparatus for collaboration in multi-disciplinary/multi-hypotheses studies?

1.4. How can a model which reproduces historical regime shifts be validated and be used for prediction?

1.5 What can we expect for the CCCC Program from a synthesis of WOCE results?

Discussion Group 2: Lower trophic level modeling

2.1. What are the target ecosystem properties at lower trophic levels?
- complete the ecosystem properties listed in the Implementation Plan

2.2. What kind of conceptual / theoretical / numerical models are required?
- consider the evolution of model approaches towards complete 3D coupled models

2.3. How to define ecosystem boundaries and how to cope with within-ecosystem heterogeneity?

2.4. What should be the structure of the models?
- state variables (key species, functional groups, age/size structure)
- trophic interactions

2.5. What processes and parameters require most attention?
- identify important processes and parameters that are not studied very well

2.6. How to standardize the process models for comparative ecosystem studies?
- what are the process models that have to be standardized?

2.7. What are the information flows to and from other levels?

2.8. What kind of observation system is needed for validation and data assimilation?

2.9. Should we consider incorporating the results of JGOFS into CCCC studies?

Discussion Group 3: Higher trophic level modeling

3.1. How can a model be used for guiding/designing studies of higher trophic level processes?
- identification of important factors
- identification of missing processes
- identification of methods for validation of hypotheses

3.2. What are the criteria for defining ecosystem boundaries from the view point of higher trophic level modeling?

3.3. How can a model be used as a common apparatus for collaboration in multi-disciplinary/multi-hypotheses studies?

3.4. How can a higher trophic level sub-model be validated?
- selection of key species
- description of trophic relations
- levels of input abundance

3.5. What does a higher trophic level sub-model require from physical and lower trophic level sub-models?

3.6. How should inter-regional migrants be modelled to join regional sub-models?

3.7. What procedure is recommended for developing higher trophic level sub-models to reach a coupled atmosphere-ocean-ecosystem prognostic model?

3.8. How should we prepare for incorporating the results from WG11 on marine birds and mammals?

Discussion Group 4: Model integration and management

4.1. How can a model be used for guiding/designing process studies in the CCCC study? - identification of important factors
- identification of missing processes
- identification of method for validation of hypotheses

4.2. How can a model be used as a common apparatus for collaboration in multi-disciplinary/multi-hypotheses studies?
- e.g. how to integrate potentially different time and space scales among model components;

- how many components are relevant?

4.3. How can an ecosystem model be validated?

4.4. How can results from different types of models be integrated and/or compared with each other. (e.g. box models vs spatially-explicit models)

4.5. Role of PICES, e.g., should there be a center(s) for model integration and management for the CCCC Program?

4.6. Should we ignore the prognostic power of empirical models such as neural networks because they are not mechanistic and not based on first principles?

6.1. REPORT OF THE ATMOSPHERIC-OCEAN PROCESSES GROUP

Contributors: Chang, Kono, LeBlond (Chairman), Nagata, Navrotsky, Su, Sugimoto, Taft, Werner

Models of ocean properties and circulation have been developed, as documented in the report of PICES Working Group 7, to a realistic level of simulation. These models yield patterns of circulation and water properties similar to those observed, although improvements are still necessary. General circulation models (GCM's) describe basin-wide properties, usually as part of models including broader areas of the ocean, or even models of the whole coupled ocean-atmosphere general circulation system. Regional models, applied to specific regions, are also available in many areas; they are generally of a much higher resolution, adapted to local bathymetric features and have usually received much more stringent observational verification.

Development of PICES-CCCC ecosystem models for both lower and higher trophic levels could proceed immediately using existing GCM's and regional models as a physical environmental basis. A number of these models have already been identified in the PICES Working Group 7 report.

The resolution of existing GCM's in space (1.8 of a degree), and time (1 day) is quite sufficient to accommodate the information requirements of ecosystem models for flow rates and ocean properties. Similarly, the smaller scales of regional, coastal models are well adapted to the more demanding requirements of coastal ecosystem models. Thus, although models are not claimed to be perfect, it should be possible for ecosystem modelers to use the output of existing physical models to start their own efforts. There is no single model which will apply to the whole area of interest: GCM's do not have the resolution necessary to resolve the details of coastal areas, so that regional models, preferably already tested against local data, must be used in local areas. GCM's may however be useful in providing offshore boundary conditions for regional models.

There is also a requirement for higher trophic level modeling, and particularly fish migration, for models of regions hundreds to thousands of kilometers in lateral extent - parts of GCM's or extensive regional models - with sufficient high resolution to resolve meso-scale features and advective jets between them, as in the western boundary currents region and their eastward extension off Japan and the Kuriles. Current GCM resolution is inadequate to the purpose.

However, basin-scale GCM's are recognised to be incapable of sufficient resolution within the upper, wind-mixed layer, where a resolution of the order of 5-10 m is required down to a depth of about 200 m for representing processes relevant to the dynamics of lower trophic levels. There already exist one-dimensional mixed-layer models which deal with the details of upper-layer heat and momentum exchange, nutrient fluxes and phyto-zooplankton dynamics in that critical zone. Such models should be grafted onto GCM's for lower trophic level modeling. In each grid area of a GCM, a sub-model of the details of the upper-layer structure can be inserted. Because the vertical structure of the upper layer does not change quickly in space, the same sub-model may serve for many adjacent grid areas. However, the wind and other relevant meteorological forcing inputs used to drive the GCM must be available at each time step with sufficient resolution to specify the evolution of the upper layer. Providing these data and computer outputs is thus a major task for basin-scale lower trophic level modelers. It is also worth noting that only the near-surface (approx. 200 m, with exact thickness to be determined) results of oceanic GCM's are relevant to lower-level trophic models.

Depending on the degree of vertical resolution in regional scale models, the same task may or may not be necessary there. Such models, encompassing shallow coastal areas, must also include tidal mixing effects and must be able to represent correctly the buoyancy fluxes associated with land runoff. There has also been some concern expressed about the accurate representation of high-intensity, episodic events, such as storms, whose influence may be highly non-linear and which may have a strong effect on some physical (e.g. erosion, mixing, ...) and especially biological characteristics over much longer time and space scales.

There is considerable interest in the CCCC program in identifying the oceanic conditions corresponding to variations described by some as "regime shifts", as well as their ecosystem consequences, especially their impact on the oceanic carrying capacity for commercially relevant species. There is also some expectation that it may be possible to predict the occurrence and persistence of such situations. A program of research which may help in this respect consists in the examination of historical observations and model results which may reveal large-scale patterns, in the period range from ENSO to decadal variations, which may be associated with "regime shifts", perhaps relating ENSO and longer-period events with North Pacific phenomena. Physical oceanographers are not optimistic about the predictability of such events, especially beyond the ENSO time scale, in the near future, given the state of present understanding of large-scale air-sea interaction dynamics.

Understanding is thought to be at least as important as predictability. The examination of existing model and observational results should focus on the documentation of significant ecosystem-relevant properties in the various parts of the North Pacific, such as variability, vertical and horizontal mixing intensities, the importance of advective effects, contrasts between the warm and cold phases of El Nino, and "regime shifts" years contrasted to "normal' periods. Such a retrospective analysis of existing information, with special attention to those variables relevant to ecosystem models, is an important step in the study of the North Pacific ecosystem. This diagnostic analysis may yield some understanding of the relations between the ecosystem and its environmental substrate (realising of course that some ecosystem variability may arise from nonlinear biological interactions which have nothing to do with the environment).

Returning to the question of prediction, we note that testing predictive skills of numerical models may be achieved through hindcasting, i.e. predicting past conditions from prior circumstances. Considerable improvements in predictive capabilities arise through continuous corrections of models by assimilation of current information. This is the technique which keeps weather forecasts in line with actual conditions. Similarly, predictive capabilities of GCM's may be improved by data assimilation, in the hindcasting as well as forecasting modes. This is a cutting-edge area of research that requires extensive (and expensive) data support and is currently the aim of major efforts by large modeling groups. Oceanic data assimilation may not be available in the PICES area for some years to come. In the meantime, ecosystem model development should take advantage of available GCM solutions in a simplified hindcast mode with forcings appropriate to specific "regimes" of past decades. If possible, new simulations should also include enhanced near-surface vertical resolution in anticipation of the ecosystem modeling community's needs.

Improvements in numerical models, their physics and numerics, as well as their foundation in observations (e.g. through the WOCE data set) will continue to take place within the wider scientific community. PICES CCCC program participants should be on the lookout for new developments in ocean/atmosphere modeling and take advantage of the progress that will inevitably be made.

6.2. REPORT OF THE LOWER TROPHIC LEVEL RESPONSE GROUP

Discussion Group Members: Dugdale, Frost, Kishi, Terazaki, Wang, Wheeler, Yoo (Chairman)

Additional Participants: Chang, LeBlond, Nagata, Navrotsky, Su, Sugimoto, Taft

Objectives

The overall purpose of the lower trophic level modeling effort is to test the hypothesis that physical forcing factors are regulating primary production and that the effect is apparent in zooplankton standing stocks and then transferred to variations in higher trophic levels. The objectives of the Lower Trophic Level Discussion Group then are to review the role and nature of lower trophic level modeling activity required for accomplishing CCCC goals, to decide on the relevant scientific issues and to suggest necessary steps towards the goals of CCCC program.

Target ecosystem properties

The Lower Trophic Level Discussion Group first reviewed the target ecosystem properties in the CCCC context. The Group felt that the program output specified in the Implementation Plan needed more precise description and recommended changes should be made as follows. These changes should also be incorporated into the Implementation Plan:

- physical factors controlling lower trophic level production
- annual and seasonal primary production and new production
- annual and seasonal secondary production
- temporal and spatial pattern of plankton abundance and species composition
- temporal and spatial pattern of nutrient fields
- identification of major taxonomic groups
- population parameters for key species or taxonomic groups

The level of modeling required for CCCC implementation

The Group felt that for the lower trophic level, the current scientific knowledge is adequate for building quantitative numerical models. Modeling efforts should start with a 1D model with vertical resolution as initial efforts towards a full 3D model. The Group recommends the initial development of a generic numerical foodweb model with at least two functional groups of phytoplankton and three functional groups of zooplankton, although the difficulties of this additional complexity on development of the models was recognized.

The limitation of modeling

The Group also recognized that simulation models cannot automatically accommodate qualitative changes in the ecosystem, i.e., change in the ecosystem structure. One example is in East China Sea where the change in the circulation pattern results in the change of zooplankton assemblages with different key species. Attention should be paid to this limitation.

Boundaries of ecosystem and within-ecosystem heterogeneity

Boundaries of ecosystems defined in the PICES CCCC plan reflect the hydrographic and oceanographic characteristics of the regions. For modeling purposes, the boundaries should be apparent from the distribution of physical forcing properties. For expansion from 1D to 2D and 3D models, individual models should specify how heterogeneity within each ecosystem is to be addressed.

Structure of the model

The Group agreed that the structure of the model should be as simple as possible but at the same time it should provide appropriate description of crucial tropho-dynamic linkages and top-down control effects. This requires that biological state variables should be composed of functional groups based either on size (for phytoplankton) or on developmental stage (for zooplankton with cohort structure). Thus the Group recommends the following list of state variables as the minimum structure.

- nutrients
- phytoplankton with two functional groups (sizes or diatoms and non-diatoms)
- zooplankton with three functional groups divided into three classes of developmental stages (seven compartments in total):
  - microzooplankton
  - copepods (eggs and immature, juveniles, adults)
  - euphausids (eggs and immature, juveniles, adults)

Processes and parameters that need most attention

The Group recommends that process studies be focused on the following processes and related parameters, in particular:

- nutrient uptake kinetics
- zooplankton grazing
- predation of fish on zooplankton
- vertical migration of zooplankton
- cannibalism
- pelagic-benthic coupling in shallow seas

In addition, where anthropogenic influences (nutrients and other pollutants input, and fishing) are significant, the effects of these factors on the biological production should be studied.

Standardization of models for comparative ecosystem studies

The Group next considered the needs of standardization of models on the grounds that using different process models (mathematical description of the processes) for different ecosystem models might hinder appropriate comparison of ecosystem responses. Therefore, the Group recommends the use of standard process models. Selection of equations for processes will be based on scientific knowledge and data available. Sensitivity analysis is also needed to decide which equations to use. Standard process models should be used with the flexibility for development and modification as appropriate. Examples of process models needing standardization (or at the very least inter-calibration) are:

- P vs I
- nutrient uptake
- grazing and predation

Information flows with physical forcing and higher trophic level

The Group recognized that for proper lower trophic level modeling following physical properties should be given for input to the lower trophic level model:

- temperature
- salinity
- mixed layer depth
- vertical and horizontal nutrient fluxes (diffusion, upwelling and horizontal advection)
- meterological information (cloud cover, wind, insolation, etc.)
- finer vertical resolution in upper 50 m from GCM model

The lower trophic model will produce food density as input to the higher trophic level. From higher trophic levels, predator abundance and food selection characteristics are required to incorporate the top-down effects.

Data requirement and validation

The Group recommends that the following monitoring activities are required in both BASS and REX studies for validation and data assimilation:

- time series for seasonal patterns (at an interval that can reveal temporal variation of production)
  - nutrients
  - vertical profiles of chlorophyll
  - zooplankton (three functional groups)
  - phytoplankton (two functional groups)
- longer time series

During the CCCC implementation, more than 10 new ocean color sensors are expected to be launched, OCTS (ocean color and temperature sensor, Japan) being the first. These sensors will provide information on the surface distribution of chlorophyll *a*, which can be used for validation and data assimilation of phytoplankton dynamics model.

BASS and REX related issues

The group discussed whether or not different modeling approachs are needed for REX and BASS. The generic models are appropriate for both. If the models are correct, the dominant components and fluxes of both coastal and oceanic lower trophic level processes will reflect the observed differences between BASS and REX regions.

Minimalistic approach

The Group recommends that even before the food-web model can be constructed and ready for application, simpler approaches to estimate potential new production in the CCCC ecosystems should be attempted. Possible approaches include examination of temperature-nutrient relationships, GCM estimated mixed layer depth, and annual-seasonal changes in mixed layer nutrients. More than one approach may be necessary to achieve estimates for all of the CCCC ecosystems. The results can be further compared with fish yield data to provide a benchmark for its prediction of changes in carrying capacity as a result of modeled change in environmental conditions.

Priority of action

Work plans for modeling efforts were discussed but no specific plan was generated. However, the Group recommends that the following should be included in the short term workplan:

- One action item relevant to REX would be to assemble lists of data sets available in regions 1-10.
- Modellers of CCCC implementation should organize a workshop for standardization (or inter-calibration) of process models.
- Retrospective modeling should be attempted using existing data such as Canada JGOFS data and Japan JGOFS data.

6.3. REPORT OF THE UPPER TROPHIC LEVEL GROUP

Participants: Beamish, Boltnev, Dahlberg, Hargreaves, Hinckley, Hollowed, Karpenko, Kim, Kobayashi, Lehody, Livingston (Chairman), Sakurai, Tang, Wada, Wakabayashi, Wooster, Yamamura

Justification

The PICES Implementation Plan has a central scientific question specifically regarding upper trophic level species: How do life history patterns, distributions, vital rates and population dynamics of higher trophic level species respond directly and indirectly to climate variability? Models that include details of processes that affect abundance trends, distribution, population parameters and food web structure of upper trophic level species would be an important component of a program to accomplish the goal of improving our understanding of climate effects on these species in PICES regions.

Assessment of data availability for models

Several model types were identified as potentially useful for advancing our understanding of climate change effects on upper trophic level species (Table 6.3.1). These models ranged from conceptual models of the food web to a dynamic ecosystem model. The assessment of available data to parameterize such models in PICES regions indicates that for most regions there are enough data to parameterize many of these models for a subset of the key upper trophic level species in each area. A listing of the key upper trophic level species, prey, and physical factors in each region (Table 6.3.2) indicated many common species and processes across areas. These commonalities suggest that a modeling effort that would allow inter-regional comparisons would be very useful.

Suggested models

There are several models that can assist in answering the PICES Implementation Plan's central scientific question with regard to upper trophic level species. Different modeling approaches would be required to enhance understanding of climate change effects on abundance trends and distributions, population parameters, food web structure, and production of upper trophic level species. Five modeling approaches were identified as currently feasible and desirable for inclusion in a proposed plan of work (Table 6.3.3). The five approaches include: single species bioenergetics, mass balance modeling, early life history transport, top-down multispecies trophodynamics modeling, and a more detailed bottom-up multispecies trophodynamics model. For each of these approaches a standard model and set of computer code would be identified. Within each approach, the simplest model that is needed to address the issue should be identified.

A simple bioenergetic model of adult upper trophic level species growth is currently feasible for many of the species in the PICES regions. Such a model would enhance understanding of climate change effects on growth of upper trophic level species. Because some of the regions have species in common with other regions, this approach could improve understanding of differences in growth and production of a given species across its range. This type of model requires diet information of the species being modelled along with parameters defining the bioenergetic processes (e.g., respiration, activity, consumption). The simplest form of this model would not consider changes in prey abundance and would allow predators to feed at their maximum rates in order to predict growth changes at age. The main physical parameter required is temperature.

A mass-balance box model for each of the regions and basins could be done in order to identify gaps in knowledge and allow comparison of ecosystem characteristics across regions. Although this type of model is not dynamic and does not have predictive capabilities, a model containing the main species groupings in each area could be parameterized for two different climate regimes. Changes in ecosystem characteristics between time periods could then be identified. This type of model requires estimates of biomass, mortality, and consumption rates and diet links between groups of upper trophic level species and lower trophic level species. Zooplankton biomass and phytoplankton production estimates are also needed.

A simple model of early life history movement and survival would allow a more direct understanding of physical transport as the mechanism for observed changes in recruitment of key upper trophic level species in PICES regions. This model would be primarily driven by physical processes of horizontal mixing, cross-shelf transport, vertical mixing, and temperature.

Two sorts of multispecies upper trophic level trophodynamics models could be proposed. One model would be similar to the Robinson-Ware model in which upper trophic level species are primarily entered as a top-down force for determining the degree of utilization of zooplankton. This type of model does not include age-structure or any description of maturation or reproduction so it could be considered one of the simplest types of models that could be used to understand multispecies food web dynamics. In order to better understand the effects of bottom-up forces on upper trophic level species, however, a more detailed model that includes age structured growth and mortalty is required. Both of these models would require detailed dynamics of zooplankton on a daily or monthly time step. Temperature is the most important physical variable needed to determine changes in upper trophic level species growth rates.

Modeling issues with regard to upper trophic level species

There was a recognition that the physical boundaries of a species could differ depending on the process and life stage being modelled. However, for multispecies models the ecosystem boundaries would include the habitat boundaries of all main species (predators and prey) included in the model.

Validation of upper trophic level species models has many problems including multiple outputs and how to examine and compare outputs to observations, multiple data inputs of varying quality, and a limited observation set to compare results against. If large observation sets are available, one method of validation would be to tune the model against a subset of observations and check the model's ability to reproduce observations not used in the parameter tuning/estimation stage. Models can also be examined by their ability to reproduce observations when parameters are changed within their ranges of uncertainty (sensitivity analysis). Model assumptions regarding the functional form of the processes being modelled can also be examined.

How to handle inter-regional migrants is an important modeling issue. Emigration and immigration rates may not always be known and tagging studies to determine these rates are often difficult, time consuming and expensive to conduct. A regional scale model could treat the species as a member of the ecosystem. When it migrates out, treat it as a boundary condition to the regional model. Alternative approaches would be to utilize linked regional models or to aggregate regional models. The results of Working Group 11 may help provide inputs of seasonal abundance and food consumption rates that could be aggregated by region for input into regional models.

Direction and Priorities

It is suggested that one of the five models identified above be selected for immediate examination and use in each of the regions. Perhaps a mass balance model such as ECOPATH may provide the best framework for initially embarking on such a modeling effort. The ultimate goal would be to move towards an intermediate scale upper trophic level species model that includes mechanistic details for one or two key upper trophic levels species. Such a model could be used as a submodel for a coupled ocean-ecosystem model that would advance our ultimate goal of predicting climate change effects on upper trophic level species. A coupled model such as this would highlight the types of information still required, help guide process studies, and could be strengthened by an observation system needed for validation of results.

6.4. MODEL INTEGRATION AND MANAGEMENT

<u>Participants</u>: Blackford, Brown, Kashiwai, McKone, Megrey, Perry (Chairman), Suk, Welch (Werner, Dahlberg, LeBlond)

General Concepts

Conceptual, theoretical, and/or numerical simulation models are essential to integrate and focus large, multi-disciplinary and multi-national marine science programs. These models are tools, however, and not necessarily the end product of the science program. Modeling is a formal process which helps organize thinking about the problem, provides guidance to the planning of observational activities, and assists with the integration of the results. Modeling plays a central role in the development and analysis of the multi-national CCCC program.

CCCC Objective and Sequence of Activities

"The ultimate goal of the CCCC program is to forecast the consequences of climate variability on the ecosystems of the subarctic Pacific" (PICES/GLOBEC Implementation Plan, PICES Scientific Rept. No. 4, p. 22). Discussion Group 4 found it useful to restate this as a conceptual model and comment on a sequence of activities which involve modeling:

Conceptual model:

- biological productivity in the North Pacific has varied over time;
- these variations are caused by changes in the ocean climate (which includes top down and/or bottom up forcings).

Related CCCC activities (not strictly sequential):

- focussed retrospective analyses (e.g. Science Board symposium at PICES V). In addition to being a useful activity in itself, it will provide data for development and evaluation of models in the North Pacific;
- initial modeling activities, e.g. obtain output from physical models, and develop lower trophic level models coupled to these physical model outputs;
- iteration of modeling with observation programs (BASS, REX);
- review progress and results of these initial models in a workshop or symposium;
- evaluation and incorporation of upper trophic level models into the coupled physics-lower trophic level model framework.

CCCC Model Management Strategy

Discussion Group 4 recommends a strategy of modular sub-models for particular ecosystem components (e.g. physics, lower trophic level models, upper trophic level models, and their constituents) which could be run independently or linked together through a common modeling framework. The focus should not be on developing a single large ecosystem model. This modular strategy allows for development and comparison of alternative representations of processes, e.g. feeding by fish on selected zooplankton species or sizes, versus feeding on aggregate zooplankton biomass, with both sub-models coupled to the same physical and lower trophic level forcings. It also allows for researchers to construct their own models from the available sub-models, in order to emphasize certain processes (and spatial regions) if desired.

Similar linkages would be developed in space, with outputs from a model for one region, e.g. the NE Pacific deep basin, providing the boundary conditions and advective inputs to models of the continental margins and regional seas.

The Discussion Group recommends that development of sub-models use existing models if they are available and appropriate for the CCCC program requirements. Sub-models for the various processes (physics, lower trophic levels, upper tropic levels) would then be developed as necessary.

When dynamic linkages among sub-models are required, a common modeling framework is needed in order for this linked sub-model strategy to be successful. The intent of this framework is to facilitate integration or coupling of sub-models. It is fully expected and intended that different and innovative solutions be found for the problems of particular sub-models; the common framework, if followed from the outset, provides for a familiar "feel" to the models and for their easy integration with other sub-models (which internally may use quite different modeling approaches).

Guidelines

The CCCC model program needs to provide guidelines for the development and integration of sub-models. These guidelines should include:

- language - preferably avoiding platform-specific versions;
- standard output formats (including output naming conventions) - this is to facilitate integration with other sub-models;
- recommended platforms - to try and reduce the number of platform-dependent problems with model use and integration;
- technical issues - such as parameters input from files so that the sub-model need not be re-compiled;
- detailed documentation criteria, and presentation of results of sub-model evaluations (model results compared against observations).

Evaluation

Evaluation is a crucial issue in the acceptance and use of sub-models the N. Pacific marine science community. The Discussion Group consensus was that model evaluation is the responsibility of the developers/contributors of each sub-model. The fit of sub-model outputs to observations should be included in the sub-model documentation. The real test of a sub-model, of course, is how well it compares with future observations, or observations not used to adjust model parameters. In modeling the effects of climate variability, there is a difficulty with these changes affecting factors in the real world that are not included in the model (because these factors may have been unimportant under earlier conditions), e.g. the movements of mackerel into B.C. waters with warmer conditions, and their predation on salmon. Close coupling and evaluation of observations with model outputs throughout the program is needed to recognize (new) important processes which may not be included in the models.

Potential Goals for Initial Modeling Activities

As examples of how this common modeling framework could work, the Discussion Group proposed the following as an initial potential modeling goal, and how to reach it.

Goal 1: Model the temporal and spatial variability of phytoplankton and zooplankton biomass (and productivity) in the North Pacific Basin.

Strategy:

- use results from an existing circulation model for the North Pacific (a small number of potential candidates are available, see WG 7 report);
  - this model may need to be run with different forcings to represent the circulation under different climatic conditions ("regimes"), e.g. the IPCC approach;
  - minimum required outputs are temperature, salinity, velocities (u,v,w), diffusivities;
  - scales are determined by the chosen model, e.g. 1/8 degree lat, daily time step;
  - model outputs are archived in formats available to the PICES community, and which can be extracted based on user-defined ranges of time and space co-ordinates;
  - meteorological data (e.g. cloud cover, solar irradiance) should be available on similar spatial scales - perhaps from inputs to the physical model, or as links provided to where these data could be obtained;
  - for linkage to lower trophic level models, there is a crucial need for inclusion of upper mixed layer dynamics and outputs from the physical model. If these are not available in the existing circulation models, an effort should be made to encourage their development.
- use existing or develop new lower trophic level sub-models
  - these are linked to the circulation model and upper trophic level models by inputs and outputs as defined by the common modeling framework and guidelines;
  - if upper trophic level sub-models are not available to provide estimates of grazing and predation, these latter need to be parameterized in the lower trophic level sub-models. The output from such sub-models could be archived for use by upper trophic level models which do not require dynamic linkages with lower trophic level sub-models.
  - such a lower trophic level sub-model would provide information on plankton production for use by individual researchers or community efforts in higher trophic level modeling;
  - if dynamic linkages with lower trophic level sub-models are required by the upper trophic level sub-models, then both sub-models would need to be run in a coupled, feed-back process, e.g., predator-prey interactions;
  - physical data are also available directly for use by upper trophic level sub-models if needed, e.g. Lagrangian larval fish distribution models;
  - there is a clear need for higher trophic level researchers to specify the inputs and outputs they require to and from lower trophic level sub-models.

Goal 2: Model the temporal and spatial variability of phytoplankton and zooplankton biomass (and productivity) in the continental margins and regional seas of the N. Pacific.

Strategy:

- similar strategy to Goal 1, regarding use of the common modeling framework. Goal 2 differs from Goal 1 primarily in scale.
- it is suggested not to archive the results of the circulation models at this time. Many are still in

development, and there would be outputs from models for several different regions (e.g. PICES Implementation Plan);
- in some cases, available physical and circulation data may be better than model outputs (e.g. Sea of Japan);
- boundary conditions are defined by outputs from models in adjacent areas, if necessary.

CCCC "Model Integration Center/Activity"

Recognizing that development of a community framework and archiving of model outputs requires a dedicated effort, Discussion Group 4 suggested establishing a PICES-CCCC "Model Integration Center (or Activity)". The duties of this Activity would be:
- to facilitate the integration of sub-models, and retain documentation on sub-model structure, processes, evaluation (as contributed by sub-model developers);
- to archive (or provide directions to obtain standard outputs of) sub-models;
- to provide technical support for coupling sub-models;
- comparisons of alternative sub-models and documentation of differences
- provide visualization tools for viewing the model outputs (but not to develop these visualization tools).

The difficulty with such a Center or Activity is funding. It should be established in conjunction with recognized modeling activities and researchers, as existing leadership (in the field of modeling) is crucial. It should be supported by a Steering Committee, and consist of at least one person who would do the technical work of archiving data (or keeping track of new model outputs and improvements and where they could be obtained) and supporting sub-model linkages. The example of the ERSEM modeling centre at Plymouth Marine Laboratory was discussed (e.g. J.C. Blackford and P.J. Radford, Netherlands Journal of Sea Research 33 (3/4): 247-260). This activity should not be established until progress has been made on guidelines for sub-model linkages, outputs from physical circulation models are available, and lower trophic level models are beginning to be available for coupling to the physical models. In any case, it should have a finite time period for its existence (e.g. 3 years).

Suggestions from Discussion Group 4 for funding/supporting this Center included:
- soliciting proposals from member nations to host and fund this center;
- voluntary efforts by existing centers;
- by sabbatical or secondment of an individual to PICES (with the Institute of Ocean Sciences providing the associated modeling leadership);
- funding by PICES through member contributions.

Table 6.3.1. Status of information available to parameterize models in PICES regions.

PICES REGION

Model	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Conceptual Food Web	+	+	+	+	+	+	+	+	+	U	+	+
Eco-Path	+	+	+	+	+	+	P	P	+	U	P	P
Early life survival	+	P	P	P	+	+	P	P	P	U	-	-
Single species bioenergetic	P	P	P	P	P	+	P	P	-	U	P	P
Distribution and Movement	P	+	P	P	P	+	P	P	+	U	P	P
Full life cycle model	P	P	-	P	P	+	P	P	+	U	P	P
Multispecies trophodynamic	P	P	P	P	P	+	P	-	P	U	P	P
Ecosystem	-	-	-	P	-	+	-	-	-	U	-	-

+ - Available
– - Not available
P - Available for some species
U - Unknown

Table 6.3.2. Key biological and physical components of PICES regions and basin areas.

	California Current South	California Current North	Oyashio / Kuroshio	Japan Sea/East Sea	Bohai Sea
Key fish species	Northern anchovy	Pacific herring	Anchovy	Pacific sardine	anchovy
	Pacific sardine	Pacific sardine	Pacific sardine	Pacific saury	yellow croaker
	Pacific hake	Pacific hake	Pacific saury	Pacific herring	Spanish mackerel
	Jack mackerel	Pink salmon	Jack mackerel	Walleye pollock	Japanese squid
	Pacific mackerel	Sockeye salmon	Pacific mackerel	Pink salmon	fleshy prawn
		Chinook salmon	Walleye pollock	Japanese common squid	rough shrimp
		Chum salmon	Albacore tuna		Acetes chinensis
		Coho salmon	Skipjack tuna		
			Japanese common squid		
			Lanternfish		
Key marine mammals	California sea lion	California sea lion	Northern fur seal		
		Steller sea lion	Minke whale		
			Dolphin		
			Porpoises		
Key fish prey	euphausiids	euphausiids	euphausiids	euphausiids	euphausiids
	copepods	copepods	copepods	copepods	copepods
	dinoflagellates	dinoflagellates			chaetognaths
Key seabirds	Cassins auklet		Shearwater		
Key physical factors	Upwelling	Upwelling	Vertical mixing	Winter monsoon	
	Strength of California Current	Strength of California Current	Intensity + meander of Oyashio/Kurshio	Tsushima current	
	El Nino	El Nino	Winter monsoon	Liman current	
	S/F transitions	S/F transitions	Seasonal transtions	MLD	
	MLD	MLD	MLD		
	MLT	MLT	MLT		
		Freshwater runoff	Storms		
		Cross-shelf transport			

Table 6.3.2. (cont.) Key biological and physical components of PICES regions and basin areas.

	Southeast, Central Alaska	**Eastern Bering Sea**	**Western Bering Sea**	**Sea Okhotsk**
Key fish species	Pacific herring	Pacific herring	Pacific herring	Pacific herring
	Capelin	Capelin	Capelin	Capelin
	Walleye pollock	Walleye pollock	Walleye pollock	Walleye pollock
	Pacific cod	Pacific cod	Pacific cod	Pacific cod
	Sockeye salmon	Sockeye salmon	Sockeye salmon	Sockeye salmon
	Chinook salmon	Squid	Squid	Squid
	Chum salmon	Snow crab	Snow crab	Snow crab
	Coho salmon	Stenobrachias leuopsarus	Myctophiids	Yellowfin sole
	Pink salmon	Yellowfin sole	Chum salmon	Chum salmon
	Rockfish	Rock sole	Pink salmon	Pink salmon
	Arrowtooth flounder	Pacific halibut		Kamchatka crab
	Sablefish	Predatory sea stars		
		Jellyfish		
Key marine mammals	Harbor seals	Northern fur seals	Northern fur seals	Northern fur seals
	Steller sea lion	Steller sea lion	Steller sea lion	Steller sea lion
	Humpback whales		Harbor seals	Harbor seals
	Orca whales		Walrus	Ringed seal
Key fish prey	euphausiids	euphausiids	euphausiids	euphausiids
	copepods	copepods	copepods	copepods
	shrimp	polychaetes	hyperiids	Hyperiids
		clams	chaetognaths	
Key seabirds		Shearwaters	Shearwaters	
		Kittiwakes	Auklet	
		Common murre		
Key physical factors	Downwelling	Sea ice	Sea ice	Sea ice
	Strength of the ACC and AK Stream	Strength of slope current	Kamchatka current	Circulation
	El Nino	Cold pool	Cold pool	Tidal Mixing
	S/F transitions	Spring bloom	Spring bloom	Spring bloom
	MLD	MLD	MLD	MLD
	MLT	MLT	MLT	MLT
	Freshwater runoff	Storms	Storms	Storms
	Cross-shelf transport	Aleutian low	Aleutian low	Aleutian low
	Storms	Mesoscale eddies		Freshwater ronoff
	Aleutian low	Tidal mixing		
	Mesoscale eddies	Slope-shelf exchange		

Table 6.3.2. (cont.) Key biological and physical components of PICES regions and basin areas.

	Western Subarctic Gyre	Eastern Subarctic Gyre
Key fish species		
	sockeye salmon	sockeye salmon
	chinook salmon	chinook salmon
	chum salmon	chum salmon
	pink salmon	pink salmon
	coho salmon	coho salmon
	Pacific mackerel	pomfret
	sardine	yellowtail
	anchovy	salmon shark
	Pomfret	blue shark
	Yellowtail	skipjack tuna
	Salmon shark	boreal clubhook squid
	Blue shark	eight-armed squid
	Skipjack tuna	flying squid
	Albacore	
	Boreal clubhook squid	
	Eight-armed squid	
	Flying squid	
Key marine mammals		
	Northern fur seals	Northern fur seal
		sea lion
		Dall's porpoise
		Pacific white-sided dolphin
Key fish prey		
	copepods	copepods
	euphausiids	euphausiids
	chaetognaths	chaetognaths
	amphipods	amphipods
	pteropods	pteropods
Key seabirds		
	Shearwaters	shearwaters
	Common murre	common murre
	Auklets	auklets
		albatross
Key physical factors		
	vertical mixing	vertical mixing
	meander of Oyashio/Kuroshio	strength of California current
	El Nino	El Nino
	MLD	MLD
	MLT	MLT
	storms	S/F transitions

Table 6.3.3. Suggested model types for addressing questions on effects of climate change on upper trophic level species in PICES regions.

Proposed models				**Top down**	**Bottom Up**
	Bioenergetic	**Mass Balance**	**Early life history**	**Multispecies-Trophodynamics**	**Multispecies-Trophodynamics**
Purpose	* Growth	* Gaps	* Transport	* Migration/Habitat Preference	* Migration/Habitat Preference
Species	Adult UTL	All UTL / and prey	Key pelagic species	Key UTL /and prey	Key UTL /and prey
Lower trophic level	Zooplankton	Zooplankton Biomass Phytoplankton Biomass	Zooplankton	Zooplankton abundance Growth rates	Zooplankton abundance Growth rates
Spatial scale	Basin / Regional	Basin / Regional	Regional	Regional/basin	Regional/basin (subareas)
Time step	Annual	Annual / Regime	weekly	daily	monthly
Software	Hewett+Johnson	ECOPATH	Walters	Robinson + Ware	BORMICON
Physical	Temperature		Horizontal mixing Cross shelf transport Vertical mixing Temperature Density	Vertical mixing (upwelling) Advection Temperature	Temperature

Key

* Growth = Interannual variations in growth

* Gaps = Identify gaps in knowledge and ecosystem characteristics

* Simple surface advection model

* Hake, Pacific sardine, Sockeye salmon, Sablefish

UTL = Upper trophic level

7. REPORT OF THE MODEL TASK TEAM MEETING - June 27 and October 13, 1996

Chairmen: Sinjae Yoo, Korea Ocean Research & Development Institute, Seoul, Korea
Ian Perry, Dept. of Fisheries & Oceans, Canada, Nanaimo, BC, Canada

The MODEL Task Team of the PICES CCCC program met near the end of the workshop (afternoon of June 27, 1996) to evaluate progress and discussion from the workshop and to propose a workplan for the next year to further the modeling activities of the PICES Climate Change and Carrying Capacity program. This report includes the discussions and decisions of this meeting as modified by subsequent review of the final Discussion Group reports and further deliberations by the MODEL Task Team held on October 13, 1996, just prior to the Fifth Annual Meeting of PICES.

Concept: The Task Team agreed that modeling for the CCCC program should take place as distributed activities at several locations in all the member nations, rather than be a centralised activity located at one or a few centers.

Roles: The roles of the MODEL Task Team within the PICES-CCCC program are:

1. to encourage, facilitate, and co-ordinate modeling activities within the member nations with respect to the goals and objectives of the program. It was recognised that a large number of modeling activities currently take place within member nations but outside of the present composition of PICES, and that contact and co-ordination should be made with these other groups or agencies to expand the expertise available to the program;
2. to promote and facilitate linkages among the modeling activities taking place at the various component levels, for example, promote linkages among physical, lower trophic level, and upper trophic level models, and among the basin scale (BASS) and regional (REX) observation Task Teams;
3. to identify and encourage modeling activities in areas or subjects which may be important but not yet well studied or integrated into existing models of the North Pacific, for example air-sea interactions, especially as they influence upper mixed layer dynamics; the microbial loop; or non-commercial fishes (e.g. myctophids) and marine mammals;
4. to interact with the field programs to provide an integrating context for planning these programs, for analysing results, and for comparisons among regions.

Strategy: The strategy that was developed to work towards and fulfil these is as follows:

1. *Availability of circulation model results.* (A) Following discussions and recommendations from this workshop, the MODEL Task Team will undertake to contact authors of general circulation models for the North Pacific, and to make available their model outputs to the general community. These outputs would be available for any number of uses, including linkages to lower trophic level models, the physical background for models of the distribution and migration of upper trophic level species (e.g. fishes), etc. The output from simulations with two different sets of initial conditions are preferred, to include conditions during the 1960's and early 1970's (i.e. before the marked change in conditions that occurred in the late 1970's), and conditions during the 1980's. Data on the meteorological forcings for these simulations should also be available, since they can be important inputs to modeling other trophic levels. Details on the availability of these model outputs will need to be worked out with the authors of the models, but might include storage of outputs by PICES Secretariat and access via the internet, or notification that these results are available and the website where they may be obtained. **Action: Perry, LeBlond.** (B) For coastal regions and regional seas, the use of regional models are recommended. There are usually many

different circulation models available for regional seas, each with different spatial and temporal resolutions, modeling techniques, etc. It is therefore not likely to be useful to obtain outputs from any single model for community use; instead the MODEL Task Team (in conjunction with the Regional Task Team [REX]) will compile an inventory of circulation models in regional seas that should be available for integration with lower and upper trophic level models. This inventory will include a meta-analysis or synthesis of the results, to identify what is being done where and what is not being done (gaps in activities). This is a natural regional follow-up activity to the work of PICES Working Group 7 on modeling of the subarctic North Pacific circulation. **Action: tba**.

2. *Development of upper mixed layer models*. The workshop identified a need for development of models of the upper mixed layer, and their integration into circulation models and lower trophic level models. These upper layer dynamics models can be used to simulate physical properties of the upper layer, given circulation model outputs with auxiliary data on forcings such as wind, solar radiation, precipitation, and evaporation. PICES will compile an inventory and develop a synthesis (meta-analysis) of available upper layer models and required data sets, for use in communicating and stimulating inclusion of these models into general circulation and lower trophic level models. **Action: tba**.

3. *Lower trophic level modeling*. There are two immediate needs for co-ordination of lower trophic level modeling activities that were identified during this workshop and that PICES can facilitate within the next year. These are (i) development of a database for vertical distributions of nutrients (nitrate) in the North Pacific, on spatial scales similar to the circulation models. These are needed for initial conditions for the lower trophic level models. (ii) Comparisons of models for specific physiological processes within the lower trophic level models, e.g. photosynthesis *vs* light, nutrient uptake, and grazing/predation models. The issue here is that apparently relatively small differences in basic assumptions or parameter values in these process models can generate large differences in their outputs. It is crucial to compare and understand the reasons for these differences, and whether they relate to "real" differences or to variations in modeling techniques. The MODEL Task Team proposes to convene a small workshop in December 1997 or January 1998 at Tiburon, California, to address these issues. **Action: Yoo, Dugdale**.

4. *Upper trophic level modeling.* The Upper Trophic Level discussion group considered five models with varying degrees of complexity and analytical capabilities that might be appropriate for CCCC modeling activities. They recommended that at least one be selected for early examination and use in each of the regions identified by the PICES-CCCC Implementation plan. The MODEL Task Team endorses this recommendation, and suggests that a simple and widely available mass-balance model such as ECOPATH could be attempted for each region. This first exercise can be considered as a teaching tool that could identify gaps in knowledge, which would help focus the regional experiments and allow an initial basis for the intercomparisons among regions. To facilitate this comparison and familiarity with ECOPATH, Dr. Daniel Pauly will be invited to the fifth annual meeting of PICES for a demonstration of this program. To facilitate comparisons of any regional ECOPATH models that may have been stimulated by this presentation, and to introduce other more detailed models linking climate variation with fish dynamics, the following was proposed to the Fisheries Science Committee of PICES as the special topic session for the Sixth Annual Meeting in 1997:

    Models for Linking Climate and Fish. Quantitative methods for evaluating the effect of climate variability on fish and other upper trophic level animals may take a wide variety of forms. Retrospective analysis of time series data may require a statistical approach, while prediction of single-species and multi-species effects may be done using both statistical and simulation approaches. Advancing understanding of climate effects on upper trophic level dynamics requires application of available tools to existing data and discussion of innovative methods or models that may provide new insights to system dynamics. This session will invite papers that discuss or apply quantitative methods or models to the analysis of climate and upper trophic level dynamics, including bioenergetics (growth), mass-balance models, transport and migration, and multi-species or multi-trophic level analyses. The intent is to assess and advance the current status of models of climate variability and upper trophic levels and to identify techniques and models that can be applied with developing circulation and lower trophic level studies in the North Pacific.

Action: Livingston

5. *Linkages among sub-models.* The workshop recognized the issue of facilitating linkages among sub-models, for example, agreement on common input and output variables and formats so that results of one model could be readily used as inputs to another. At the simplest level, this requires specification or agreement as to standard data formats and their temporal and spatial resolution; at a more complex level however, model integration may require dynamic linkages among sub-models such that separate model runs may need to be conducted for each simulation. For example, the incorporation of non-linear interactions in predator-prey responses between lower and upper trophic level sub-models may require both models to be coupled and run simultaneously. The MODEL Task Team will develop recommendations for methods to facilitate linkages among sub-models.

   Action: tba.

6. *Interaction with other Task Teams.* The MODEL Task Team must interact closely with the activities of the other Task Teams (e.g. BASS, REX) that may conduct studies in regional seas and the deep basins of the North Pacific. This interaction requires discussion and collaboration on appropriate scales and locations for observations, and assistance with the integration of results into a framework allowing a more coherent understanding of ecosystem structure and functioning. It is expected that the generic models and approaches will be appropriate for both BASS and REX studies. The MODEL Task Team should act as a reference resource for modeling expertise in the North Pacific that can be consulted on topics of interest to the observational programs. Data produced by these observational programs are also extremely valuable to the refinement and elaboration of existing models and development of new models for the regions. For example, information on the diets of key upper trophic level species is crucial to the development of simple bioenergetic models that could be constructed to explore differences in growth and production of a species throughout its range. Discussion at the MODEL Task Team meeting of October 13, 1996, suggested that MODEL may have a larger role in the Basin studies, since the Regional studies and their modeling needs are being conducted by the national GLOBEC programs. One of the principal objectives of the CCCC Basin program is to compare ecosystem processes and dynamics between the eastern and western halves, and modeling provides an objective method to facilitate this comparison. For example, simple mass-balance models could be constructed for comparison of gross ecosystem characteristics in each basin, followed by more complex and dynamic coupled circulation-lower trophic level and possibly upper trophic level models. In the regional comparisons, the MODEL Task Team felt that its role was to facilitate the regional comparisons, for example by identifying overlaps and gaps in modeling activities, and suggestions to resolve these.

Comments: At the MODEL Task Team meeting on 13 October 1996 these was considerable discussion of the issue of co-ordination and standardization of models and model development. The MODEL workshop in Nemuro clearly preferred the distributed approach, in which various models are developed using different assumptions and tech-niques, in the various member nations of PICES. This approach was endorsed by the meeting on October 13, 1996, which recognised that no one modeling approach or technique is sufficiently well-advanced or dominant over other techniques to warrant endorsement as a community model at this time. The Task Team further recommended a need to anticipate differences in model results and to facilitate investigations to understand these differences. Such investigations should include intercomparisons of models for the same areas, if possible using similar forcings. The proposed lower trophic level workshop in California is an initial step in this direction. Once the inventories and synthesis of regional circulation models has been completed, comparisons of these models in similar areas would be a logical next step.

Although not discussed in detail, suggestions were made at the October 13, 1996 Task Team meeting for a test case to develop methods and recommendations for linking the various sub-models. This could be done by starting with models which are already advanced and which apply similar technologies in different regions, for example the Robinson and Ware model off the west coast of Vancouver Island (Robinson, C.L.K. and D.M. Ware. 1994. Modeling pelagic fish and plankton trophodynamics off southwestern Vancouver Island, B.C. Can. J. Fish. Aquat. Sci. 51: 1737-1751) and the Wada *et al.* model for the Oyashio region (see Appendix 2 of this report on the Japan-GLOBEC Symposium). Another suggestion was to choose a specific region, e.g. the Sea of Japan, and attempt to facilitate development of an integrated model system for that area. These ideas will serve as suggestions for the next meeting of the MODEL Task Team.

Summary of Recommendations/Activities (with proposed time scale): The MODEL Task Team will:

At PICES V -

- provide an opportunity to explore the use of ECOPATH as a simple mass-balance representation of regional ecosystems, and encourage application of this program to several regional seas.

6 Months -

- contact and attempt to make atmospheric data inputs and North Pacific circulation model outputs widely available to the PICES community, if possible with physical forcings typical of pre- and post-1977 conditions.

1 Year -

- compile an inventory and provide a synthesis of available models and required data sets to facilitate development and integration of upper mixed layer models into the North Pacific general circulation models;
- develop an inventory and provide a synthesis of circulation models available for the regional seas (in association with REX);
- convene a small workshop in December 1997 or January 1998 to develop a database of nutrient (nitrate) vertical distributions in the North Pacific, and to compare specific lower trophic level physiological models;
- convene a topic session at the next PICES meeting to compare and contrast results from regional applications of ECOPATH models (if available) and to promote other modeling techniques for linking climate and fisheries variability;

Continuing -

- develop recommendations for linking components of North Pacific ecosystem models, e.g., among physical models, lower trophic level, and upper trophic level models;
- interact with developing observational programs as to the appropriate key parameters, locations, and measurement scales, and facilitate integration and comparisons of results.

8. WORKSHOP SUMMARY

Ian Perry, Dept. of Fisheries & Oceans, Canada, Nanaimo, B.C., Canada

The major objective of the Nemuro MODEL workshop was to develop the model-related requirements of the PICES Climate Change and Carrying Capacity (CCCC) program, and to produce a plan to further these activities. The four Discussion Groups and the MODEL Task Team report present reasonable and considered approaches to this objective which will be developed and elaborated throughout the course of the CCCC program.

Overall, the workshop underlined the central role of models in this PICES program. Models serve to extrapolate retrospective and new observational data through space and time, allowing inferences to be made of conditions which have not been directly observed. Models assist with the design of observational programs, by identifying locations and parameters to which the model results (and presumably the "real" world) are highly sensitive. Models also serve to test our understanding of the integration among components of the ecosystem, from atmosphere-ocean interactions to the distribution, growth, and survival of fish, seabirds, and mammals. The emphasis in these roles, however, is one of service rather than the end product of the CCCC program - the goal of this program is understanding the linkages and impacts of climate variability to the biological productivity and high trophic level carrying capacity of the North Pacific, for which models are one of the principal tools.

The workshop identified clear differences in the level of advancement or integration of the various disciplinary models. It identified how far along modeling is with atmosphere-ocean interactions and the ocean circulation, to the extent that the physical community was comfortable with obtaining and applying present circulation models to the CCCC objectives. Advances in physical modeling are certainly still required, for example in data assimilation, in coupling more detailed upper mixed layer models into the general circulation models, and with representing small and meso-scale features in regional circulation models, but circulation models acceptable for the immediate (basin-scale) needs of the CCCC program appear to be available (the report of PICES Working Group 7 on modeling the subarctic North Pacific circulation [PICES Scientific Report No. 5, 1996] provides more detail). Participants at the workshop believed that suitable lower trophic level models are not far behind the circulation models, and notable successes are being achieved with coupled circulation - plankton production models for the open North Pacific, particularly in the Japan and Canada JGOFS and GLOBEC programs (see also Chapter 3 by M. Kishi of this workshop report). The Discussion Group and MODEL Task Team have proposed activities to assist development of these models and their implementation within the CCCC program. With upper trophic level models, however, no consensus was reached on leading models, or even modeling approaches, suitable for the goals of the CCCC program. The Discussion Group identified five types of models, each appropriate for somewhat different problems in upper trophic level biology and management issues. These problems range from growth to migration to multi-species interactions. The consensus of the workshop and the MODEL Task Team was that this is an area that needs particular attention by the modeling components of the CCCC program, requiring presentations of existing models and evaluations as to strengths, weaknesses, and compatibility to the circulation and lower trophic level models, and the goals, of the program.

The issue of standardization of modeling techniques and approaches was discussed at length, which led to discussion of the "community model" concept. This concept sees a single, widely accepted ecosystem model as a goal of modeling activities within the CCCC program, which would be available to all participants. The ERSEM experience (see Chapter 5 of this workshop report, by Jerry Blackford) was seen as an excellent example of this concept. However, it was felt that such a community model is impractical at present for the PICES community without funding from a central source to support model integration. It was also widely believed that such standardization of approaches and techniques is not desirable for the North Pacific at the present level of model development in all three fields from circulation to top predators. The diversity of approaches, however, does make it difficult but also very important for the CCCC program to facilitate model integration and model comparisons. Modeling activities within PICES therefore need to be particularly aware of and concerned about the ability of common specification of inputs, outputs, and parameter initialization, so that different models can be assembled into larger models, whose results then need to be carefully compared. The concept here is of models (or component sub-models) as tools in a "tool-kit" which can be assembled in several ways depending on the particular problem under investigation.

One class of models that was generally absent at the workshop, yet was included as a component in the workshop title, were conceptual and theoretical models (in contrast to simulation models). There is a need to identify specific problems and issues which require development by conceptual models, for example the definition and measurement of carrying capacity.

In conclusion, I must express the thanks of all the participating scientists to the members of the Local Organising Committee for their help, hospitality, and hard work at making this workshop a success. The Service Room, computers, and meeting arrangements do not just happen - they require much work and planning, and it was appreciated.

I also thank Mayor Ohya and the citizens of Nemuro for their support. Nemuro City has contributed substantially to the funding for this workshop, including support for seven foreign scientists who would not otherwise have been able to participate, and so we had representatives from all the PICES member nations.

The members of the Workshop Steering Committee must also thank all of the participating scientists for attending the workshop and making it a success.

APPENDIX 1. NATIONAL GLOBEC REPORTS

A1.1. CHINA GLOBEC SUMMARY

Qi-Sheng Tang, Yellow Sea Fisheries Research Institute, Qingdao, China
Jilan Su, Second Institute of Oceanogrpahy, Hangzhou, China

The China GLOBEC program, titled "Ecosystem dynamics and sustainable utilization of living marine resources in China seas", has been identified as a high priority national science program. It is supported by the National Natural Science Foundation of China, and is designated as a contribution to the SCOR/IGBP GLOBEC program and to the PICES CCCC program.

The goal of China-GLOBEC is to identify how the changes in climate and anthropogenic influences will affect the dynamics of coastal ecosystems, with the aim of predicting fluctuations in the ocean and its living resources. The program identifies five research themes:

1. structure, carrying capacity, and health of the coastal ecosystem;
2. food chain and trophodynamics;
3. role of physical processes and physical-biological interactions on control of marine production;
4. recruitment variability and replacement mechanisms of dominant species;
5. coupled physical-biological-chemical modeling.

The first field process studies are planned for the Bohai Sea, with a timetable of planning in 1996, followed by field studies and monitoring in 1997-2000. This program is conducted by institutions from the State Oceanic Administration, Ministry of Agriculture, Academia Sinica, and university staff including physical oceanographers, chemical oceanographers, biological oceanographers, and fisheries scientists.

The Bohai Sea Ecosystem Dynamics and Sustainable Utilization of Living Resources program has four principal foci:

I. Bohai prawn life history and key dynamic processes studies -
   A. Bohai prawn life history and population dynamics;
   B. key physical processes influencing the prawn ecosystem;
   C. key biogeochemical processes influencing the prawn ecosystem;
   D. impact of climate change on the key bio-physical processes of prawn life history;
   E. impact of human activities on the key bio-physical processes of prawn life history.

II. Zooplankton population dynamics and their controling role for the ecosystem productivity in the Bohai Sea -
   A. dynamic variations of the primary productivity structure and its control process studies;
   B. zooplankton feeding strength and transformation efficiency;
   C. key zooplankton population dynamics;
   D. response of the zooplankton community structure to environmental changes;
   E. exchange of matter at the water - sediment interface and dynamic changes of benthic productivity.

III. Trophodynamics of the food web and the shift mechanisms of dominant species in the Bohai Sea -
   A. characteristics of food web structure and its changes;
   B. trophodynamics at high trophic levels and prey-predator relationships;
   C. shifts of dominant species and their responses to climate change;
   D. influence on shifts of dominant species caused by human activities.

IV. Bohai Sea ecosystem dynamics modeling -
   A. model of primary production dynamics;
   B. ecosystem dynamics and forecast models;
   C. analyses of the influence of human activities and climate change on ecosystem health;
   D. assessment of carrying capacity and the sustainable yield of living marine resources;
   E. ecosystem information system.

A1.2. KOREAN GLOBEC ACTIVITIES

Suam Kim, Korea Oceanic Research & Development Institute, Seoul, Korea

Changes in the abundance and production of marine animals with respect to environmental changes have not been well studied in Korea. Some zooplankton biologists have examined the vertical flux of zooplankton and their fecal pellets, and others have studied the grazing pressure of zooplankton under different food concentrations. However, most zooplankton research has not followed the GLOBEC concepts.

Some fishery scientists have considered the global warming issue and its influence on fishery resources in the North Pacific and Korean waters. Recently, scientists from the Korea Ocean Research and Development Institute (KORDI) and the National Meteorology Institute jointly organised an informal research group to find evidence of climate regime shifts in Korean waters. Specifically, a pilot study revealed that a warming trend of sea water temperature in the East Sea/Japan Sea occurred off south and north Korea in the mid 1970's, and that dramatic changes in some fish catches happened during the same time period. With this preliminary result, they are requesting research funds for a continuation of the study on climate change and its influences on the marine ecosystem.

A1.3. PHYSICAL AND BIOLOGICAL MODELS IN RUSSIA GLOBEC

Vadim Navrotsky, Pacific Oceanological Institute, Vladivostok, Russia
Boris Kotenev, VNIRO, Moscow, Russia

The first stage of the GLOBEC-RUSSIA project (1996-1998) includes activities in three directions: 1) Ocean-atmosphere interaction; 2) Modeling the fluxes of matter in the marine ecosystems; 3) Modeling the formation of lower trophic levels of the marine ecosystems, and ecosystem relationships with higher trophic levels.

As the first step in a retrospective analysis of ideas, models and observational results are needed to find out the most appropriate ways for advancing the goals of CCCC.

Ocean-atmosphere interaction

In the problem of climate change and variability due to ocean-atmosphere interaction, the role of horizontal temperature gradients and anomalies in the ocean surface layer are regarded as important and appropriate for investigation. The basic ideas were proposed in 1964 (Navrotsky, 1964 a,b), and can be summarised as follows:

1. Due to the vertical fluxes of heat and moisture, horizontal gradients of surface temperature effect the horizontal gradients of pressure in the atmosphere and hence the intensity of the cyclonic circulation. This influence must be especially considerable above the ocean

because of the high heat accumulation and loss (by the mechanism of vertical convection), and neighbouring warm and cold waters in most boundary currents.
2. Temperature anomalies in ocean currents lead to anomalies in cyclonic activity and changes in the trajectories of the cyclones.
3. Feedback of the atmosphere on ocean surface temperature anomalies tends to change the direction and intensity of ocean currents and destroy the horizontal surface layer gradients (thus abolishing the cause of the atmosphere circulation anomalies).
4. Because of circulation of water in ocean gyres there must be some periodicities in the alternation of warm and cold anomalies. The range of periodicities is rather large as the exchange between deep and surface waters goes on at many space and time scales.
5. The causes of ocean temperature anomalies can be internal and external. In both cases there are no grounds to expect any kind of stationarity (stochastic or quasiperiodic). The only pertinent external influence is likely to be from the sun, and investigations of relations between solar activity and ocean temperature anomalies are very promising.
6. If we look for long-term changes in the ocean-atmosphere system as caused by external factors, then the intertropical zone of the ocean is the most important, because waters there receive the largest amount of heat and are most influenced by changes of solar radiation.

Almost the same ideas (not including the hypothesis about the role of solar activity) were developed by G.I. Marchuc, V.P. Dymnikov, Yu.V. Nicolaev, T.N. Palmer and S.A. Zhaobo (Palmer, Zhaobo,1985) and became the foundation for the long-term Soviet program "Sections" (for example see Atmosphere, ocean, kosmos - the program "Sections", vol.8, Investigation of role of energy active zones in the short-term climate fluctuations. Ed. G.I. Marchuk, Moscow. 1987). Regular expeditions of the Far-Eastern Regional Hydrometeorological Institute (Vladivostok) were fulfilled as a part of that global program.

The main results of these works have direct concern to the ocean climate changes from seasonal to interdecadal scales. From the point of view of the CCCC Program the following issues should be emphasized:

1. Maximum differences between positive and negative anomalies of heat transport into the Pacific midlatitudes through the upper layer (0-300 m) in the Kuroshio current system can be about one-half of the average transport. The same is true for the layer 0-1000 m.
2. The changes of position of the Kuroshio frontal zone are correlated with temperature anomalies and can influence the pattern of the atmosphere pressure system and trajectories of cyclones over the North Pacific and adjacent lands.
3. Temperature anomalies in the Kuroshio system are correlated with ENSO and have prevailing scales of 2-3, 5-7 and 9-11 years (Nelezin 1993, a, b).

The periodicities about 11 years clearly indicate the possible influence of solar activity on the ocean-atmosphere climatic system. The most powerful verification of this hypothesis was made lately by W.B. White (unpublished report) using the analysis of about 2.5 million temperature profiles in all oceans. The correlation of these global ocean temperature fluctuations with solar cycles is very high (98%), although the amplitudes of global anomalies of both solar radiation and ocean temperature are very low (less than 1%). It becomes rather evident that climate change and variability should be characterized not so much by global averages as by the distribution of long-term anomalies over the globe.

The plan of the Russian investigation in physical forcing of climate and ocean ecosystem variability is: 1) To study the interaction of temperature and dynamical characteristics in the North Pacific; 2) To study the physical mechanisms responsible for the correlation between solar activity and ocean temperature anomalies.

Modeling the fluxes of matter in marine ecosystems

The main goal of studies in this direction is to model and understand the basic mechanisms of ocean bioproductivity. It is known that the functioning of living matter is based on coupled polycyclic reactions, which form chains. Ecosystems are associations of living organisms and nonliving matter, so they must function (that is, carry out the fluxes of matter between living and nonliving parts) under the same laws of cyclicity, forming ecological and bio-geochemical cycles.

At the first stage, the photosynthetic production (primary production) was modeled. Due to the complexity of the biological components of the process it is practically useless to build models on the basis of mechanistic differential equations. But biological processes tend to stationarity (changing on scales much longer than basic cyclic reactions), so it is reasonable to try algebraic equations for their description. The general method and the model of the photosynthetic process was developed by V.I. Zvalinskii and F.F. Litvin (1984, 1986). In the steady state the equations for the rate of a system of coupled cyclic reactions was obtained in the form of a continued (chained) fraction, reflecting the structure of the chain of reactions itself. The scheme may be easily extended to take into account the reversibility of the reactions, branching of chains, multisubstrate reactions, the effect of inhibitors and so on. In all cases we can obtain solutions from a system of recursive relations. For the case of primary production the internal parameters of the process are constants of relative resistances of reactions, which can be determined with good accuracy. Inhibition of some enzymes can be also accounted for rather strictly. If we can determine the resistances of the degradation of biomass of heterotrophic and autotrophic organisms, the model of the simplest ecological system from two productive links is easily constructed.

What problems will arise on the way to real multi-component ecological systems? First, we have to analyse polycyclic chains. It is shown that if there is no branching, any polycyclic chains may be reduced to two cycles. From the other side, mathematical and experimental results show that a complex, polysubstrate process practically always is regulated by one limiting factor (the transition from external to internal limitation is very sharp). Difficulties in the analysis of real ecosystems arise because of two circumstances: 1) There are many points of sequential and parallel branching, and we have to take into account many cycles which have very different time and space scales without the possibility to reduce them. 2) The constants of reaction between neighbouring links and at the ends of chains are not physical or chemical constants (as in the case of photochemical reactions), but should be determined from experiments depending on many physical and biochemical factors. But once the algorithm is found and, if we have the scheme of a chain of the cyclic coupled processes, we can write down the solution. So we can formulate the main problem for the near future as experimental and mathematical investigation of interrelations between different links of ecological chains to determine rate constants and relative resistances for use in the proposed scheme of model construction.

Modeling ecosystem relationships

The first stage of the Russian GLOBEC project implementation (1996-1998) provides for modeling to concentrate on the formation of lower trophic levels of marine ecosystems and ecosystem relationships at higher trophic levels. The former models permit one to describe adequately the functioning of the lower trophic levels during the whole year (based on the relatively scarce field observations), and to reveal the knowledge gaps of the physical processes, which should be a priority in our expedition studies.

We could introduce parameters of the already known climatic epochs into these models and see the reaction of the lower trophic levels to the climatic variability. To illustrate the models of the first kind, we present the Okhotsk Sea ecological model (Fig. A1.3.1). This model describes the correlated biogeochemical cycles of N, P, and Si along with the major transformations of C_{org} and O_2 in the two-layered water ecosystem. The model presents 8 areas of the Okhotsk Sea (Fig. A1.3.2) and can illustrate the dynamics of biochemical parameters, the dynamics of the biomass of heterotrophs, the dynamics of the primary production rates of diatoms, peridiniums, and blue-green algae (A1.3.3), as well as the herbivorous and carnivorous zooplankton (Leonov et al., 1996). This model, based on the 1991-1993 data, allowed us to describe the characteristics of organic matter biotransformation and the primary production in the Okhotsk Sea ecosystem.

Running the model has identified the knowledge gaps, which should be covered so that we can develop a more precise description and measure-ments of primary production in any marine ecosystem. Thus, the model gives a constant organic matter flux to the sub-surface layer from the deeper layers for the entire sea, though we know that this is not correct. The precise knowledge of the spatial heterogeneity of this parameter could undoubtedly allow one, first, to change considerably the assessment of the value of primary production in this sea, and also to reveal the characteristics of the exchange of matter at the boundaries of the marked sea areas.

The authors conclude that the advective transfer of organic substances is insignificant compared to the processes of vertical exchange, which occur in the specific areas. However this conclusion could be due to an absense of reliable information about the water circulation in winter and spring, when the advection rates of these compounds can increase several times. Despite these and other disputable conclusions of the authors, the work has indicated interesting possibilities in study of marine ecosystems.

The next stage of the work on this model shall examine the variability of climatic, oceanic, and chemical parameters and shall take into account the available data of other climatic epochs, so that it could show the possible reactions of the lower trophic levels to climatic variability. This stage could also allow us to investigate the influence of the variability of herbivorous and carnivorous zooplankton on the basin produc-tivity. The model could also be applied as an instrument for more accurate determination of the ecosystem boundaries in the sea. On the whole, this model permits one to take into account the organisms of the higher trophic layers.

For more effective multispecies fishery management and more precise annual and long term TAC forecasting, knowledge of ecosystem interactions between the main fishery populations seems to be very important. These problems cannot be solved even on the basis of reliable data without utilization of multispecies models. Based on the experience of multispecies models of the Barents Sea ecosystem (Bulgakova et. al., 1995 a,b,c,d) it is proposed to apply a modified version of MSVPA as a paramount task in the Russia GLOBEC (Far-Eastern Seas) Program.

The methodology of multispecies virtual population analysis (MSVPA) adopted by us, implies the consideration of age structures of all the species included in the model of the community. On the basis of catch-at-age data, abundances by age group are calculated retrospectively for all species included in the model. Coefficients of natural mortality for each population are split into 2 components - mortality from predation (M2) and natural mortality from other causes (M1). The value of M2 depends both on population sizes of all predators and other prey species. Hence the estimation of natural mortality and fishing mortality parameters turns out to be a rather complicated iterative process. Thus the predator-prey interactions among populations are modelled.

The time step for the model is equal to one quarter of a year. The input data for the model include: catch-at-age by species by quarter and year; weight-at-age by quarter and year (the new version); ration by quarter for all groups of predators of M1 by age and quarter (the new version gives the possibility of considering seasonal post-spawning mortality); consumption rates (quarterly rations) by age groups of predator and by quarter, and - in the version to be elaborated - by year.

Stomach content data are introduced into the model as mean weight (for a given quarter) of every age group of every prey species in the stomach of the predator of the given age. These data are input for all years for which information on stomach content exists.

All the necessary information will be obtained from a specialized data base which is to be created on the basis of ICES methodology (Anon 1991). Elaboration of a multispecies model on such a large scale and especially the development of a Data Base are impossible without strong international cooperation. This is especially important for completion of the data base with retrospective data.

Processing of feeding data is one of the most complicated tasks connected with the preparation of input data. It gives rise to a number of additional problems. For proper processing of data a number of special algorithms and programs for determination of prey ages in the stomachs of the predators are being developed. These programs are planned to be revised and updated. For example, a proper method for estimation of reconstructed prey weights based on the degree of digestion has yet to be found.

Even for a large number of stomachs sampled the information on their contents often turns out not to be representative, especially for older ages. This gives rise to a number of problems of interpolation and extrapolation of functions of two variables. Averaging of data on food composition from the data base may result in a biased estimate of the mean diet for the entire population, because the area sampled does not include the whole area of cod distribution and because samples are not distributed evenly. Since the predator is characterized by different diets in different areas, it is proposed to make use of "geostatistical" methods to take this variability into account. The rations of predators will be estimated by the method proposed by Dos Santos and Jobling (Norway). This method provides possibilities to take into account different digestion rates for various prey species and also dependencies of rations on environmental temperature as well as other parameters. Values of M1 by quarter will be estimated by tuning the results of annual surveys.

The tuning of the model (estimation of fishing mortality coefficients for the terminal year of the calculations) will be undertaken by means of independent survey information. It is planned to investigate the possibility of "automatic" multispecies tuning methods within the model.

The Prognostic model should incorporate the dependence of recruitment of every species on stock size and on environmental factors. It is also necessary to estimate sustainable harvesting rates by means of computer experiments. Experience of the application of this method in the Barents and Norwegian Seas was recently rewiewed and approved in Reykjavic by ministers of fisheries and experts from North Atlantic countries (second North Atlantic Conference of Fisheries Ministers, Reykjavik, 28-30 May 1996). In discussions it was outlined that there is now a possibility for more effective fishery management. It is now known that marine mammals of the Barents and Norwegian Seas compete for food with commercial fish and shrimp stocks. They also consume an enormous biomass of herring, cod, capelin and shrimp. For example, in 1992, whales (Minke Whales) in the Barents Sea consumed about 1.5 million tons of fish (including 335 thousand tons of capelin, 450 thousand tons of herring, 75 thousand tons of cod). The Greenland seals and Minke whales together consumme more than 2.5 million tons. These data indicate the necessity to include multispecies modeling into managenemt strategies for fish and sea mammal stocks.

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A1.4. JAPAN GLOBEC SUMMARY

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The Japan GLOBEC Committee was established in 1994, and presently consists of 21 members, of whom the Chairman is Dr. T. Sugimoto (University of Tokyo). The Japan-GLOBEC program is supported by several universities associated with the Ministry of Education, Science, Culture and Sport; by the Japan Fisheries Agency of the Ministry of Agriculture, Forestry and Fisheries; by the Japan Meteorological Agency and the Japan Oceanographic Data Center of the Ministry of Transportation; and by the Science and Technology Agency of Japan.

The program has several research activities:

I. **Dynamics of the food chain through zooplankton and micronekton**. GLOBEC will predict how marine ecosystems respond to changes in the ocean physics resulting from global climate change based on the study of the structure and dynamics of the food chain, the most basic biological process sustaining marine ecosystems.
   - A. **Response of the Oyashio ecosystem**. The ecosystem in the Oyashio region is mainly driven by the energy produced by the phytoplankton bloom. GLOBEC will clarify how the energy is distributed to zooplankton and micronekton through the food chain, and how such a process responds to climatic changes.
   - B. **Response of the Kuroshio ecosystem**. The ecosystem in the Kuroshio is mainly controlled by changes in the axis and front of the Kuroshio represented by the large meander of the axis and the interaction between these changes and bottom topography such as sea ridges. GLOBEC will clarify how variation in these controlling factors affect the distribution and abundance of marine organisms and the structure and function of their food chain.
   - C. **Response of the transition zone ecosystem**. The warm water tongue formed by the Kuroshio intrusion into the Oyashio and the warm water mass cut off from the Kuroshio are the major physical processes controlling the ecosystem in the transition zone. Accordingly, GLOBEC will examine the effect of these processes on the composition of organisms and their productivity.
   - D. **Response of the ecosystem in meso- and bathypelagic zones**. Every night from the mesopelagic zone (deeper than 200 m depth) where light levels are insufficient for phytoplankton growth, a large biomass of animals migrates up into the epipelagic ecosystem to forage, and then transports a substantial amount of energy and substances from the euphotic zone into the deeper zone (biological pump). GLOBEC will elucidate the response of the ecosystem in the deeper zone to changes in the epipelagic ecosystem through the study of the food chain of these animals.

II. **Dynamics in the response of marine ecosystems to climate change.** Focusing on ecosystems expected to be largely affected by climatic change, such as the subarctic Oyashio region, the Kuroshio and the Kuroshio extension regions, and the Antarctic Ocean, GLOBEC will examine mechanisms causing variability in the stocks of the major fish resources in these ecosystems.
   - A. **Mechanisms of variability in the Oyashio ecosystem**. GLOBEC will predict how the Oyashio affects the ecology during the early developmental stages and which may lead to changes in the stock of walleye pollock, a key species in the northern region. This will be a principle focus of the project **HUBEC**.
   - B. **Mechanisms behind abundance shifts in the dominant species of pelagic fish**. GLOBEC will clarify the relationship between changes in stock size of pelagic fish such as sardine and the physical changes in the ocean, and examine the mechanisms resulting in the shift of the

dominant species in the pelagic fish population.

C. **Studies on the response of the Antarctic ecosystem to changes in sea ice**. If global warming proceeds at the present rate, the warming will increase ice break-up. In this case, global warming will cause direct and indirect impacts on the ecosystem in the Antarctic Ocean. This study proposes to clarify the relationship between polar ice cover and subsequent changes in the Antarctic ecosystem. It is called **SO-GLOBEC**.

III. **Development and application of new technologies for measurement and modeling in marine ecosystems**. GLOBEC will establish new technologies enabling *in situ* multi-dimensional measurements of organisms in marine ecosystems and their environment. GLOBEC will also develop ecosystem models and individual behavioural models based on these measurements, in order to predict fluctuations in ecosystems.

A. **Development of acoustical and optical instruments for measuring the distribution and abundance of zooplankton and fish larvae by continuous sampling systems**. GLOBEC will develop instruments for *in situ* measurements of species, size, and density of plankton by adopting multi-beam acoustics and image analysis systems for continuous sampling of plankton.

B. **Observation and modeling of zooplankton behaviour under different levels of turbulence**. GLOBEC will clarify mechanisms of patch formation and swimming behaviour of zooplankton in relation to the micro-scale physical environment, observing both the intensity of turbulence and its affect on swimming behaviour of zooplankton.

C. **Development of a marine ecosystem model**. GLOBEC will construct numerical models showing the interaction between physical processes and production of zooplankton and pelagic fish corresponding with the *in situ* observations. These models will enable us to understand and predict changes in marine ecosystems.

D. **Development of sampling gears and acoustic technologies for assessment of stock size**. GLOBEC will develop new net systems enabling the quantitative sampling of micronekton and fish juvenile stages which have relatively high swimming abilities. Acoustic systems will also be developed to estimate fish biomass and body length in a natural state.

A1.5. SYNOPSIS OF CANADA-GLOBEC PACIFIC OCEAN PROPOSAL

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Conceptual framework

Pacific Ocean fish and plankton communities undergo large and ecologically significant fluctuations over years to decades. Stock collapses and extreme failures of steady-state fisheries forecast models have tended to accompany major shifts in the marine climate. There is increasing evidence that these large changes in fishery yield are environmentally, rather than purely fishery harvest, driven. Variations in zooplankton production, biomass, and composition (as mediated by physical transport and nutrient supply processes), and variations in predation (also mediated by ocean conditions), are key components regulating growth and survival of juvenile and adult salmon, herring, and larval and juvenile groundfishes. Understanding the linkages to zooplankton and predators, and how these are related to variations in the physical oceanography, will allow transformation of existing management indices into more realistic and reliable ecosystem models.

The Pacific component of the Canadian-GLOBEC program has two principal but linked objectives:

- how do physical and biological processes affect the ecosystem structure off the west coast of Canada; and
- what are the relative roles of the shelf region and the deep ocean in determining the production of salmon?

The research will emphasize food web pathways leading to production of the most important west coast finfish species: salmon, herring and hake. Target processes and species include: alongshore and cross-shore advection, seasonal cycle of upwelling, horizontal currents and water mass boundaries (physical environment), euphausiids and copepods (zooplankton), and both adult and juvenile finfish. The conceptual model for the west coast GLOBEC program consists of three advectively- and biologically-linked ecosystems operating at increasing spatial scales (west coast of Vancouver Island, B.C. continental margin, open NE Pacific Ocean). Each has important seasonally variable and physically-driven exchanges of nutrients and plankton with its surroundings. Each also contains large populations of migratory fish. In particular, Pacific salmon integrate, over the course of their life cycle, the consequences of physical and biological processes occuring in both coastal and offshore regions.

At the gyre scale, GLOBEC's emphasis is on how maturing Pacific salmon utilize and respond to changing environmental conditions (both physical and food-supply) in the open North Pacific. Major components of this interaction include horizontal and vertical circulation, zooplankton (primarily copepod) production, and salmon growth/survival as a function of their distribution and foraging strategies. The major tools will be retrospective analysis and modeling, together with a limited amount of ongoing time series sampling.

Along the British Columbia continental margin, the emphasis is on sensitivity of yearly ecosystem production to the place-and-time interaction between key annual physical and biological events: shifts in current direction, intensity of upwelling, peak zooplankton population growth, outmigration of juvenile salmon and herring, and migratory arrival of major predators. Major elements will be a spatially-detailed physics-biology model, on-going time series observations, and focussed process studies of biology-current interactions along the shelf break boundary between shelf and oceanic ecosystems.

Project Elements

Central NE Pacific - Modeling
- develop a coupled ocean general circulation and food-web model; and use to study seasonal to interdecadal variability of the central NE Pacific and the consequences to the marine ecosystem;
- develop biophysical-bioenergetic migration models of sockeye salmon for the central NE Pacific to identify the importance of circulation and zooplankton production for the marine growth and distribution of sockeye on interannual and decadal time scales.

Central NE Pacific - Observations:
- provide an index of interannual variability in mesozooplankton production at Station P in the central NE Pacific, and evaluate under what conditions the zooplankton community at Station P is representative of the whole gyre;
- evaluate covariance between past changes in zooplankton production at Station P and measured salmon growth rates, and develop a mechanistic understanding of salmon growth under varying temperature and food levels;
- incorporate information about open ocean food-supply and physical environment into a retrospective multivariate analysis of survival rate similarities and differences among selected salmon stocks .

Continental Margin - Modeling:
- construct retrospective models of hydrographic conditions and circulation along the entire B.C. continental margin;

Continental Shelf - Time-Series Observations
- monitor hydrographic properties, circulation, and plankton characteristics, along the continental shelf west of Vancouver Island;
- develop a index stock time series for selected salmon species;

- determine year-to-year changes in the arrival time and total biomass of hake and quantify consumption by hake of euphausiids, herring and juvenile salmon;
- track year-to-year changes in the distribution and growth rate of out-migrating juvenile salmon during their first year in the marine environment.

Continental Shelf - Process Study

- determine the temporal and spatial pattern of primary productivity, new, and regenerated production across the shelf and slope relative to current patterns;
- identify the spatial and temporal distributions of larval and adult euphausiids in relation to the seasonal changes in physical and biological characteristics;
- identify the seasonal evolution of cross-shelf exchange between shelf and oceanic copepod communities, and distribution overlap of copepods with larval and juvenile fish;
- determine the flow patterns around submarine canyons off the west coast of Vancouver Island and their significance in inhibiting offshore and along-shore zooplankton advection;
- Use compound-specific fractionation of stable isotope tracers to evaluate spatial and seasonal changes in food web linkages between phytoplankton, zooplankton, and fish.

Continental Shelf - Modeling

- develop a spatially-detailed coupled physics/plankton/fish model of the western continental margin of Vancouver Island. The ultimate goal of the modeling is to recognize and forecast ecosystem production trends based on physical forcing of the lower trophic levels, and both natural and anthropogenic forcing of the higher trophic levels.

A1.6. U.S. GLOBEC RESEARCH PLANS FOR THE PICES AREAS

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The U.S. GLOBEC program developed research plans for four of the PICES regions: the California Current, the coastal Gulf of Alaska, the Bering Sea and the open Subarctic Pacific. In April 1996, the Steering Committee narrowed the research for a U.S. program to a comparative study of the California Current system (CCS) and the coastal region of the Gulf of Alaska. This report provides a brief description of the planned activities in these two regions. A more complete summary may be found in U.S. GLOBEC Report No. 17. U.S. GLOBEC reports can be obtained at the following address and on the U.S. GLOBEC home page: http://www.usglobec.berkeley.edu/usglobec/globec.homepage.html.

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Planning for a U.S. GLOBEC program for the CCS began in 1991 with a workshop on Climate Change and the California Current System (U.S. GLOBEC Rep. No. 7). Many research scientists participated in this meeting. The workshop report provided an overview of the types of research questions that could be explored in a research program focused on the CCS. In the following years, plans for a CCS program were distilled into a Science Plan for the region (U.S. GLOBEC Rep. No. 11). My comments are primarily drawn from the Science Plan for the CCS.

There are four regional divisions embedded in the Science Plan for the CCS (Fig. A1.6.1). The biological and physical characteristics of these four regions differ providing an opportunity for comparative studies along a longitudinal gradient. The Science Plan outlines four types of research activities: modeling studies, retrospective studies, large scale spatial studies, and mesoscale spatial studies.

Four types of models were proposed for the CCS program:

- coupled mesoscale biological - physical models that resolve fronts, mixed layer dynamics, and diurnal time scales;
- regional-scale coupled biological-physical models capable of assimilating available observations (e.g. remote sensing data, buoy data);
- regional biological-physical models linked with a basin-scale GCM;
- modeling efforts that investigated the responses of biological metapopulations to spatially and temporally varying physical forcing.

Retrospective studies proposed for the CCS program included five major activities:

- document and quantify the properties of event-scale, seasonal, interannual, and interdecadal variability in the CCS ecosystems through the analysis of existing historical physical and biological data sets and sample collection;
- compare and contrast the nature of variability in processes and pattern from event through interdecadal time scales in all major Eastern Boundary Currents (EBC) from the comparative analysis of existing historical data available for the Humbolt, Benguela, and Canary systems;
- document and quantify the interdecadal and centennial-scale variability in the pelagic ecosystems of the California, Humbolt, and Benguela Current Systems through reconstruction of proxy variables from paleosedimentary records;
- using preserved samples that are archived (e.g. CalCOFI), examine the temporal and spatial genetic variability in target populations, especially as it relates to possible shifts in ecosystem state;
- determine the linkages of the mesoscale, seasonal, and interannual scales to the longer-term interdecadal scale through the integration of contemporaneous sediment trap studies with field process studies in the California Current with a full set of retrospective analyses for both proxy and paleological data and historical data sets.

Five large-scale spatial studies are recommended in the CCS Science Plan:

- assess and quantify the relative impact of physical processes in different latitudinal regions on the distribution, abundance, vital rates, and life history of key populations of marine animals;
- understand the mechanisms behind these physical/biological linkages;
- identify variables and sites for monitoring, to document future ecosystem changes;
- use the understanding of mechanisms by which populations respond to present differences in forcing to formulate specific parameterizations for biophysical models, which will then project the responses of these populations to different climate change scenarios;
- use the spatial and temporal variability determined by the large-scale study to develop a conceptual model for the EBC ecosystem response to various climate change scenarios.

Seven mesoscale spatial studies were recommended:

- examine the degree to which the amplitude, position, and timing of mesoscale features may be altered by climate change;
- examine the role of various mesoscale features in determining cross-shelf and along-shore transport of meroplankton, holoplankton, and ichthyoplankton;
- study the role of frontal dynamics in producing or maintaining gradients in vital rates, and the exchange between or genetic isolation of populations;
- examine the role of mesoscale features in determining the links between plankton dynamics and the ultimate spatial and temporal variability in recruitment of fish and benthic organisms;
- study the extent to which zooplankton within mesoscale features use behaviour to mediate their net transport;

- examine links between life histories of target species and the timing of seasonal changes in atmospheric forcing and mesoscale circulation features.

U.S. GLOBEC planning for the northern regions followed a pattern similar to the CCS, but was completed in one year rather than four. Efforts to explore potential research activities in this region began in 1995 with a workshop focused on Climate Change and the Carrying Capacity of the North Pacific Ecosystem (U.S. GLOBEC Rep. No. 15). A second meeting was held in January 1996 to develop a science plan for the Gulf of Alaska, Subarctic Pacific and the Bering Sea (U.S. GLOBEC Report No. 16).

The structure of the planning meeting in 1995 included a day of discussions focused on six general research topics and a day of discussions focused on identifying key research questions for the coastal Gulf of Alaska, Subarctic Pacific, and Bering Sea. The six general research topics were:

- climate change: what are the likely scenarios for climate change in the North Pacific and how do they influence the ecosystem?
- regime shifts and decadal shifts: can they be detected, what is their impact, are they predictable?
- what is carrying capacity?
- what is required to model the impact of climate change on the carrying capacity of the region?
- what are the technological impediments to measuring the effects of climate change on the carrying capacity?
- what are the spatial and temporal scales required to resolve the questions concerning climate change and the carrying capacity?

The implementation meeting held in January 1996 was convened to develop a focused science plan for the three northern study regions: Subarctic Pacific, the coastal Gulf of Alaska, and the Bering Sea. During the meeting the Subarctic Pacific group and the coastal Gulf of Alaska group were joined because of the clear overlap in research activities between the two groups.

The U.S. GLOBEC Steering Committee met in April 1996. At this meeting, the Steering Committee decided that modeling efforts should be encouraged for all four study regions: Bering Sea, Subarctic Pacific, coastal Gulf of Alaska, and the CCS. However, process oriented research programs would be limited to comparative studies of the CCS and the Gulf of Alaska.

The following key species for the coastal Gulf of Alaska program were identified:

- salmon: pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*)
    - ∗ show shifts that appear to be strongly associated with the apparent shifts in climate;
    - ∗ short residence times in freshwater;
    - ∗ salmon from different regions of the North Pacific have responded differently to “regime” shifts;
    - ∗ salmon are both economically and ecologically important in the North Pacific Ocean;
    - ∗ extensive historical data on salmon abundances, and opportunities to examine past vital rates (e.g. growth, size-at-age using archived scale samples) of salmonids.
- salmon predators: adult salmon, pollock, herring, marine mammals (northern fur seal, harbour seals, perhaps sea lions), and bird predators (cormorants, pelicans, murres, alcids, and others).
- salmon prey: copepods *Neocalanus*, *Calanus*, perhaps others, and the euphausiids *Euphausia* and *Thysanoessa*.

The Subarctic Pacific research plan will examine two hypotheses:

- Hypothesis 1 (H_1): ocean survival of salmon is primarily determined by survival of juvenile salmon in coastal regions, and is affected by interannual and interdecadal changes in the Gulf of Alaska physical forcing;
- Hypothesis 2 (H_2): variation in size-at-age of returning salmon is determined largely by interdecadal and interannual variation in physical conditions and productivity of the

oceanic realm of the subarctic Pacific, and may show density dependence.

Four types of models will be required to support this program:

- a physical model of the North Pacific that has the ability to be coupled with larger scale atmospheric models to allow hindcasting;
- a basin scale "gyre and coastal" coupled biophysical model that resolves the details of exchange of water and organisms between the coastal shelf and deeper oceanic waters;
- regional nearshore biophysical models. These should be capable of including coastal transport processes and detailed biology, including food web relations and organism behaviour;
- detailed biological models, with perhaps less physical detail. An example might be bioenergetic models of juvenile salmon, predator relations, seasonal prey switching behaviour, or nearshore food web dynamics for several environmental scenarios.

Several monitoring studies were identified to support this program:

I. continue or establish time-series to address the following questions:
    A. how does the Aleutian low drive physical forcing?
    B. how does physical forcing affect the availability and production of prey and the abundance of predators of juvenile salmon in the coastal Gulf of Alaska?
    C. how does physical forcing affect the production and availability of salmon prey as indicated by zooplankton in the open ocean (deep water of the Gulf of Alaska)?

    We recommend that several (for example, three) deep water moorings be placed in the Alaskan Gyre. Ships of opportunity could be used to expand geographic coverage in the Alaskan gyre beyond those of the moorings.
II. develop methods to measure cross-shelf exchange, perhaps using chemical or biological tracers;
III. large-scale monitoring: recommend that U.S. GLOBEC monitors the circulation and characteristics of the Alaska Gyre and the bifurcation of the west wind drift as it nears North America by a combination of remote sensing, a few strategically placed moorings and/or transects, and atmospheric models.

Process studies include:

- process-oriented investigations of juvenile pink salmon conducted on the shelf region outside Prince William Sound in the northern part of the Gulf of Alaska. It is proposed to conduct studies over the shelf (outside Prince William Sound), ranging from approximately 143° - 150°W;
- seeding of Prince William Sound with *Neocalanus* populations from offshore is of interest;
- elucidate the mechanisms by which these interzonal copepods, which overwinter in the deep-water off the shelf, recruit onto the coastal shelf and into Prince William Sound;
- recommend that studies sample the migrating juvenile salmon further to the west, perhaps even into and beyond Shelikof Strait.

Three cruises are proposed to be conducted each year of the study: during March, July-August, and September-October. The March cruise would be used to document the conditions of the coastal environment just prior to the spring bloom; the July-August cruise would be just before the principal out-migration of pink salmon from Prince William Sound onto the shelf proper, and is primarily intended to determine the abundance, distribution, and species composition of the zooplankton populations; and the September-October cruise would be during the period when the juvenile pink salmon are in the coastal environment (outside Prince William Sound) and would focus on measuring their growth and survival, as it is impacted by the trophodynamics.

The U.S. GLOBEC program secured funding to initiate the Northeast Pacific program and released an announcement of opportunity in November, 1996. The closing date for proposal submission was Febuary 14, 1997. Investigators will be notified of the status of their proposals in July 1997.

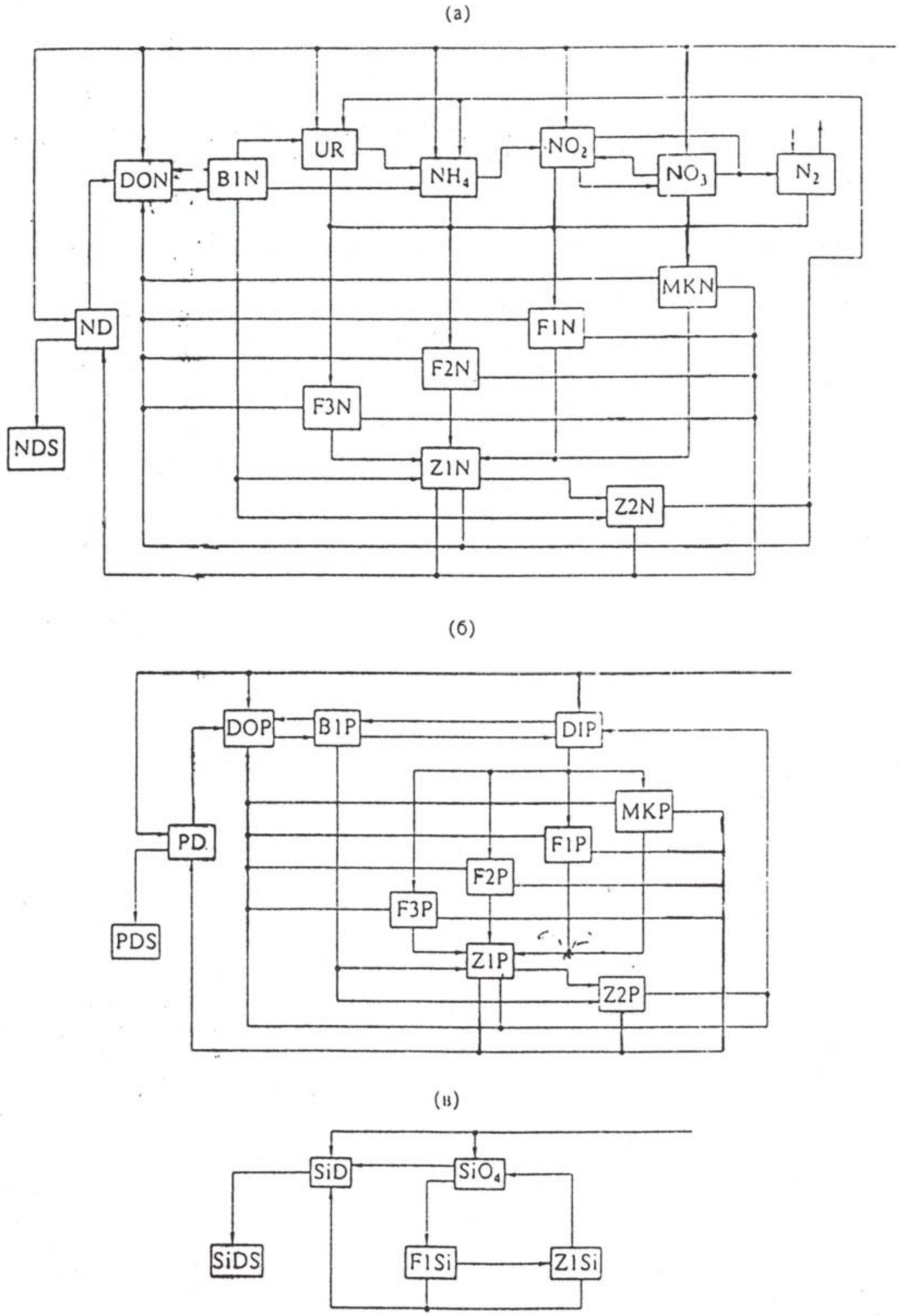


Fig. A1.3.1. The relationships of the nutrient compounds included in the model. (a) Nitrate, (b) Phosphate, (c) Silicate.

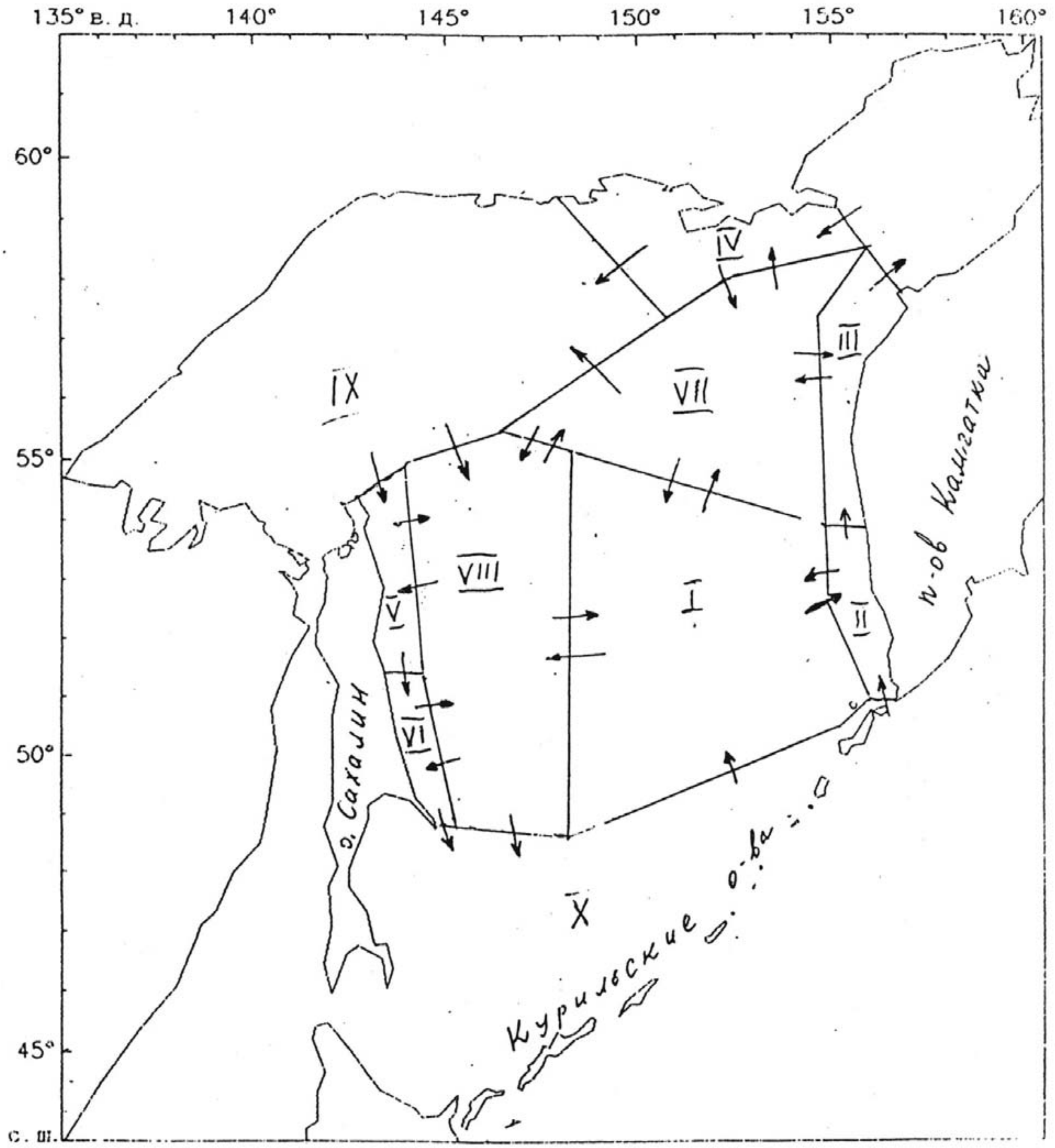


Fig. A1.3.2. The division of the Okhotsk Sea onto areas based on the field observations in 1991-1993.

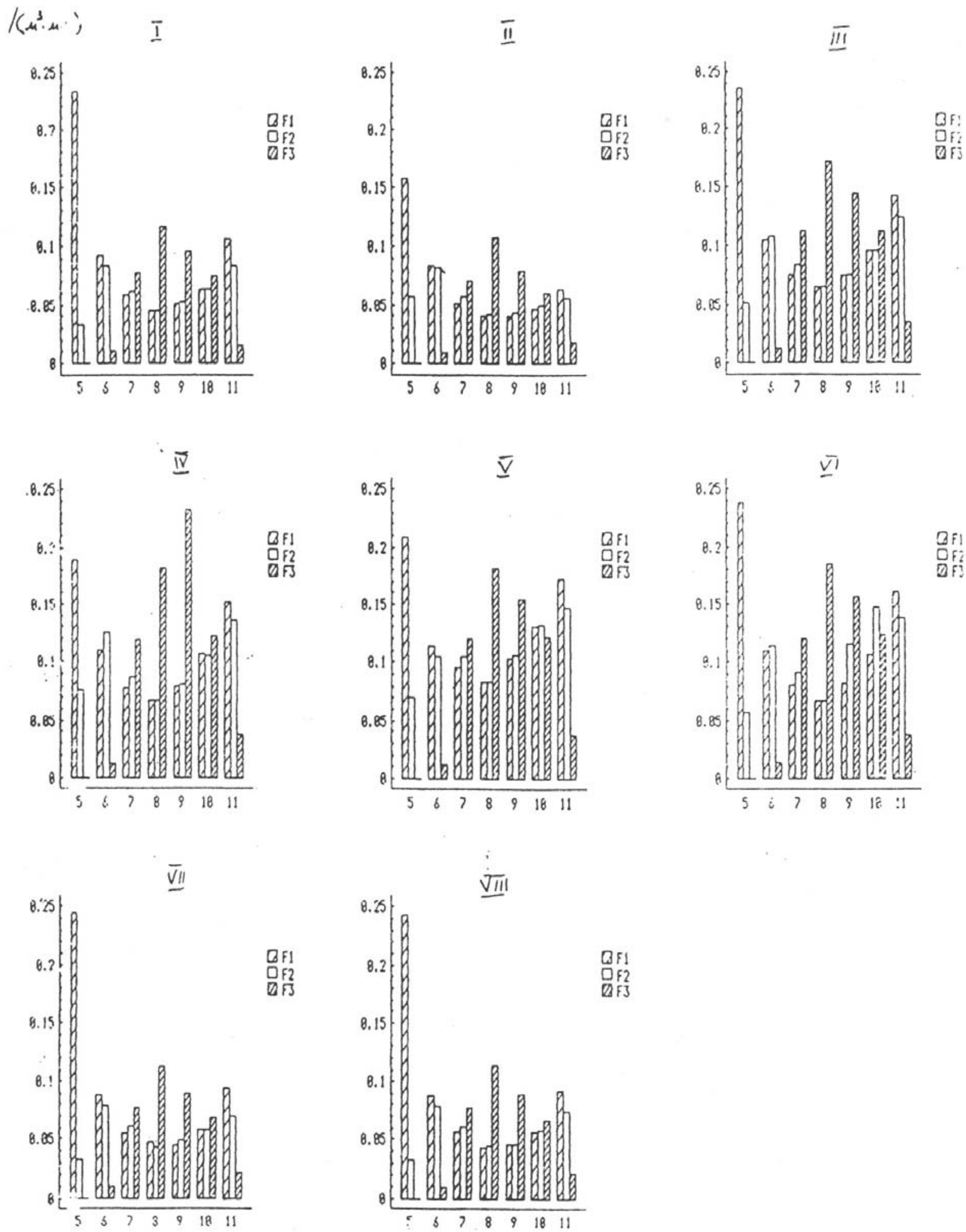
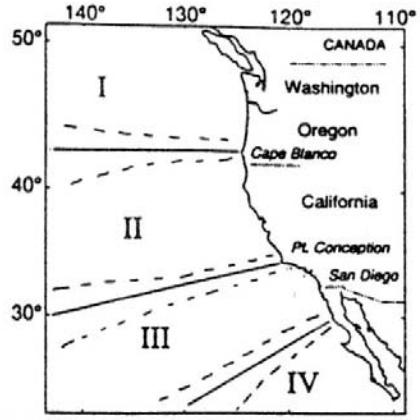


Fig. A1.3.3. The dynamics of the rates of primary production of diatoms (F1), peridiniums (F2), and blue-green algae (F3) in areas 1-8 of the Okhotsk Sea, May-November 1991-1993.



	Region I	Region II	Region III	Region IV
Storms	Winter storms frequent and strong	Moderate winter storms	Fewer winter storms	Infrequent storms from tropics
Winds	Seasonal wind stress reversals	Winds mostly upwelling favorable	Minimum in longshore wind stress	Modest and persistent longshore wind stress
Upwelling	Moderate upwelling in spring / summer	Strongest upwelling in spring / summer	Weak upwelling	Modest upwelling year-round
Freshwater input	Significant freshwater input	Minor freshwater input	Negligible freshwater input	Negligible freshwater input
Coastal relief	Relatively smooth coastline	Major coastal promontories	Concave coast, islands, subsurface basins	Several major promontories
Shelter/Nurseries	Major estuaries / nursery grounds	A few major bays, estuaries	Sheltered bight, major nursery	Several sheltered bays
Circulation	Moderate advection, mesoscale activity	Extreme advection, mesoscale activity	Strong local recirculation, longer residence times, weak mesoscale activity, stronger stratification, major water mass mixing	Moderate advection, mesoscale activity
Productivity	Primary productivity strongly seasonal	Primary productivity strongly seasonal	Damped seasonality in primary productivity	Moderate seasonality in primary productivity
Zooplankton biomass	Zooplankton biomass strongly seasonal (Copepods commonly overwinter at depth)	Zooplankton biomass seasonal	Modest seasonality in zooplankton biomass	Damped seasonality in zooplankton biomass
Spawning	Patchy spawning by epipelagic fish	Latitudinal minimum in spawning by epipelagic fishes	Latitudinal maximum in spawning by epipelagic fishes	Patchy spawning by epipelagic fish

Fig. A1.6.1. Generalized regional variations in physical and biological processes within the CCS. The boundaries between regions I, II, III, and IV are only approximate and vary over time. The generalizations regarding Region III apply primarily to the Southern California Bight (from U.S. GLOBEC Rep. No. 11, 1994).

APPENDIX 2. JAPAN-GLOBEC SYMPOSIUM

Makoto Terazaki, University of Tokyo, Tokyo, Japan

The Japan-GLOBEC symposium was held on June 27-28, 1996 at Nemuro during the PICES workshop on modeling. The title of this symposium, "Development and application of new technologies for measurement and modeling in marine ecosystems" is one of the core projects of Japan-GLOBEC research activities. This program consists of four subjects; 1) Development of acoustical and optical instruments for measuring the distribution and abundance of zooplankton and fish larvae by continuous sampling systems, 2) Observation and modeling of zooplankton behaviour under different levels of turbulence, 3) Development of a marine ecosystem model and 4) Development of sampling gears and acoustic technologies for assessment of stock size.

There were a total of 15 presentations in this symposium. The program was the following;

Thursday, June 27, 1996

08:30-08:50 Opening address
Dr. Takashige Sugimoto (Chairman: Japan-GLOBEC Committee: Univ. of Tokyo)

Session I: Chairman: Dr. Tsutomu Ikeda (Hokkaido Univ.)

08:50-09:25 Sei'ichi Saitoh and Sang-Woo Kim (Hokkaido Univ.)
"Oceanographic application of satellite ocean color remote sensing in the sub-Arctic North Pacific Ocean"

09:25-10:00 Hideji Tanaka (NIPR), Y. Takagi (Univ. of Tokyo), Y. Yokosawa (Iwate Pref.) and Y. Naito (NIPR)
"Swimming behavior of homing chum salmon as determined by micro data tags"

10:00-10:15 Tea Break

Chairman: Dr. Bruce Frost (Univ. of Washington)

10:15-10:50 Kozo Takahashi (Hokkaido Tokai Univ.)
"Time-series collaborative study with bottom tethered moorings in the subarctic Pacific"

10:50-11:25 Koji Iida (Hokkaido Univ.)
"Preliminary acoustic investigation to estimate walleye pollock stocks around Japan"

11:25-11:40 Discussion

11:40-13:00 Lunch

Session II: Chairman: Dr. Ichiro Aoki (Univ. of Tokyo)

13:00-13:35 Teisuke Miura (Hokkaido Univ.)
"Development of improved sampling gear for stock assessment"

13:35-14:10 Makoto Terazaki (Univ. of Tokyo)
"The Vertical Multiple Plankton Sampler (VMPS): Design and results"

14:10-14:45 Katsumi Matsushita (Univ. of Tokyo)
"An apparatus for continuous sampling of plankton"

14:45-14:55 Discussion

14:55-15:10 Tea Break

Session III: Chairman: Dr. Kouichi Kawaguchi (Univ. of Tokyo)

15:10-15:45 Hidekatsu Yamazaki (Tokyo Univ. of Fisheries) and K. Squires (Univ. of Vermont)
"Lagrangian study of planktonic organisms: a progress report."

15:45-16:20 Yutaka Isoda, S. Shimizu and Y. Sakata (Hokkaido Univ.)
"Physical transport of walleye pollock eggs around Funka Bay in winter as nferred from a barotrophic model"

16:20-16:55 Hitoshi Iizumi (Hokkaido National Fisheries Res. Inst.), M. Minagawa, M. Hirota (Hokkaido Univ.), K. Watanabe, S. Imamura (Japan Aquaculture Association), T. Minami (Japan Sea National Fisheries Res. Inst.)
"Food web dynamics at an estuary in northern Japan"

16:55-17:05 Discussion

Friday, June 28, 1996

Session IV: Chairman: Dr. R. Ian Perry (Pacific Biological Station)

08:30-09:05 Kazumi Sakuramoto (Tokyo Univ. of Fisheries)
"A method to estimate relative recruitment from catch-at age data using fuzzy control theory"

09:05-09:40 Vadim V. Navrotsky (Pacific Oceanological Inst., Russia)
"Some ways to overcome difficulties in measurements, data processing an modeling of ecological processes"

09:40-10:15 Patrick Lehodey (South Pacific Commission, New Caledonia)
"Modeling the distribution of skipjack tuna in the Pacific Ocean with environmental data"

10:15-10:30 Tea Break

Chairman: Dr. Takashige Sugimoto (Univ. of Tokyo)

10:30-11:05 Tokio Wada (National Research Inst. of Fisheries Sci.), D.M. Ware (Pacific Biological Station), O. Yamamura and M. Kashiwai (Hokkaido National Fish. Res. Inst.)
"Response of fish production to changes in physical environment in Oyashio shelf region off Hokkaido"

11:05-11:40 Francisco E. Werner, B.R. Mackenzie, R. I. Perry, R.G. Loygh, C.E. Naimie, B.O. Blanton and J.A. Quinlan (Marine Science Program, Univ. of North Carolina)
"Larval trophodynamics, turbulence, and drift on Georges Bank"

11:40-11:55 Discussion

11:55-12:00 Closing address: Dr. Ichiro Aoki (Univ. of Tokyo)

Dr. Saitoh described the annual variation of primary production in the Japan Sea (1978-1986) by using Satellite Ocean Color Remote Sensing. Utilization of ocean color data from the new series of ocean colour sensors, OCTS on ADEOS (launched in August 1996) and SeaWiFS on SeaSTAR (launched in January 1997) is expected for monitoring the marine envoironment, especially primary production in the Subarctic Pacific.

Dr. Naito has developed many micro data tags to study migration behaviour of salmon, flatfish, seals, sea turtles, dolphins, sea birds and penguins. He mentioned the results of field experiments on swimming behaviour of homing chum salmon by micro data tag in his presentation. The results suggest the salmon reacted to higher water temperatures and took refuge into deeper water to avoid it.

Dr. Takahashi and his group have accumulated a solid 5-year long data set since August of 1990 at both Station SA (49°,174°W) in the central subarctic Pacific and at Station AB(53.5°N, 177°W) in the Aleutian Basin of the Bering Sea, by using time-series sediment traps. Their data clearly suggest that the biological pump in these regions is working efficiently. Hence, these regions are generally acting as a CO_2 sink, although there is cosiderable seasonal variability in the efficiency of the biological pump.

According to Dr. Iida, the use of acoustic surveys is a promising technique that allows quick and precise estimates of fish stock size. In recent years, several acoustic surveys using scientific echosounders have provided useful data. He reported the results of acoustic investigations to distinguish walleye pollock from other species, and adults from juveniles. He also mentioned the improvements in downward-looking echosounders.

Dr. Miura developed new sampling gears a midwater trawl net with mouth-opening canvas devices and a towed midwater gill net with a single warp that controls net depth for stock assessment. He introduced the results of test operation of both gears. Those new gears were very effective for sampling pelagic fish such as sardine.

Dr. Terazaki mentioned the design of his developed vertical plankton sampler (VMPS) and the results of its operation. The required towing time from 2,000 m depth is about 90 minutes, therefore, it is possible to collect more than ten time-series samples from the deep sea each day. Diel vertical migration of copepods and chaetognaths were recognized by continuous sampling with the VMPS in various waters of the Pacific. This sampler is effective at collecting soft-bodied plankton without damage.

Dr. Matsushita introduced his hand-made apparatus for continuous sampling of fish eggs and plankton. This continuous plankton sampler (CPS) collects micro-plankton by using the sea water pumped up during ship running. The CPS was operated for a survey of anchovy egg distribution and plankton blooms in the coastal waters.

Drs. Yamazaki and Squires have compared the observed rms turbulent velocity and swimming ability of several planktonic organisms, and found that the swimming ability of zooplankton in the seasonal thermocline generally exceeds the rms turbulent velocity. They developed a new Lagrangian model to examine how an organism may take advantage of existing flow structures in order to reduce biological energy in the upward swimming effort. A preliminary result by using the new model was presented.

Dr. Isoda used a barotropic model to investigate the physical transport of walleye pollock eggs around Funka Bay, northern Japan. Specific features of egg distributions observed in late February were reproduced by this model, such as the accumulation of eggs in the central part of Funka Bay. The modeled flow pattern shows that a predominant northwesterly wind in winter is responsible for the formation of the vortex pair within the bay.

Dr. Iizumi used stable isotope ratios of particulate carbon and nitrogen to investigate trophic level relationship among invertebrates living in the small estuary, Akkeshi-Ko, northern Japan. Detritus in the estuarine water is derived mainly from epiphytic microalgae, phytoplankton and seagrass, all of which are of estuarine origin, that is, producted within the estuary, despite a large input of organic matter from the river. Nitrogen isotope ratios of Crangon (Decapoda) increased with the increase of its body weight, suggesting changes in food habit with its growth. The same trend was observed when nitrogen isotope ratios of all invertebrates were plotted against their body size irrespective of their species.

Dr. Sakuramoto introduced the fuzzy control model to estimate relative recruitment from catch-at-age data. In the fuzzy control approach, the size of recruitment is inferred using information about the level of catch, not by using the fisheries equations for cohort analysis. Simulation tests were conducted to determine the performance of this approach including comparison with a conventional method. The fuzzy method possessed a higher robustness to the noise in the catch-at-age data than the conventional method.

Dr. Navrotsky discussed the distribution of sea weeds in the Japan Sea to explain the data processing and modeling of ecological processes.

Dr. Lehodey analyzed the distribution of skipjack tuna catches in the western Pacific Ocean in relation to their oceanic environment. A general linear model (GLM) is used to seek the best relationship between skipjack catches and the environmental parameters. The modeled distribution of the skipjack food is the second parameter selected in the GLM after the sea surface temperature. This provides a plausible explanation for the distribution of skipjack tuna in the two major surface fishing zones in the Pacific exploited by purse seiners. The influence of the oceanic circulation on the distribution of the food of skipjack appears as a possible response to the paradoxical presence of a high tuna biomass in low productive waters.

Dr. Wada and his group developed a trophodynamics model combining the models describing plankton dynamics and prey-predator systems among the dominant plankton and fishes in the Oyashio shelf region to forecast the response of fish production to possible changes in the physical environment. The model consists of four physical forcing functions, six biological pools, and twenty processes among these functions and pools. Changes in the level of primary production, timing of the peak, and level of zooplankton production were more strongly influenced by variations in physical conditions than they were by changes in sardine biomass. Warm conditons increased primary and zoopalnton production, especially euphausiid production, and pollock production. The model structure suggested that pollock compete with sardine for food, therefore reduced migrations of sardines into pollock areas was favourable for pollock growth.

Dr. Werner and his group considered trophodynamic effects on the growth and survival of larval cod and haddock on Georges Bank during late winter/early spring by using an individual based model approach. The results suggest that larval feeding behaviour, and especially the ability of larvae to purse encountered prey, could be an important input to larval growth and survival models. The inclusion of turbulence in determing the position of passive larvae in the water column allows the larvae to sample the entire water column, contributing to a decrease in the variance of the size of the larvae over time.

APPENDIX 3. PROGRAM

PICES/GLOBEC International Program on Climate Change and Carrying Capacity
Workshop on Conceptual/Theoretical Studies and Model Development
Nemuro, Hokkaido, Japan June 23–28, 1996

Sunday, June 23

10:00-12:00 Workshop Scientific Steering Committee meeting (closed)
- review of workshop procedures and outputs
- review of Discussion Group assignments

16:00-18:00 PICES-CCCC Implementation Panel /Executive Committee meeting (closed)
- agenda of full IP meeting
- NPAFC related matters
- interactions with TCODE

18:00-21:00 Welcome Reception for all participants

Monday, June 24

0830-0900 Workshop Opening Ceremony (Chairman: Prof. Yutaka Nagata)
Opening Remarks: Prof. Yutaka Nagata
Welcome: Mayor Kaiji Ohya

Plenary Session Chairman: Dr. Sinjae Yoo

09:00-09:15 Workshop objectives and organisation - Dr. Sinjae Yoo

09:15-09:45 PICES - CCCC Program overview - Dr. Makoto Kashiwai

09:45-10:00 Break

10:00-12:00 Reports of GLOBEC activities in member nations:

10:00-10:20	China	Dr. Ji-Lan Su
10:20-10:40	Korea	Dr. Sinjae Yoo
10:40-11:00	Russia	Dr. Boris Kotenev
11:00-11:20	Japan	Prof. Makoto Terazaki
11:20-11:40	Canada	Dr. Ian Perry
11:40-12:00	U.S.A.	Dr. Anne Hollowed

12:00–13:00 Lunch

Plenary Session Chairman: Dr. Ian Perry

13:00-15:40 State-of-the-Art Reviews of Modeling Activities:

13:00-13:40	Atmosphere/Ocean Circulation Prof. Paul LeBlond
13:40-14:20	Lower Trophic Levels Dr. Michio Kishi
14:20-15:00	Higher Trophic Levels Ms. Patricia Livingston
15:00-15:20	Break
15:20-16:00	Model Integration/ Managementment Mr. Jeremy Blackford

16:00-16:20 Objectives of Discussion Group Sessions - Dr. Ian Perry

16:20-17:00 Questions and Discussion

Tuesday, June 25

08:30-12:00 Discussion Group meetings (Chairmen):

1. Atmosphere/Ocean Processes (Prof Paul LeBlond)
2. Lower Trophic Level Processes (Dr. Sinjae Yoo)
3. Higher Trophic Level Processes (Ms. Patrica Livingston)
4. Model Integration/Management (Dr. Ian Perry)

12:00-13:00 Lunch

13:00-14:15 Discussion Group meetings continue

14:15–14:30 Break

14:30–18:30 Meetings of BASS and REX Task Teams (Open)

BASS meeting (Chairmen: Dr. Richard Beamish; Prof. Makoto Terazaki)

REX meeting (Chairmen: Dr. Tokio Wada; Dr. Anne Hollowed)

Wednesday, June 26

08:30-09:40 Plenary Session Chairman: Dr. Bruce Frost
Brief progress reports of Discussion Groups (Discussion Group Chairmen)

09:40-10:00 Break

10:00-12:00 Discussion Group meetings continue

12:00-13:00 Lunch

13:00-14:30 Discussion Group meetings continue

14:30-15:00 Break

15:00-18:00 Meeting of CCCC Implementation Panel (Open)
Chairmen: Prof. Warren Wooster; Prof. Yutaka Nagata)

Items
- discussion on draft BASS workplan
- discussion on draft REX workplan
- meeting plan during PICES V
- intersessional workshop in 1997
- symposium plan at PICES VI or VII
- CCCC logo contest

Thursday, June 27

08:30-12:00 Japan-GLOBEC Symposium "Development and Application of New Technologies for Measurement and Modeling in Marine Ecosystems"
Writing of Discussion Group reports (Discussion Group Chairmen)

12:00-13:00 Lunch

13:00-17:00 Japan-GLOBEC Symposium on Development and Application of New Technologies for Measurement and Modeling in Marine Ecosystems

15:00-17:00 MODEL Task Team meeting (Chairmen: Dr. S. Yoo; Dr. I. Perry)
- development of MODEL workplan

18:30- Sayonara Party (open to all) fee: 3,000 yen

Friday, June 28

08:30-12:00 Japan-GLOBEC Symposium on Development and Application of New Technologies for Measurement and Modeling in Marine Ecosystems

12:00-13:00 Lunch

Plenary Session Chairman: Dr. Ji-Lan Su

13:00-15:00 Discussion Group reports (Discussion Group Chairmen)

15:00-15:30 Break

Closing Ceremony Chairman: Prof. Warren Wooster

15:30-15:50 Japan-GLOBEC Symposium summary (Prof. Makoto Terazaki)
15:50-16:10 Workshop summary (Dr. Ian Perry)
16:10-16:20 Speech by Vice-Chairman of Nemuro Supporting Committee
16:20-16:30 Closing remarks (Prof. Warren Wooster)
18:00-20:00 Informal Science Board meeting (closed)

APPENDIX 4. PARTICIPANTS

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BASS WORKPLAN

Introduction

The Basin Studies Task Team will facilitate the exchange of scientific data and encourage scientific research relating to the implementation of the PICES Science Plan. In general, the oceanography and ecology of the eastern and western basins of the subarctic Pacific are poorly understood relative to the coastal areas. It is known that the central subarctic Pacific is productive as indicated by the large abundance of Pacific salmon, squid and other important fishes. Recent studies also suggest that the oceanography of the gyres is closely linked to the decadal scale changes in climate. It is important, therefore, that there is a coordinated effort to focus on the priority research issues and to exchange scientific information on a timely basis.

In developing the BASS work plan, we noted that the science plan of the North Pacific Anadromous Fish Commission is closely associated with the climate change and carrying capacity program of PICES. The NPAFC Science Panel is formatted to identify research on the life history of Pacific salmon, salmon population dynamics, and on the habitat and ecosystem of salmon. It is the research relating to the habitat and the ecosystem of salmon that is most closely related to the immediate plans of the PICES, CCCC Program. NPAFC identified three areas of interest, physical-biological interaction and productivity, climate change effects and regime effects. While the NPAFC Science Plan is focused on salmon and the PICES, CCCC Program addresses the broader, ecosystem interactions, it is clear that both plans are inter-related and mutually supportive.

BASS, therefore must ensure that the results of all research activities are distributed as quickly as possible. To do this will require developing a system of identifying research activities.

BASS had its first meeting during the Fourth Annual PICES Meeting in Qingdao, China, when an agreement on organization and general objectives was achieved. The task of BASS is to facilitate studies of the impacts of climate change and climate variability on the physical and biological processes in the gyres of the western and eastern subarctic Pacific Ocean. In general, it can be considered that these processes drive the shelf processes that impact on coastal marine resources.

The objective of the CCCC Program is to identify the impacts of climate change on the ecosystems of the subarctic Pacific. A key component to understanding this linkage is the relationship between plankton production and the production at higher trophic levels. The CCCC Program incooperation with other national and international programs, provides a unique opportunity to understand the mechanisms that affect the carrying capacity for species within the two gyres and in the coastal areas of the member countries. The key scientific questions are as follows:

- Physical forcing: What are the characteristics of climate variability and 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, distributions, vital rates, and population dynamics of higher trophic level species respond directly and indirectly to climate variability?

- Ecosystem interaction: How are subarctic Pacific ecosystems structured? Do higher trophic levels respond to climate variability solely as a consequence of bottom up forcing? Are there significant intra-trophic level and top down effects on lower trophic level production and on energy transfer efficiencies? The key research activities were identified as (1) retrospective analyses; (2) development of models; (3) process studies; (4) development of observations systems; and (5) data management.

At this second meeting of BASS, we invited other participants of the MODEL Workshop to help develop an action plan that was achievable and would facilitate the implementation of the CCCC Program.

The approach of BASS was to identify the following tasks and seek the support of the Implementation Committee and Science Board to ask the member countries to facilitate the involvement of their scientists. BASS noted that it may be necessary for the Science Board to consider that a specific plan of action may need to be approved for the subarctic gyres because countries tend to focus their research within their coastal areas.

BASS developed a work plan consisting of some general, longer-term goals and some specific action items. The long-term plan is intended to be a general indication of the activities over the next 5 years and the short-term plan is the work expected to be completed each year. The plans are overly ambitious and lack specific commitment from the participating countries, however they provide background information for any group or country planning research in the subarctic Pacific. The annual plans will require a considerable effort, and will succeed if all BASS members in particular, and PICES participants in general, can assist in the management of the plans.

Long-term (5 year) Plan

1. Retrospective comparison of lower trophic level dynamics in the eastern and western subarctic gyres: a link between climate change and higher trophic levels.

Lower tropic level dynamics have been well studied and modeled for Station P in the eastern gyre (SUPER references 1993). Sufficient data may now exist for comparison with the western subarctic gyre (Taguchi 1995, PICES Report No. 3). Comparisons of seasonal data for nutrient dynamics, Chlorphyll and zooplankton standing stocks, and sedimentation of C and N should provide insights into factors controlling total and exportable production and how these factors are affected by climate change. Important questions include:

i. Is there sufficient data available from representative sites in each gyre for this comparison?
ii. Are there significant differences between the gyres in seasonable changes of these parameters?
iii. If so, what are the implications for factors controlling total and exportable production at each site?
iv. What are best sites for long-term observations and process studies?

Maximum exportable (sedimentation or transfer to higher trophic level) production is set by the seasonal utilization of nitrate by phytoplankton. Differences between seasonal nitrate use and accumulation of nitrogen in biomass (LTL) and sinking flux indicates the amount of nitrogen that can be passed on to higher trophic levels. Preliminary comparison of the data sets are shown in Table 1.

Table 1. Seasonal changes in nitrate and LTL nitrogen pools.

	Western Gyre	**Alaskan Gyre**
Nitrate	18 uM	6 uM
Phytoplankton-N	4.95 uM	0.1 uM
Zooplankton-N	2.82 uM	0.6 uM
Sinking PON	low?	low
HTL	10 uM	5 uM

Differences between the sites (and possibly long-term climate affects) may be due to physical forcing features which affect mixed layer depth or atmospheric inputs of iron.

We propose to complete a review of nitrate concentrations which would include a comparison of the physical regime at both gyres.

Contacts for existing data sets:

Alaskan Gyre	U.S.A.	SUPER Program
	Canada	JGOFS Program
Western Gyre	Japan	Taguchi - phytoplankton & primary production
		Ikeda - zooplankton
		Koike - N and C Budget

2. Zooplankton standardization

A major barrier for both retrospective analyses and on-going process/monitoring studies is the lack of standardization of sampling equipment and methodology for zooplankton sampling. We propose to resolve these differences by:

i. identification of important datasets of zooplankton abundance for the eastern and western gyre (with assistance of TCODE).
ii. documentation of sampling methodologies used in these datasets.
iii. development of conversion algorithms and guidelines for their application. This may involve new sample collections using different gear and methods.
iv. develop recommendations for common sampling equipment and methodologies for mesozooplankton for use in the PICES region.

3. Time series measurements of primary productivity and zooplankton stocks

Time-series measurements of primary productivity and zooplankton stocks in the open ocean sector of the subarctic Pacific are required to better understand the relationship between changes in plankton populations and changes in the physical-chemical environment. A long time-series (1952-1981) of weathership data in the eastern subarctic Pacific was obtained at Ocean Station P (50 N 145 W). These data show chlorophyll levels varying between relatively narrow limits of 0.15 - 0.75 mg/m (Wong et al., 1995) which indicates phytoplankton stocks are nearly constant through the year even though there is a strong annual cycle in primary productivity. Miller (1993) has suggested that the lack of a strong seasonal cycle in phytoplankton stock can be explained by the variation in the intensity of grazing by zooplankton. However the Station P data are suitable for demonstrating whether variations in zooplankton stocks are related in some direct fashion to primary productivity. There are no comparable time series data from the western subarctic Pacific that can be used to study the variability of phytoplankton/zooplankton stocks. Higher production rates and greater zooplankton standing stocks are thought to occur in the western subarctic Pacific. It is anticipated that the relationships in the western Pacific will be different because the physical conditions there differ markedly (deep mixed layer).

The BASS Task Team recommends that PICES promote the installation of robust instrumented surface moorings in the subarctic Pacific which are capable of providing well-calibrated data on phytoplankton standing stock, primary productivity, dissolved inorganic nutrient concentration and zooplankton biomass. Additional physical variables will be measured which will be useful in interpreting the relationships. Appropriate sensors are available, or are under active development, to measure these variables. A minimum measurement program would be to place one mooring at the centers of the Alaska and Western Pacific Subarctic gyres. Comparison of the two data sets should document the dynamics of the variability of the phytoplankton and zooplankton stocks in the two regions. There also is a strong argument for a mooring at the site of Station P because of the valuable historical climatic record which exists there. The moorings should be maintained long enough to document interannual variability and hopefully a "regime shift".

4. Inventory of higher trophic level species

It is difficult to consider the impact of physical changes in the two gyres because it is not possible to identify easily the higher trophic level residents. As part of the initial effort of standardizing data and building data bases, BASS will identify the key higher trophic level species, produce brief life histories and provide data from fisheries. Data will be assembled from as far back as possible, but the focus will be to identify the current species composition.

5. BASS will need to acquire the work or science plans of all agencies carrying out research in the eastern and western gyres. As part of the annual report of BASS, the proposed and completed research should be identified.

Short-term plan

BASS is recommending that a series of theme papers on the dynamics of the ecosystems in the eastern and western gyres of the subarctic Pacific be produced. Each theme paper would be produced by at least one North American and one Asian author, possibly with an author from each country. One author would coordinate the writing of the paper and summarize the results at a one-day symposium to be held at the PICES Annual Meeting in 1997.

Title: "Ecosystem Dynamics in the Eastern and Western Gyres of the Subarctic Pacific".

Co-convenors: Warren S. Wooster (U.S.A.), Richard J. Beamish (Canada), and Makoto Terazaki (Japan), Suam Kim (Korea)

1. Ocean Responses
2. Climate Forcing
3. Nutrients and Primary Production:
4. Remote Sensing
5. Sediment Traps
6. Microplankton Biomass and Composition
7. Netplankton Biomas and Composition
8. Model of Phytoplankton Production Dynamics
9. Salmon
10. Common Fish
11. Nekton
12. Marine Mammals and Birds

Future Short-term Issues

1. Retrospective comparison of lower trophic level dynamics in both gyres.
2. Zooplankton standardization will be covered jointly with REX 1997.

REX TASK TEAM RECOMMENDATIONS

Introduction

An implementation plan (PHASE 1) for the Climate Change and Carrying Capacity (CCCC) program was presented at the fourth annual PICES meeting in Qingdao, China (PICES Scientific Report No. 4). During the annual meeting, the Executive Committee (EC) of the Implementation Panel (IP) recommended and approved the formation of the REX (Regional Experiment) Task Team. The REX Task Team is responsible for developing a plan for inter-comparison of regional studies, as proposed in the implementation plan. This document contains the REX research plan.

Regional Components:

The CCCC Science Plan (PICES Scientific Report No. 4) identifies 10 regional components of the Climate Change and Carrying Capacity program:

1. California Current System, south
2. California Current System, Oregon to Vancouver Island
3. Southeast, 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 Sea
10. East China Sea

The CCCC Science Plan calls for comparative studies of ecosystems along the continental margins of the subarctic Pacific. These regional scale ecosystem studies should compare how variations in ocean climate affect species dominance and fish populations at the coastal margins of the Pacific Rim. Several national programs are underway or have been proposed for most of these regions (PICES Scientific Report No. 4).

Common Set of Program Outputs

The implementation plan identified a common set of program outputs required for successful comparison of ecosystem properties and responses to climate variability embodied in the following four Central Scientific Issues.

1. Physical forcing: What are the characteristics of climate variability; can interdecadal patterns be identified; how and when do they arise?
   - Location of major fronts/current boundaries
   - Atmospheric pressure gradients (winds and storms)
   - Air-sea heat exchange (insolation, cloud cover)
   - Major physical features (e.g., fresh water input, ice)
   - Mixed layer temperature (MLT), depth (MLD)
   - Velocity of major currents
   - Eddies
   - Vertical and horizontal mixing, fine structure
   - Nutrients in MLD and / or pycnocline

2. 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 North Pacific?
   - Annual and seasonal productivity
   - Temporal and spatial pattern of plankton dynamics and nutrient fields
   - Identification of major taxonomic groups
   - Population parameters for key species (or taxonomic groups)

3. Higher trophic level response: How do life history patterns, distributions, vital rates, and population dynamics of higher trophic level species respond directly and indirectly to climate variability?
   - Abundance trends and distributions of life stages of key species and their predators and prey
   - Population parameters (growth, mortality, reproduction)

- Food web structure (including diets and trophodynamic linkages of key species)
- Production and productivity structure

4. Ecosystem interactions: How are North Pacific ecosystems structured? Do higher trophic levels respond to climate variability solely as a consequence of bottom-up forcing? Are there significant intra-trophic level and top-down effects on lower trophic level production and on energy transfer efficiencies?

The REX Task Team identified two outputs that could be added to items that could be added to the list above.

- Species diversity of lower trophic and higher trophic level organisms (under items 2 and 3 above).
- Total lower trophic level production available for higher trophic level consumers (under item 2 above).

These data outputs are required as data inputs to ecosystem models, indicators of mechanisms, or will serve as parameter estimates for models. The phase/ function of these outputs in research activities should be specified. The REX Task Team will work with the PICES Technical Committee on Data Exchange (TCODE) to review the availability of information for each of the program outputs and to provide access to existing sources.

Terms of Reference

A principal purpose of the REX Task Team is to promote the intercomparison of regional experiments. To accomplish this goal REX must strive to ensure that a common set of outputs is produced that will form the basis of meaningful inter-regional comparisons. The proposed terms of reference for the REX Task Team include:

1. The REX Task Team will be responsible for promoting and coordinating research activities related to the CCCC program among member nations. This goal could be accomplished by convening meetings or distributing information designed to foster cooperation among existing or developing programs;
2. The REX Task Team will foster communication among PICES members regarding advancements in scientific method or research findings. This may be achieved through written communi-cations (e.g. newsletters, home pages, or e-mail communi-cations), and by convening periodic scientific symposiums or workshops. Communication and data exchange that will be coordinated jointly through REX and TCODE;

3. The REX Task Team will encourage establishment of component programs where needed;

4. The REX Task Team will identify linkages between regional studies and basin scale studies; and

Among these, 1 and 2 will benefit component programs of REX, and 3 and 4 will be CCCC specific activities.

Recommended Regional Experiments

The design and implementation of research activities in coastal regions of the PICES area is determined by the national research programs of each member nation. The role of the REX Task Team is to identify aspects of the national programs that would benefit from coordination with other PICES member nations. The following activities are recommended to provide data sets that could be utilized for inter-regional comparisons. They are broken into four major research activities: monitoring, retrospective studies, modeling and process oriented studies. In all cases, communication between nations will be required to ensure that the data collections are made in a consistent manner using a standardized research protocol that is agreeable among member nations.

MONITORING

Monitoring programs are needed to acquire observations of physical, chemical and biological aspects of the environment to support investigations of interannual variability over an extended period of time. Activities recommended in this section should be considered in conjunction with the PICES Monitoring Working Group (WG 9). PICES WG 9 is responsible for planning the monitoring activities in the PICES area. WG 9's activities will include proposing scientific and technical priorities and schedules, and designing methods to collect physical, biological and chemical measurements (PICES Scientific Report No. 3). The design and implemen-tation of the PICES-GLOBEC CCCC monitoring program should be coordinated with existing international planning efforts of outside agencies such as the Ocean Observing System Development Panel (OOSDP) and Global Ocean Observing System (GOOS).

Transects

Observations of physical and biological parameters should be made along a few key cross-shelf transects (sampled every other month, and more frequently during critical periods). This approach was proposed by the Subarctic Working Group (WG 6) (PICES Scientific Report No. 1). The bimonthly sampling interval may be inadequate to resolve the dynamics of the shorter lived zooplankton that are potential prey of the higher trophic level species. A study could be conducted to determine the sampling frequency required to capture low frequency variations in ocean conditions. The following measurements could be made at the cross-shelf transects: 1) current speed and direction, 2) temperature and salinity profiles, 3) measurements of nutrients, 4) chlorophyll concen-tration and particle size distribution, 5) micro and macro zooplankton abundance and species composition, 6) micronekton collections. Current speed and direction could be measured using Acoustic Doppler Current Profiler (ADCP). Temperature and salinity data should be collected using hull mounted probes and regularly spaced CTDs. Chlorophyll measurements would occur using a fluorometer or a spectrophotometer (such as a chlorophyll absorption meter) which would be dropped at each CTD station. Zooplankton abundance would be continuously monitored using multi-frequency acoustics. Net sampling would occur to verify acoustic sign types and to establish the species composition.

It should be noted that observations along repeated lines are presently being collected by most of the PICES member nations. We encourage these nations to continue this effort, and promote efforts to expand current sampling to include collection of biological data.

Moorings

The detailed transect data should be complemented with continuous time series ADCP, acoustics, bio-optics, and physics measured from a small number of moorings, to prevent aliasing of the data, and to capture large spatial amplitude events that occur during the interval between transects. It is desirable for these moorings be equipped to measure acoustic backscatter, preferably at multiple frequencies, to provide an estimate of zooplankton biomass (and perhaps size), light and fluorescence sensors (to measure phytoplankton stocks), and sensors to measure nutrients. Sediment traps might also be placed near moorings to monitor production cycles and to measure the amount of production energy that reaches the sea floor. Inflow through narrow passages could be effectively monitored by measuring electro-magnetic current along submarine telephone cables.

Whenever possible moorings should be placed in "pulse" points to capture key ecosystem features. Pulse points are locations that exhibit characteristics that have historically indicated, or significantly influenced, the status of marine ecosystems. Pulse points may be located at the confluence or bifurcation of major current systems. Pulse points can also be located in regions occupied during key life history stages of the target species (e.g. spawning locations of major fish species).

Remote Sensing

Remote sensing could be used where possible to measure surface productivity and mesoscale ocean features. Geostrophic currents or their variability can be resolved using satellite altimetery. Likewise ocean color can be used to monitor surface productivity and ocean temperature. Measures of wind stress, sea ice extent and insolation can also be measured using remote sensing equipment. While collection of this information will not be an activity, the analysis of such data will be a necessary activity of scientists participating in the CCCC program.

Satellite-tracked buoys

Satellite-tracked buoys should be deployed at a few pulse points to resolve mesoscale circulation features (eddies) and to resolve the flow direction and speed. These measurements will be utilized to ground truth physical models of the coastal regions.

Freshwater Runoff

In northern regions, freshwater inflow has a strong impact on the upper mixed layer of coastal ecosystems. Knowledge of the salinity distribution is required to provide accurate estimates of the geostrophic transport in the region. Direct measures of freshwater runoff (stream gauges) or indices of freshwater runoff should be developed for the CCCC program.

Acoustic Trawl / Bottom or Mid-water Trawl Fish Surveys, and Commercial Fisheries Monitoring

The agencies and universities of many nations conduct bottom - trawl and/or hydroacoustic midwater trawl surveys of the coastal regions of the North Pacific. These surveys provide an excellent opportunity to enhance the CCCC monitoring effort. In addition, member nations often monitor the age composition, length, weight and maturity of fish obtained from samples of commercial fisheries catch.

PICES Coastal Pelagic Fishes Working Group (WG 3) made several recommendations regarding the use of data collected on major fish stocks (PICES Scientific Report No. 1). Many of these recommendations are relevant to the PICES CCCC program and should be included in the design of the regional experiments. Fishery information should include the following annual data: stock size, commercial catch, and recruitment estimates, estimates of size at age and weight at age. Survey data should provide information on the distribution, species composition and abundance of fish.

Information on populations of seabirds and marine mammals is needed for the CCCC program. Some nations monitor seabird and marine mammal populations. Likewise information on the diet and size or weight of seabirds and pinniped populations is often collected. More detailed information on the foraging behavior of pinnipeds could be collected by placing satellite transmitters on animals.

Vital Biological Rates

A considerable amount of information regarding the relative health of the ecosystem can be inferred from analysis of vital rates such as annual and daily growth (length and weight), maturation schedules, fecundity, and birth/spawn dates. Collection of this type of information should be conducted whenever possible to provide time series for comparative studies. More detailed information regarding the relative health of an organism can be obtained from histological comparisons of tissue samples or studies of RNA/DNA ratios.

Ships of Opportunity

Ships of opportunity should be used to expand geographic coverage beyond that of the transect and mooring locations. Ships of opportunity could be equipped with automated flow through systems that allow underway sampling. These automated devices would enable the collection of measurements of temperature, salinity, chlorophyll-a, nitrate, pCO_2, total CO_2, and pH. TCODE and the PICES Secretariat plan to accumulate information on cruise schedules for each member nation. These schedules should have include information required to facilitate coordination in multi-national ecosystem monitoring.

Large-scale monitoring

Large scale physical monitoring is needed to evaluate how variability in atmospheric forcing influences ocean conditions. Key measurements would be the position and strength of major storm tracks, pressure gradients and derived winds, circulation and water mass characteristics of the CCCC region. This is needed to document the effects of large scale forcing on the productivity of the coastal systems, and on the distribution, growth and survival of upper trophic level organisms and their prey in the coastal environment. Monitoring of the entire subarctic Pacific basin will require a coordinated multinational effort and should include input from the BASS Task Team of the PICES CCCC IP. Large scale physical monitoring would be achieved through a combination of remote sensing, and atmospheric models. The large-scale circulation of the North Pacific could be examined using a combination of PALACE floats, satellite track drifters and satellite altimetry. PALACE floats are programmed to follow a density surface (perhaps at 800-1000 m depth). Periodically they are programmed rise to the surface, allowing the collection of high-quality temperature, salinity and pressure profiles. Hydrographic data is transmitted via ARGOS transmitters while the floats are at the surface.

RETROSPECTIVE STUDIES

The PICES CCCC Science Plan (PICES Scientific Report No. 4) defines retrospective studies as analyses of existing atmospheric, physical, biological and paleoceanographic data, to identify recent (and historical) changes in the subarctic Pacific. Retrospective studies are a high priority for the CCCC program. They are necessary to refine hypotheses regarding climate influences on marine ecosystems. Retrospective studies will also assist in the design of comparative studies between regions. Nine activities are recommended in the Science Plan.

1. Examine atmospheric and physical oceanographic time series in eastern and western Pacific to determine if regime shifts occurred and if these shifts were synchronous across the North Pacific.

2. Examine long-term plankton and fisheries records from the eastern and western Pacific for shifts in species composition and biomass changes, and determine if these changes are synchronous on both sides of the Pacific.

3. Analyze plankton and higher trophic level carnivore biomass data from the North Pacific ecosystems to determine the average slope and intercept of the biomass spectra for different ocean regimes.

4. Examine the statistical evidence for a link between variations in ocean conditions, plankton, and catches of key fish stocks, and investigate the relationship between fish catches and total production, or recruitment.

5. Reconstruct interdecadal- through- centennial scale variability in biological populations and associated environmental changes for the past two millennia.

6. Examine historical variations in salmon growth through the analysis of their scale patterns.

7. Conduct comparative studies of somatic growth of fish populations around the Pacific Rim.

8. Compare the dynamics of coastal fish stocks of the North Pacific.

9. Examine how physical forcing affects the subarctic Pacific marine mammal (e.g. harbor seals and sea lions) and seabird populations via changes in the abundance and availability of their food.

Implementation of many of these studies, and studies like them, is dependent on: identifying principal data sources that could be utilized, obtaining the data sets required, and evaluating the methods used to collect the historical data sets to enable standardization. These tasks should be coordinated with the on-going efforts of TCODE. Efforts to reconstruct historical time series of fish populations through analysis of sediment cores will require a multi-national effort to locate regions where anoxic sediments exist.

We recommend that REX should cooperate with other programs to facilitate the exchange of methods, data and results. For example, the GLOBEC International - Small Pelagic fish and Climate Change (SPACC) program recently recommended that comparative studies on the variability and production of sardine and anchovy should be initiated. These comparative studies will be relevant to the REX Task Team.

MODELING

The PICES CCCC Science Plan calls for four types of modeling activities:

1. Develop a variety of foodweb formulations representing the appropriate dynamic ecosystem properties of interest to PICES-GLOBEC.

2. Combine the various formulations of foodweb models in one-dimensional mixed layer models forced by surface wind, heat and moisture exchanges typical of the subarctic Pacific, on time-scales from hours to years.

3. Combine mixed layer dynamics and foodweb models in the three dimensional circulation models, and run retrospective simulations of the last 30-50 years with observed atmospheric inputs.

4. Develop second generation models to generate projections of physical and biological responses to possible future climate variation and large scale environmental change.

International coordination of model development will be facilitated by the CCCC MODEL Task Team. The MODEL Task Team convened a workshop in Nemuro Japan in June 1996. During this workshop several ongoing modeling activities outside of PICES were identified. Efforts to encourage the use, or modifi-cation, of existing models to address the scientific issues relevant to the REX Task Team will be an important goal.

PROCESS ORIENTED STUDIES

Process oriented studies must be developed after the key species of study have been identified. Key species have been identified in only a few GLOBEC proposals. Once target species have been noted, REX will attempt to identify research approaches that would facilitate regional comparisons.

RECOMMENDATIONS

1. We recommend that a community outreach subcommittee should be established. This sub-committee will be responsible for reviewing the science plans and program objectives of GLOBEC-like programs to identify the potential for cooperative research.

2. Comparative retrospective studies are critical for the success of the REX Task Team. Retrospective studies could be initiated immediately because they do not require large financial commitments from the member nations. Data sets must be made available to scientists from the member nations in order to accomplish this goal. REX recognizes that TCODE has the responsibility for obtaining, assembling, and documenting data series that could be used in the retrospective studies. The REX Task Team strongly encourages TCODE to place high priority on accomplishing this responsibility.

3. The REX Task Team, in consultation with the BASS Task Team and WG 9 propose a workshop to be convened prior to the PICES Annual Meeting in 1997. The purpose of the workshop will be to: a) identify and prioritize desired retrospective and process oriented research programs that could be conducted to allow regional comparisons; b) standardize plankton sampling methods; c) identify key species within the 10 REX regions; and d)

identify methods for monitoring the distribution and abundance of selected species.

Prior to the meeting a background document will be prepared. These background documents should include summaries of GLOBEC-like programs including the key scientific hypotheses being addressed. Summaries of existing biological and physical datasets or models (e.g. ECOPATH, individual based models or circulation models) will also be prepared. These data summaries will be obtained in coordination with TCODE. Preferably, summaries of existing data will be presented in tabular form to illustrate areas where monitoring systems may be required. Participants will be expected to be ready to propose comparative studies at this meeting.

Tentative Workshop Schedule:

Day 1

08:00-08:20 Morning Introductions

08:20-12:00 Breakout sessions by higher trophic level species groups. The breakout groups will be responsible for identifying comparative projects of the following types: retrospective studies, observing programs, modeling studies, and process studies.

12:00-13:00 Lunch

13:00-15:20 Continuation of breakout discussions

15:20-15:40 Break

15:40-17:00 Plenary session: review of recommendations for comparative studies for higher trophic level species.

Day 2

08:00-12:00 Breakout sessions: physical oceanography, lower trophic level response, and modeling.

12:00-13:00 Lunch

13:00-15:00 Continuation of breakout sessions.

15:00-15:20 Break

15:20-16:20 Plenary session: review of recommen-dations for comparative studies.

16:20-17:00 Future actions of REX

Each Breakout group will be asked to accomplish the following tasks:

- Develop a list of recommended comparative studies.
- Recommended standard methods for data collection and analysis.
- Identify programmatic needs required to conduct comparative studies.
- Identify regions where these comparative studies could be initiated.