Global Ocean Ecosystem Dynamics
Implementation Plan
Global Ocean Ecosystem Dynamics (GLOBEC) Implementation Plan

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Implementation Plan

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Cover Illustration: The front cover photographs illustrate major components of GLOBEC research; the interactions between, clockwise from the top left, physical oceanography, zooplankton, climate and fish populations.

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EXECUTIVE SUMMARY

This document describes plans for the implementation of the Global Ocean Ecosystem Dynamics (GLOBEC) programme element of the International Geosphere-Biosphere Programme (IGBP). This Implementation Plan is an international response to the need to understand how global change, in the broadest sense, will affect the abundance, diversity and productivity of marine populations comprising a major component of oceanic ecosystems.

The Plan describes the consensus view, developed under the auspices of the GLOBEC Scientific Steering Committee (SSC), on the research required to fulfil the scientific goals laid out in the GLOBEC Science Plan (IGBP Report No. 40). The Implementation Plan expands on the Science Plan, drawing on the results and recommendations of workshops, meetings, and reports thereof, that have been sponsored under the auspices of GLOBEC.

The GLOBEC research programme has four major components which, are described in detail in this Implementation Plan; the research Foci, Framework Activities, Regional Programmes, and Integrating Activity. These are summarized in the Table of Contents, and in schematic diagrams within the text. They are the elements that have been planned by, and will be implemented under the auspices of, the GLOBEC SSC. National GLOBEC programmes may select those aspects of this international framework which are relevant to meeting national objectives, or they may develop new directions as needed to meet specific national needs.

Firstly the four research Foci, which form the core of GLOBEC research, are described:

Focus 1: Retrospective analyses and time series studies
Focus 2: Process studies
Focus 3: Predictive and modelling capabilities
Focus 4: Feedbacks from Changes in Marine Ecosystem Structure.

For each Focus, major Activities are identified and described. The Activities are broken down into a series of initial Tasks, but the lists of Tasks are not intended to be complete; they are indications of the types of research projects which would lead to progress in each area of GLOBEC research.
The Implementation Plan then goes on to describe a series of Framework Activities, which are “cross-cutting” efforts requiring international coordination. They include, sampling and models: protocols and inter-comparisons, data management, scientific networking and capacity building.

GLOBEC is currently implementing four major regional research programmes and plans for these are outlined. The four programmes are the Southern Ocean GLOBEC (SO-GLOBEC) programme, the study on Small Pelagic Fishes and Climate Change (SPACC), the Cod and Climate Change (CCC) programme in the North Atlantic Ocean which is cosponsored by the International Council for the Exploration of the Sea (ICES), and the programme on Climate Change and Carrying Capacity (CCCC) of the North Pacific Marine Science Organisation (PICES).

After a description of the plans for these regional programmes, the Implementation Plan concludes with a preliminary consideration of how the observations and results from the various pieces of the GLOBEC programme will be drawn together and integrated to develop a global synthesis. This Integrating Activity aims towards a GLOBEC synthesis, and focuses on ecosystem comparisons.

GLOBEC is cosponsored by the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC) of the UN Educational, Scientific and Cultural Organization (UNESCO).

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INTRODUCTION

“Natural variability, occurring over a variety of time scales, dominates the health of complex marine ecosystems, regardless of fishing or other environmental pressure. We are only now beginning to compile quantitative documentation of such variability, and consequently our knowledge concerning its causes remains at the level of hypotheses. Understanding of the role of variability in the function of marine ecosystems is essential if we are to effectively manage global marine living resources such as fisheries during this period of tremendously increased human impact, and concurrent dependence, on these resources.”


GLOBEC, a study of Global Ocean Ecosystem Dynamics, was initiated by SCOR and the IOC of UNESCO in response to the recommendations of a joint workshop which identified a need to understand how global change, in the broadest sense, will affect the abundance, diversity and productivity of marine populations comprising a major component of oceanic ecosystems.

GLOBEC soon developed a focus on zooplankton - the assemblage of herbivorous grazers on the phytoplankton (which is a focus of the Joint Global Ocean Flux Study (JGOFS) and the primary carnivores that prey on them; both groups, in turn, are the most important prey for larval and juvenile fish. Thus, the zooplankton form an important route for the transport of carbon through the marine ecosystems by processing photosynthetically produced organic matter and passing it up the food web to the higher trophic levels, and down through the water column in the form of faecal pellets and excretion products. In addition, because of their critical role as a food source for larval and juvenile fish, the dynamics of zooplankton populations, their reproductive cycles, growth, reproduction and survival rates are all important facets influencing recruitment to fish stocks. Planktonic organisms are especially sensitive to physical processes such as currents, turbulence, and light and temperature regimes. Inevitably, variability in these physical processes must affect the stability of biological processes.
The GLOBEC Goal

The SCOR/IOC workshop gave detailed attention to these scientific issues, recommended the establishment of an international scientific programme, and reached a consensus on the overarching goal for GLOBEC which was later developed together with the IGBP and justified in the GLOBEC Science Plan. This document represented a major milestone for the GLOBEC programme and was submitted to the Scientific Committee for the IGBP (SC-IGBP) for consideration. Recognizing the importance of an understanding of the sensitivity of marine ecosystems to global change, the IGBP adopted GLOBEC as an element in its international global change effort.

The primary goal for GLOBEC is:

“To advance our understanding of the structure and functioning of the global ocean ecosystem, its major subsystems, and its response to physical forcing so that a capability can be developed to forecast the responses of the marine ecosystem to global change”.

GLOBEC considers “global change” in the broad sense to encompass the gradual processes of climate change as a result of greenhouse warming and their impacts on marine systems, as well as those shorter-term changes resulting from anthropogenic pressures such as population growth in coastal areas, increased pollution, overfishing, changing fishing practices and changing human uses of the seas.

The rationale for the GLOBEC goal is laid out in detail in the Science Plan (GLOBEC Report No. 9 / IGBP Report No. 40) which also specified four detailed scientific objectives, dividing the overall goal into several components:

Objective 1 To better understand how multiscale physical environmental processes force large-scale changes in marine ecosystems

Physical conditions over a broad range of scales in the sea, both vertical and horizontal, influence marine ecosystem processes. At the very smallest scales, those where turbulent dissipation occurs, water motions, over distances of a few cm and over a few seconds, are known to influence predator-prey interactions among planktonic organisms. Moving to the mesoscale, encompassing distances of kilometres to tens of kilometres, the possible physical influences on biological processes become more extensive. Strong currents associated with mesoscale features, such as coastal or shelf break currents, can transport planktonic organisms over great distances. Organisms may become trapped in mesoscale eddies and isolated from their original environment and their customary food supply. Water motion (upwelling or downwelling) associated with jets or eddies can lead to significant variations in physical and chemical characteristics of the water and in turn lead to changes in prey availability. Finally, large-scale changes in circulation or in physical or chemical water characteristics can alter the basic environmental conditions for organisms, leading, in extreme cases, to mortality and changes in species composition.

Many interactions between organisms and their physical environment are neither well-documented nor understood in a qualitative sense. As an example, patchiness in space and time has long been known to be characteristic of marine populations. While it is suspected that such patchiness is related to oceanic mesoscale features, biological processes, and physical-biological interactions, observations adequate to
determine causes are lacking. The same is true for observations of the very small scale interactions. Knowledge of these processes, both from an observational and a modelling viewpoint, is essential if the GLOBEC goal is to be achieved.

**Objective 2**

To determine the relationships between structure and dynamics in a variety of oceanic systems which typify significant components of the global ocean ecosystem, with emphasis on trophodynamic pathways, their variability and the role of nutrition quality in the food web.

Carbon flux pathways through marine ecosystems provide a valuable framework for estimating productivity at different trophic levels. However, it is extremely difficult to quantify the flows of carbon in food web networks. A much more sensitive indicator or predictor of change is alteration in species composition. An example can be taken from fisheries. For many of the dramatic changes in fish communities, there has been no associated evidence of changes in overall trophic energy flow. The past focus of fisheries studies has been on changes in individual stocks rather than on the competitive or predatory interactions among these stocks. Yet, these interactions must determine the ability of marine systems to experience major changes in species structure without any obvious changes in the energy flow through them. This is a significant difference between marine and terrestrial systems undergoing changes at these time scales.

The general or “global” problem is to describe the relationships between food web structure and trophic dynamics for ecosystems that represent the major marine environments that are representative of upwelling, coastal, oligotrophic ocean, and polar seas.

**Objective 3**

To determine the impacts of global change on stock dynamics using coupled physical, biological and chemical models linked to appropriate observation systems and to develop the capability to predict future impacts.

Models are an essential component of GLOBEC, and the strategy for their development is central to the Core Programme. Four features must be incorporated into this strategy. First, critical variables need to be identified. Second, models must focus on appropriate time and space scales (Figures 1 and 2). Third, interactions among scales must be addressed. Finally, consistency between data and model results must be tested; interaction of theory (models) and observations (experiments) is critical to the approach. Model development will be driven by observations and field programmes will be designed by taking model results into account. Throughout there will be careful regard for the degree of model complexity required to attack the problems relevant to GLOBEC.

GLOBEC modelling employs selection of the oceanic mesoscale as its fundamental scale, or starting point, with sufficient extension to provide information on interactions with larger and smaller scales. The modelling effort must resolve ecosystem dynamics and effects of physical forcing on these dynamics at the mesoscale. This will require incorporation of information from other scales.
Figure 1

Important temporal and spatial scales over which particular physical and biological models apply. Modified after Murphy et al. 1993. (From EUROGLOBEC Science Plan, 1998)
Three themes contribute to the foundation of the mesoscale modelling programme;

- The role of mesoscale physics in modulating ecosystem processes
- The dynamics of populations of copepods and other metazoan plankton
- Linking the dynamics of copepods and other metazoan plankton with fishery dynamics.

The linkages among physical conditions, marine food web structures and ecosystem or population dynamics provide a unifying theme for GLOBEC. An example of the coupling between physics, structure and population dynamics is provided by microbial loops, processes that are now recognized as important factors in ocean ecosystem dynamics. Microbial loops influence nutrient supply but are in themselves dependent upon vertical density stratification, which also influences the nutrient supply. The interactions are complex. Variations in the physical system will be reflected by changes in the trophic structures, hence, ultimately in fishery dynamics. From another viewpoint, this structure highlights the importance of metazoan plankton as key links between processes involved in nutrient recycling and the population dynamics of higher trophic levels.
Changes in the physical and biological properties of very large scale marine ecosystems, such as those having ocean basin scale, are so extensive, and impact such a large portion of the world ocean, that they themselves can be considered as global changes. Moreover, by virtue of their geographic extent, they have the potential to influence other components of the earth system. Shifts in ecosystem composition at higher trophic levels can cause changes in the phytoplankton assemblage or standing stocks, and vice versa. These changes can in turn affect the transport of gases across the sea surface because photosynthetic efficiencies and physiologies of phytoplankton species vary. Such shifts and the associated potential feedback are of particular interest to two other IGBP projects, JGOFS and IGAC. A change in phytoplankton composition can also affect CO₂ exchange through mineralization processes and bring about the release of other gases, such as dimethyl sulphide, to the atmosphere with implications for atmospheric acidity and particle formation.

Objective 4 To determine how changing marine ecosystems will affect the global earth system by identifying and quantifying feedback mechanisms

Other, direct effects of marine ecosystem changes include the impact that changes in commercial stocks have on coastal human populations. GLOBEC research on the response of small pelagic fish populations to climate change in the coastal zone will be of particular interest to LOICZ. GLOBEC can identify a number of the significant processes and will cooperate with other IGBP projects in pursuing an answer to the question of how changing marine ecosystems will influence the overall earth system.

GLOBEC Implementation

In moving toward the fulfilment of these scientific objectives, a GLOBEC research strategy was defined by the SSC. This strategy was set out briefly in the GLOBEC Science Plan in the form of four Research Foci. These have now been developed in much more detail with a series of Activities and sub-sets of specific Tasks under each Focus.

Accordingly, this Implementation Plan for GLOBEC describes fully the consensus view, developed under the auspices of the GLOBEC SSC, on the foreseeable aspects of the research required to fulfil the scientific goals laid out in the GLOBEC Science Plan. The Science Plan explains why specific questions need to be answered. This Implementation Plan expands on the Science plan, drawing on the results and recommendations of workshops, meetings, and reports thereof that have been sponsored under the auspices of GLOBEC. In particular the first Open Science Meeting of GLOBEC, held in March 1998, was a critical step in the development of the GLOBEC Implementation Plan.

In theory, fundamental programme planning documents such as the GLOBEC Science and Implementation Plans set out the framework for international research programmes. In practice, of course, research is paid for by national funding agencies which must respond to national scientific priorities utilising nationally-based facilities, resources and expertise. The role of an international programme, therefore, is to provide a significant “value added” effect to these diverse national efforts through
coordination and by the facilitation of those activities which require cooperation between nations, such as data management and sharing, development of methodological protocols, efficient deployment of major resources such as research vessels, and eventually, the emergence of a truly global synthesis of scientific results which is the ultimate goal of all large-scale global change research programmes.

With these points in mind, the GLOBEC SSC has developed a framework for the international programme which encourages the participation of national (and, in some cases, regional) scientific efforts but does not force a rigid template upon them. The international GLOBEC Goal, its subsidiary Objectives and the strategic research Foci are intentionally stated in general terms. They should provide the underpinning for all GLOBEC research activities, whether these are at the individual, local, national, regional or international level. They will also provide the standard against which proposed contributions to the international GLOBEC effort will be judged. The question which should be posed in response to new activities seeking to be affiliated with the international GLOBEC programme is, “how does this particular activity help to meet our international objectives?”

The international GLOBEC programme has four main components which are described in detail in this Implementation Plan: the four research Foci, each with Activities and Tasks, four crosscutting Framework Activities, and four Regional Programmes, and finally the Integrating Activity. These are the elements that have been planned by, and will be implemented under the auspices of, the GLOBEC SSC. National GLOBEC programmes may select those aspects of this international framework which are relevant to meeting national objectives, or they may develop new directions as needed to meet specific national needs.

National participation in the international GLOBEC effort carries with it both benefits and responsibilities. These are described in the chapter on Operational Considerations for the GLOBEC programme (p169).

As noted above, the four Foci define the overall practical research approaches, and each is described in detail in the chapters which follow.

Focus 1: Retrospective analyses and time series studies
Focus 2: Process studies
Focus 3: Predictive and modelling capabilities
Focus 4: Feedbacks from changes in marine ecosystem structure.

For each Focus, major Activities have been identified and described. The Activities have been broken down into a series of initial Tasks, but the lists of Tasks are not intended to be definitive; they are indications of the types of research projects which would lead to progress in each area of GLOBEC research. No doubt, many national GLOBEC programmes will add to the list of suggested Tasks.

The next section of the Implementation Plan describes the Framework Activities, which are “cross-cutting” efforts requiring international coordination. These will be developed through the direct leadership of the international GLOBEC SSC and the International Project Office (IPO). They include:
• Sampling and models: protocols and inter-comparisons
• Data management
• Scientific networking
• Capacity building.

For example, data and methods from the whole array of GLOBEC research projects should be coherent and consistent. This can only be achieved if there is international agreement on the methods and standards to be applied in making field and laboratory observations. Similarly, international workshops will be required to evaluate and compare various GLOBEC-related models. All national participants will benefit from these Framework Activities, to the extent that they all contribute actively to them.

The section on Scientific Networking includes a discussion of the intersections between the interests of GLOBEC and a number of other international global change research efforts, particularly the Global Environmental Change and Human Security (GECHS) project and the Climate Variability and Prediction Research Programme (CLIVAR), as well as the emerging Global Ocean Observation System (GOOS). The need for strong ties to national and regional programmes is clear, and information on the ways in which many of these are planning to address international GLOBEC objectives is presented in this section. Networking also implies the constant exchange of information at all levels in the GLOBEC community from the international to the national to the individual researcher and back again. An important role of the SSC and the IPO is to facilitate this exchange and to make the communication and collaboration as effective as possible.

The four current Regional GLOBEC programmes are, in effect, the mechanism for the practical implementation of many of the Activities within the four research foci (see Figure 27). Two of these; Southern Ocean GLOBEC (SO-GLOBEC) and the study of Small Pelagic Fishes and Climate Change (SPACC) have been entirely developed through the efforts of the SSC and its working groups and will involve the participation of many national GLOBEC programmes. The other two are being planned primarily by two important regional partners with GLOBEC; ICES and PICES. These are the GLOBEC-ICES CCC Programme in the North Atlantic Ocean, and the GLOBEC-PICES CCCC Programme in the North Pacific Ocean. Both of these involve scientists from those countries surrounding the two ocean basins under study.

After a description of the plans for these regional programmes, this Implementation Plan continues with a preliminary consideration of how the observations and results from the various pieces of the GLOBEC programme will be drawn together and integrated in an effective manner in order to develop the global synthesis which must be its final legacy. This Integrating Activity aims towards a GLOBEC synthesis, and focuses on ecosystem comparisons. This phase of data assembly, analysis, testing and improvement of models, the coupling of physical and biological ocean models at regional, basin and global scales and the synthesis of all of these efforts must enable us to say, at the end of the day, that we have indeed achieved the understanding of the functioning of marine ecosystems and their responses to physical forcing that is the GLOBEC goal.
The Implementation Plan concludes with a section containing information on the contact points for the many current national GLOBEC efforts, the international SSC, and the IPO for GLOBEC. It also describes the general policy on the categorization of research within the IGBP and the benefits and obligations of national participation in GLOBEC.

How to use this Plan
A document of this nature, particularly for a project as challenging as GLOBEC, inevitably includes a large amount of information. The Implementation Plan is structured so that the reader may select particular sections of interest. In addition to the scientific illustrations, schematic diagrams are included throughout the text, which illustrate the overall relationships of the components of the programme described in the text. For example, Figure 3, shows how the Research Foci, Framework and Integrating Activities, and Regional and National Programmes fit together. The plan aims to layout a clear and practical framework, which will lead to the specification of the who, what, where, when and how of the planned research.
Figure 3

Relationships between the major components of the GLOBEC Implementation Plan
The four research Foci represent the elements common to GLOBEC programmes. The rational for the research is explained and the objectives, implementation, and outputs for specific research Activities and Tasks are described. The description is intentionally stated in general terms. With the four Foci the GLOBEC SSC has developed a framework for the international programme which encourages the participation of national (and, in some cases, regional) scientific efforts but does not force a rigid template upon them.

The GLOBEC research approach comprises a nested set of observations, experiments, and models in space and time. We need to be able to bridge these multiple scales to be able to address the question of how climate change may affect marine populations. It is essential that the investigators involved in the implementation of the components of GLOBEC see how their work fits into the fabric of the whole. The Integrating Activities described in the latter section of the Plan, are dependent on an ability to bridge the different scales. It is important to emphasize the importance of meso-scale biological measurements designed to allow process studies (that may be undertaken at smaller spatial and temporal scales) to be interpreted at the population level. Process studies will be nested within broader-scale observation programmes. Retrospective studies provide yet a broader window on the space and time scales but to be most effective, the measurements and variables considered should be related back to the measurements taken in the process and broad-scale observation programmes.

For example, as is described in the following sections, indices of large scale atmospheric patterns such as the North Atlantic Oscillation (NAO) provide an opportunity to examine climate patterns and their variation over decadal and larger time periods. To specifically link these macroscopic indicators of climate to process studies (i.e. to see how the broad indicator variables relate to measurements taken in the field), we need to determine how they will be manifested in GLOBEC study areas through changes in wind fields, temperature, precipitation, ice melt etc. and how these changes affect target species. Making this connection will allow us to go beyond correlative studies and to bridge the space and time scales between our studies and climate-scale events.

Models that integrate the information from these various sources that are interlinked as described in this Plan should then serve as very effective tools for synthesis.
Although developed in a particular order, each Focus is intended to be relatively self-contained so that the reader may, if required, move straight to the Focus of particular interest, without having to read the prior sections of the Implementation Plan. The section on each Focus concludes with a schematic diagram, which summarizes the Activities and Tasks and their interrelationships.
FOCUS 1  Retrospective Analyses and Time Series Studies

Background
The objective of Focus 1 is the identification and understanding of the characteristic, natural modes of physical forcing and marine ecosystem variability over a range of temporal scales (interannual and longer), but also including spatial scales ranging from large marine ecosystems, to ocean basins, to global systems. Understanding these forcings and ecosystem responses across a wide range of nested temporal and spatial scales is crucial to linking the detailed site-specific studies to population scale impacts.

The approach is to develop and examine historical information on marine ecosystems from a variety of sources (including other global change programmes). The outputs will form a foundation for the structure and parameter estimates of ecosystem models (Focus 3), detailed process studies (Focus 2), and the Integrating Activity, Towards a GLOBEC synthesis: ecosystem comparisons, and future time series and monitoring programmes. Retrospective analyses identify key parameters for such models and studies, and can be used to set limits to their ranges of uncertainty. Development of the Focus 1 Activities requires close linkages and interactions with other GLOBEC foci and global change programmes, such as Past Global Changes (PAGES) and Climate Variability and Prediction Research Programme (CLIVAR) (see Framework Activities). Although each national or regional programme will develop its own specific objectives, the Activities described within Focus 1 will facilitate analyses over long time scales (by adding other series in adjacent or similar areas) and broad spatial scales (by comparisons across and among large marine ecosystems and ocean basins).

Since ecosystems are variable over large spatial and temporal scales, which are much longer than the duration of single or even multi-year studies, retrospective analyses of historical information are essential to place the results from present studies into climatic and global perspectives. Retrospective analyses are the only methods available to identify characteristic temporal scales of ecosystem variability and their rates of change due to both natural, and natural plus anthropogenic, forcings (if the historical series pre-dates significant anthropogenic effects). They also provide the means to analyse large-scale spatial patterns, and the coherence through time and space of physical forcings and ecosystem responses. Central to understanding these responses is knowledge of the critical spatial scales. One of the outstanding problems in marine ecosystem research today is disentangling impacts due to natural variations (which may include increased anthropogenic greenhouse gas emissions) from impacts due to fishing (Focus 2) and other extractive activities. The Activities described in Focus 1 provide the larger perspective for distinguishing climate-induced perturbations from (direct) anthropogenic impacts; the latter can then be assessed through modelling studies.

In considering retrospective studies within GLOBEC, two time scales are considered to be of primary importance: the instrumental time period, covering the period of formally measured observations (which coincide with increasing anthropogenic
forcing over the past 100–150 years); and the millennial time period, covering natural variability over the past several thousand years. Within the instrumental time period, analyses should strive to attain seasonal to annual resolution so that annual, El Niño - Southern Oscillation (ENSO), and decadal modes of variability can be identified. Longer time series, e.g. > 50 years, are preferred when possible in order to identify ENSO and decadal scale variations. Within the millennial time period, annual resolution would also be ideal, although the focus should be on decadal to centennial variability (sometimes referred to as “regime-scale” variability). This millennial time period should also identify the rates of changes in climate states, for example, the duration and frequency of abrupt climate changes that could have dramatic consequences for the structure and functioning of marine ecosystems. Comparison of these two time periods within and between geographic areas will begin to distinguish natural climate variability from (direct) anthropogenic impacts such as fishing. A key question for GLOBEC is the extent to which past climates can predict, or be proxies for, future climate changes and the resulting marine ecosystem responses. The millennial time period provides this perspective, and will help to ascertain whether potential future climate conditions may have analogues in the past. Recent studies of historical climate changes have identified both global coherence and regional differences in the characteristics and responses to such changes. This indicates that identification of the spatial scales of responses to global changes are as important for understanding the processes involved and the potential outcomes as are studies of temporal variability.

Several oscillations in the global climate system which occur at decadal (or shorter) periods but which can have broad spatial scale effects have been described, such as ENSO, the Pacific Decadal Oscillation (PDO), and the North Atlantic Oscillation (NAO). They provide examples of relatively high frequency processes with often strong physical forcing to marine ecosystems that may serve as proxies for short-term climate change. It is unclear how the frequency of ENSO events might change with climate warming, for which the millennial time period might provide some guidance. The spatial extent of ENSO impacts also varies depending on the strength of the event, with some areas, e.g. the tropical Pacific, always experiencing ENSO effects whereas temperate areas may be affected only during strong events. Analyses of ENSO and other climate oscillations, and millennial period variations, within GLOBEC will need to be well-integrated into similar studies being conducted by the PAGES programme, for example the PAGES Pole-Equator-Pole (PEP) and Annual Records of Tropical Systems (ARTS) programmes.

The philosophy underlying Focus 1 involves four Activities (Figure 11). Many of these ideas have been presented in U.S. GLOBEC Reports 7, 15, 16, 17 and GLOBEC International Report No. 8. Of immediate concern is support for existing long time series studies, analyses of unanalysed samples, and preservation of the resulting data - i.e. ensuring that the sources of time series data are protected (Activity 1.1). These provide the raw material upon which retrospective studies are based, and the time periods and events that they sample can never be re-sampled if a programme is interrupted, or the samples collected are destroyed before being analysed. However, these programmes do need to be examined critically to determine if they are sampling the appropriate variables at optimum locations and frequencies. Activity 1.2 concerns the analyses of existing retrospective and time series data to identify and compare statistically the dominant modes of physical forcing and marine ecosystem
variability over a variety of temporal and spatial scales. Activity 1.3 concerns the creation of retrospective data sets, in order to complement the types of data (e.g. particular trophic level or species group), and temporal and spatial scales being examined in Activity 1.2. Activity 1.4 concerns the establishment of new time series studies to examine key variables at appropriate temporal periods and spatial locations, based on results from GLOBEC retrospective, modelling, and process studies. Clearly, these need to be coordinated with the emerging GOOS network.

Activity 1.1 Preservation of Existing Long Time Series Studies and Data

Introduction
Retrospective analysis of historical data requires in the first place that these historical data exist. Methods are available to extract long time series information about certain characteristics of marine ecosystems, e.g. fish scales and microzooplankton remains from anoxic sediments, but these locations are relatively rare and a full understanding of marine ecosystems requires information on many more components. Therefore, direct observational data on the physical, chemical, and biological components of marine systems, and how they vary with global changes, are absolutely crucial. For reasons of expense, changing personnel assignments, and changing institutional objectives, support for existing long time series sampling programmes is tenuous at best, and termination of these programmes even after decades of activity is common. Ironically, a programme which is cancelled after 20 or 30 years of activity is just at the appropriate time scale to describe decadal variability, which is also the scale for the life span of many important commercial fish species. Crucial aspects are the analyses of existing long time series programmes, and recommendations for changes based on the new knowledge derived, for example, from the GLOBEC programme, and support for the essential programmes. Coordination of this Activity with the emerging GOOS network is also expected.

There is also an urgent need to rescue and preserve samples and records from many of these long time series programmes. Collection of oceanographic and fisheries data has been ongoing throughout the world for much of the 20th Century. The number of samples collected has been enormous. However, the resources to analyse these samples have often been insufficient so that many, e.g. plankton samples, remain unanalysed in their jars. In addition, there are historical data still in paper records that have not been entered into electronic formats and modern computers. In some instances these may represent important and perhaps unique long-term information sets from local areas. There is a danger that these may become lost as personnel assignments change. Reasons for the loss of historical data include (Mathews 1993): unawareness of potential future uses, lack of facilities, concepts of ownership of data, the costs of stewardship and personal attitudes towards data. In addition to the data itself, the important meta-data associated with it need to be secured.

Overall objectives
The overall objective is to evaluate and support existing long time series sampling activities, and to analyse and preserve existing un-analysed samples and data in danger of being lost or destroyed. Specifically, this Activity seeks to:
• Evaluate existing long time series data collection activities to determine if they are in the most appropriate locations and sampling the relevant variables at the right frequencies using the best approaches

• Recommend continuation and/or modifications to series to improve their utility to future monitoring, while ensuring continuity with past measurements and broad spatial distributions of monitoring sites

• Analyse, preserve, and disseminate samples and data collected in existing and previous time series studies but that are not widely available or are in danger of being lost.

The GLOBEC approach

A large monitoring activity is being developed within the GOOS programme and JGOFS has initiated and maintained two important time-series sites, the Hawaii Ocean Time-Series (HOT) and the Bermuda Atlantic Time-Series (BATS). GLOBEC time series sites need to be coordinated with these programmes. Other, more local, monitoring activities also take place, for example to track particular coastal processes or conditions that are important to local problems. Evaluation of GLOBEC time series activities needs to consider these local programmes. Outcomes of GLOBEC research should include recommendations for continued time series locations, the variables to measure, and the appropriate methodologies and sampling frequencies.

In addition, the GLOBEC programme provides an opportunity for discovering and analysing old samples and data, and for rescuing and preserving data which may be available only in paper or old computer (or other) formats. In the case of unanalysed samples, modern techniques of chemical and genetic analyses could also be applied (e.g. Activity 1.3). Recovery and restoration of old data, and analyses of old samples, must be coordinated with the activities of the IOC’s Global Oceanographic Data Archaeology and Rescue (GODAR) project, which is on-going in a number of countries. To date most of these data rescue projects have been concerned with physical oceanographic data, and most of that for scientifically well-developed countries. There is a need for GLOBEC to encourage these activities in biological, especially zooplankton, data and in particular locations such as upwelling areas.

Once identified, these data series should be prioritized or highlighted for action depending on their potential importance to understanding global changes (e.g. unique locations such as high latitudes), length of the series, and variables measured. It would also help to identify (perhaps previously unknown) series that may be of use to particular regional or local programmes (e.g. data from the former Soviet Union collected off Africa). A Workshop or Working Group formed under the direction of the GLOBEC SSC is recommended as the method to initiate identification and evaluation of existing time series programmes, existence of unanalysed samples from present and past time series programmes, and the existence of data records in need of rescue and preservation.
Task 1.1.1 Support for on-going time series programmes

Rationale
Long time series programmes are expensive to conduct, and often require many years of data before patterns begin to emerge and relationships with ecosystem changes become apparent. As a result, these programmes are often among the first to be closed when budgets become restricted. On-going long time series programmes that are crucial to understanding the links between climate forcing and marine ecosystem responses need to be supported and continued.

Specific objectives
• To identify and evaluate long time series programmes to determine those which provide the highest and most significant information return on climate forcings and marine ecosystem responses
• Rank the on-going time series programmes and support those with the highest priorities.

Implementation
There are a number of long-time series programmes which have made outstanding contributions to our understanding of the links between climate, physical forcing, and marine ecosystem responses. These include the Continuous Plankton Recorder (CPR) in the North Atlantic (Warner and Hays 1994), Station PAPA in the North Pacific (Figure 4), and the California Cooperative Fisheries Investigation (CalCOFI) programme off the coast of California (Roemmich and McGowan 1995). Within the IGBP, the JGOFS HOT and BATS time-series are of particular relevance to GLOBEC, and coordination with JGOFS should be ensured. Other programmes need to be identified, perhaps as a result of Task 1.1.3, and their data analysed. All these programmes should be evaluated and an assessment made of their potential contributions to future retrospective data analysis activities, so that at least those programmes which are deemed to be absolutely crucial will have strong evidence to support this claim. Such an evaluation may recommend alternative or additional variables to measure, or other changes. The criteria for this evaluation should include the length of the series, the numbers of linked atmospheric, oceanographic, and biological variables measured, their measurement frequency, the extent to which they represent processes occurring over broad spatial areas and/or whether they represent important “pulse points” (e.g. from process studies and/or models), and a general recognition of a need to develop world-wide coverage of representative ecosystems. Such criteria will come from interaction with studies conducted under Foci 2 (process studies) and 3 (modelling), as well as close interaction with the GOOS programme. An important consideration in implementing recommended changes will be comparability with existing and previous data collection protocols, to ensure that the time series is not interrupted. Linkage will also be made with Activity 1.4.
Figure 4

Zooplankton time series from Station PAPA in the North Pacific, showing changes in timing from year to year with long term trends (GLOBEC-Canada)

Outputs

• Identification of important long time series activities
• Evaluation of the potential contributions and importance of these time series activities for understanding climate and oceanic forcings and marine ecosystem responses
• Recommendations for support of these activities.
Task 1.1.2 Analyses of samples from previous historical surveys

Rationale
Conducting field programmes and collecting new material are expensive activities, and cannot be done for past years. However, much preserved material from past studies exists, but remains unanalysed. In addition, new chemical analyses of preserved materials can be conducted to provide information on historical carbon sources and trophic levels.

Specific objectives
• Identification and analysis of samples of biological materials collected during past studies, but which remain unanalysed
• Chemical analyses of preserved biological material for identification of sources of carbon and potential trophic positions.

Implementation
Since the numbers of unanalysed samples from previous studies world-wide is likely to be large, it is necessary to prioritize the order of analyses. Plankton samples generally are slow and expensive to analyse, and often get back-logged during programmes with frequent survey and collection activities. In addition, the expertise in plankton identification and the recognition of distinct species improves with time, so that re-analyses of archived samples that had been previously analysed may also be useful. First priority for analyses should be placed on unanalysed plankton samples from long time series programmes that are still on-going, such as the CPR and CalCOFI programmes. These will provide the best return on investment to produce and complete missing periods in historical data. A high priority should also be placed on plankton samples from time periods representing particularly strong or abrupt changes and contrasts. Subsequent priorities for analyses should be placed on unanalysed plankton samples from shorter studies in locations which provide broad geographical coverage throughout the world’s oceans.

Archived plankton samples, and samples of fish scales and otoliths, also provide an opportunity to assess the carbon source and trophic position of the animals, for example by biochemical analyses of stable isotope ratios (primarily $^{13}$C and $^{15}$N). Preliminary studies need to be conducted on the changes to these stable isotope ratios caused by preservation in alcohol and formalin. Potential problems to be clarified include the effects on isotope ratios of loss of mass (shrinkage), partitioning within different biochemical components, and changes in carbon isotope ratios caused by binding of formalin to proteins. Such archived samples can also be useful in genetic analyses.

Outputs
• Analyses of unanalysed plankton samples to fill gaps in on-going long time series programmes
• Analyses of unanalysed plankton samples from previous studies which together provide broad geographic coverage over similar time periods, focusing especially on times exhibiting strong climate signals
• Re-analyses of key plankton samples (i.e. corresponding to critical times and / or locations in relation to GLOBEC objectives) for further detail, new chemical analyses, or newly distinguished species.

Task 1.1.3 Rescue and preservation of historical information

Rationale
Numerous records from past surveys and field programmes, in particular original data records, exist in paper copies but not in electronic formats, or only in out-dated computer formats. These records generally reside with individual researchers and risk becoming lost as assignments change and personnel retire.

Specific objectives
• To support concerted and coordinated efforts to assemble and transfer records (paper, old computer formats, microfiche) of historical marine environmental data into modern computer data bases, and to make these available to the broad scientific community.

Implementation
The precarious and ephemeral nature of paper (and other) records, in particular raw data records, from previous environmental programmes is a major problem for studies of global change impacts on marine ecosystems. Organized efforts to “rescue” these records have begun with atmospheric, snow, and selected marine data from states of the former Soviet Union. The Russian people have accumulated a wealth of data on the physics and biology of the Arctic ecosystem. In particular, their observations of zooplankton in the Norwegian and Barents Sea are of great significance for time series analyses within the framework of GLOBEC. Individual efforts based on one-to-one contacts have also been initiated with respect to fisheries data, but a coordinated effort needs to be established. However, the problem of loss of data is not unique to the former Soviet Union. A concerted and coordinated effort is required to identify appropriate meteorological, oceanographic, and marine biological data sets needing “rescue”, world-wide. Initial criteria should include the length of the data series, the variety of parameters measured (with programmes including inter-disciplinary measurements accorded higher priority), and the likelihood of successful “rescue”. Additional factors for consideration are the desire to achieve broad spatial coverage among retrospective data sets, and on-going or planned research activities in the areas sampled by the data needing “rescue”.

The process of “data rescue” requires that appropriate editing and quality control procedures be implemented, and that “rescued” data themselves be properly archived and made available to the broad oceanographic community. This Activity must be coordinated with the IOC GODAR project.
Outputs

- Identification of atmospheric, oceanographic, and marine biological data in paper records that need to be “rescued”, world-wide
- Coordinated efforts to reproduce and disseminate these records in modern electronic formats with appropriate data editing and quality controls.

Activity 1.2 Analyses of Existing Retrospective Data

Introduction
Analyses of existing sets of historical data form the core of Focus 1. Many of these data sets already exist, and many new sets will be developed under Focus 1, Activity 3. Activity 2 involves the analysis (or possibly re-analyses) of these data using appropriate and, as necessary, new techniques, and verification of processes leading to the formation of these historical data sets and their comparison with present processes.

General objectives
The overall objective of this Activity is to identify the dominant modes of physical forcing and marine ecosystem variability over long temporal periods and large spatial scales. Specifically, to:

- Identify the dominant temporal scales of physical forcing and ecosystem response, and their characteristic spatial scales, in deep ocean and continental shelf systems
- Use data on present ecosystem processes to support the interpretation of historical (often proxy) information
- Identify key time periods and/or locations signifying major changes in physical forcing and ecosystem functioning.

The GLOBEC approach
Analyses of existing time series data on atmospheric and oceanic variability and the responses of marine ecosystems are core components of GLOBEC programmes. They are the principal means by which the results of previous system changes are identified, and by which the ranges of parameter values and scenarios for modelling the effects of global changes are developed. What the GLOBEC programme can contribute is communication and coordination of these regional and national retrospective analyses, and coordination with other global change programmes (e.g. PAGES and the International Global Atmospheric Chemistry Project [IGAC]). In particular, there is a need for dissemination (and possibly development) of new and general methodologies for analyses of ecological multi-variate time series data, and for comparisons of the results of retrospective analyses at increasing spatial scales, e.g. between shelf and adjacent deep ocean systems, among regional seas and within ocean basins, and globally among ocean basins.
Task 1.2.1 Dissemination of new statistical analysis techniques

Rationale
Environmental time series data often do not conform to the statistical requirements assumed for time series data that derive from such processes as electronic signals. Therefore, simple linear statistical techniques such as cross-correlation analyses may not be appropriate. In addition, most environmental data series are short (less than 30 years), often with high autocorrelation, which reduces the useful information further. There is also a need to exploit and further develop methods which handle non-stationary, non-linear, series with missing data. The multi-variate (multiple time series) nature of these data and their analytical requirements and complexities also need to be considered. Many techniques have been developed for other applications which may be appropriate for GLOBEC retrospective studies (non-stationarity can be effectively dealt with by taking the appropriate differences of the series, there are well established algorithms for missing data, and non-linear models for time series analysis, e.g. threshold auto-regressive models), but which are not widely known or used by this community.

Specific objectives
- Provide critical reviews of methods for retrospective analyses of environmental data, to identify the key assumptions that must be met, recommend techniques for various types of data, and identify where new techniques are required.
- Make these techniques readily available for retrospective analyses of environmental data.
- Develop new statistical techniques as necessary for the analyses of non-stationary, non-linear environmental time series data, which may contain substantial numbers of missing values, in collaboration with appropriate statisticians.

Implementation
Traditional time series analysis, particularly in the frequency domain, derives from electronic signal processing, which are generally “well-behaved” systems. In contrast, environmental time series usually contain missing values and are frequently non-stationary, often with non-linear trends or abrupt transitions in the data. The techniques of time series analysis have also expanded to deal with these problems, most recently with the development of intervention analysis to describe abrupt transitions, and wavelet analysis which shows promise for non-linear regression and smoothing. Relatively few of these new techniques have been applied to, or intercompared using, marine environmental data. There is a need for a critical review of these methods as applied to marine environmental data, and recommendations of the most appropriate techniques for various applications. For some situations, new techniques may need to be developed and made broadly available to the global change research community, for example, as reports which would give full details of the methods including test datasets. Dissemination would be enhanced through use of a web page to discuss and exchange methods and problems. Training in new methods is also an important issue. A workshop or Working Group convened under the direction of GLOBEC in association with one of the Framework Activities, or one of the national programmes, is recommended to initiate this Task. This work will
also be relevant to the activities of PAGES.

These critical reviews and the development of new techniques need to consider extensions to the spatial domain, in which univariate or multi-variate time series data are examined across zonal, meridional, or coupled two dimensional spatial gradients. An example might be comparisons of palaeoceanographic data on fish scale deposition patterns compared within and across ocean basins.

**Outputs**
- Review and recommendation of appropriate statistical methods for time series analysis of marine environmental data, with extensions to include analyses in the spatial domain
- Development of appropriate new statistical techniques for identifying characteristic modes of variability in non-stationary marine environmental time series with missing data, if necessary.

**Task 1.2.2 Verification of processes leading to formation of palaeoceanographic data**

**Rationale**
Correct interpretation of palaeoceanographic data requires knowledge of sedimentation rates, and circulation and productivity characteristics of the overlying waters. This is a major research topic that has been addressed in depth by a number of other programmes. Additional experiments to calibrate sediment trap information with the local contemporary oceanographic conditions may aid analyses of palaeoceanographic data specific to GLOBEC. Verification of other indices of oceanographic conditions may also be necessary when proxy data are used to represent processes (e.g. sea surface temperature variations as estimates of mixed layer variations).

**Specific objectives**
- Contribute to an evaluation of the oceanographic and chemical processes leading to the deposition and preservation of biological material in sediments at key, high-resolution, locations with anaerobic conditions
- Calibrate indices of biological populations from sediments with population abundance indices in overlying waters, to develop appropriate conversion functions in order to estimate historical population sizes
- Evaluate other proxy measures of environmental or biological conditions with true measures of those conditions (in the present or the recent past) to understand the extent to which the proxies represent the true condition
- Perform comparisons and inter-calibrations of analytical techniques for these historical measures.
Implementation

Long historical data sets often consist of proxy measures for the true variable or process of interest. For example, sea surface temperature as measured at coastal sites is used as a proxy measure for upwelling, coastal sea level height derived from tide gauges is used to infer circulation, and oxygen isotope ratios in corals and other biological materials preserved in sediments are used to infer past temperatures and climate conditions. However, the deposition and preservation of material in sediments depends on a number of intervening processes between the oceanic production of the material and its eventual burial in the sediment. There is also the need to distinguish local spatial influences from temporal changes, such as variability in the local circulation or proximity to a faunal boundary which may be misinterpreted as signals of temporal variability. Such analyses integrate processes occurring over both short and long time scales. In the case of proxy indices for physical oceanographic processes, these too may depend on a number of intervening processes or local conditions.

Understanding processes leading to the formation of palaeoceanographic data requires information on deposition rates, e.g., from sediment traps, combined with descriptive studies of regional oceanographic and productivity conditions. This is particularly true with fish remains and attempts to relate these to historical fish populations. Such verification implies close collaboration with process studies that will be developed under Focus 2. These studies also need to be integrated into models describing how climate signals become recorded in the sediments, and how these signals are modified and degraded during burial. There is clear interaction in this Task with Focus 3.

Outputs

- A better understanding of the local oceanographic processes leading to the deposition and preservation of biological material in anaerobic sediments in key locations
- Improved understanding of the general processes leading to the transfer of signals of climate variability to sedimentary records
- Identification of local influences on proxy measures of ocean processes which may confound signals of climate variability
- Comparisons and inter-calibrations of methodologies.

Task 1.2.3 Retrospective analyses of available data

Rationale

Retrospective analyses of environmental time series are the only means we know of to identify the characteristic modes of temporal variability, and abrupt transitions, at scales beyond those of individual surveys or programmes. Placing present observations and model results into broader temporal and spatial contexts is essential for understanding the present structure and functioning of marine systems. Many data series exist which have not been analysed fully, or have not been compared with time series from other locations. This Task forms the core of the Focus 1 activities.
Specific objectives

- Identification of the characteristic modes of temporal variability, and of the duration and frequency of abrupt changes, for data sets representing atmospheric, oceanographic, and marine biological systems
- Comparisons of the characteristic modes of temporal variability, and of abrupt changes, across atmospheric, oceanographic, and marine biological systems to identify linkages and cause-effect relationships
- Comparisons of the modes of temporal variability and the linkages among systems from one region, with similar features in other regions and ocean basins, to determine the spatial extent of the characteristic modes and abrupt changes.

Implementation

Development of relevant time series of atmospheric, oceanographic, and biological data is taking place in many different programmes operating on local to global scales. These include national programmes possibly unconnected with GLOBEC, and international programmes with IGBP and the World Climate Research Programme (WCRP) affiliation such as PAGES, JGOFS, LOICZ, CLIVAR. GLOBEC will collaborate with these programmes, and provide additional data relating to the marine environment to investigate the linkages with marine ecosystems. The main activity of the Task is intercomparisons of temporal variability among subsystems (atmosphere, ocean, and biology), and comparisons across regions and in different environments (e.g. shelf, deep ocean) to determine the spatial scales of characteristic temporal variability. For example, is there coherent multi-decadal climate (atmospheric, oceanic) variability which affects marine ecosystems globally? How do marine ecosystems respond to episodic global changes compared with more gradual changes? These analyses and comparisons must use appropriate methods, for example as identified and developed through Task 1.2.1. Formal meta-analyses of published data or results of analyses may be one set of methods for conducting the regional intercomparisons. Although presented as four separate sub-Tasks, it is expected that there will be considerable overlap among atmospheric, physical oceanographic, and marine biological data analyses to take advantage of their natural dynamic inter-connections.

Outputs

- Identification of characteristic modes of temporal variability in atmospheric, oceanic, and biological systems, and their comparisons among systems and across geographic regions, to identify key spatial and temporal scales of physical forcing and marine ecosystem response
- Identification of key spatial and temporal scales and key forcings for the design of models, process, and monitoring studies of marine ecosystems.
Subtask 1.2.3.1  Retrospective analyses of atmospheric data

Methodology
Analyses of the characteristic scales of temporal and spatial variability of atmospheric indices and processes constitutes the first level of forcings to coupled physical-biological marine ecosystems. Analyses of the historical variations in large-scale atmospheric features such as the Pacific - North America pattern, North Atlantic Oscillation, and tropical monsoon systems are necessary to provide the background setting for the large spatial scale and low temporal frequency forcing of the marine environment. Particular meteorological indices which may be included in these large-scale patterns but which also may be necessary for detailed local studies and among-region comparisons include: historical atmospheric pressure fields (e.g. sea level and 500 mb heights) and estimates of wind fields, indices of upwelling, favourable winds and related meteorological indices (e.g. wind stress curl), air temperature, and precipitation. Traditional historical data sets (e.g. Comprehensive Ocean Atmosphere Data Set [COADS] will be supplemented with the new [so-called] reanalysis products [e.g. the European Centre for Medium Range Weather Forecasting [ECMWF]) and with climatic data from general circulation models - both these sources have the advantage of giving complete 3-D fields for detailed studies. At the millennial scale, changes in atmospheric conditions as recorded in ice core data, at possible annual resolution, are important for comparisons with long time series palaeoceanographic data. It is expected there will be considerable interaction between this sub-Task and the CLIVAR programme, in particular in the activities of assembly and analyses of quality controlled long time series data.

Outputs
• Description of the low-frequency shifts in the patterns of the major atmospheric systems which impact ocean dynamics
• Identification of the characteristic modes of temporal variability of indices of atmospheric processes, and analyses of their covariances, in light of known marine ecosystem variability
• Analyses of the spatial scales over which these major atmospheric systems and indices of atmospheric conditions affect marine systems.

Subtask 1.2.3.2  Retrospective analyses of physical oceanographic data

Methodology
Analyses of the characteristic modes of temporal variability in ocean processes are needed to understand their responses to atmospheric forcing, and the consequences for the structuring and functioning of marine ecosystems. Comparative studies among regions and different ocean basins will improve understanding of the response to meteorological forcing and the influence of local features such as bathymetry, coastline orientation, freshwater discharge, etc. Indices of physical oceanographic processes for which time series exist (or may be obtained through alternate proxy measures) include: surface and sub-surface temperature and salinity, circulation (e.g. from moorings, drifters, or geostrophic calculations), freshwater runoff, surface mixed layer depth, and mixing intensities as forced by surface or bottom
friction. Recently, the growing archives of satellite imagery provide excellent opportunities for broad spatial analyses, although generally limited temporal analyses, of surface temperature, ocean colour, sea level height (and therefore geostrophic circulation), and surface winds.

Outputs

- Identification of data appropriate for these analyses, i.e., with sufficiently long time series, particularly those which permit broad spatial comparisons
- Identification of characteristic temporal modes of variability of the indices of ocean processes, and determination of potential linkages with atmospheric forcing and marine ecosystem responses
- Analyses of the spatial scales over which these oceanographic indices and processes are coherent and have significant impacts on marine ecosystems.

Subtask 1.2.3.3 Retrospective analyses of chemical and biological data

Methodology

Analyses of the characteristic modes of temporal variability of marine chemical and biological ecosystem components, and comparisons with the characteristic modes of physical oceanographic variability, provide understanding of ecosystem responses to physical forcing. Many of the data series needed for this subTask, such as census information on the abundance, distribution, recruitment, growth, and survival of invertebrates, fish, and marine mammals, are produced annually by fisheries agencies. However, these data have their own internal problems, for example the dependence of catch levels on effort and improvements to fishing efficiency (a major problem for analyses of historical catch data) and the limitation of catch by management regulations. The composition of species assemblages and changes in trophic relationships (e.g. predators and prey) are important data series which may be more resilient to management actions, but which are also monitored less often. Studies of seabird populations and feeding dynamics are also useful in this subTask, particularly when considered as alternatives to traditional net sampling of the plankton. Long-term monitoring programmes of nutrients, dissolved gases (e.g. CO₂), and plankton are less common than fisheries programmes, but have been invaluable where they have occurred, e.g., CPR, Ocean Station PAPA, and CalCOFI programmes (Figures 5, 6, 7).
Figure 5

Year-to-year fluctuations of the NAO winterspring index and of the abundance of *Calanus finmarchicus* in the Northeast Atlantic and the North Sea (Upper panel). Lower Panel: Correlation between the changes in the North Atlantic Oscillation (NAO) Index and the abundance of *Calanus finmarchicus* in the northeast Atlantic (modified after Fomentin and Planque 1996).
Figure 6

Trends in salmon landings (A) and sardine catches (B) in the Pacific Ocean demonstrating what appears to be broad synchrony (USGLOBEC).
Figure 7

Seasonal patterns in abundance and variability of *Calanus finmarchicus* on George's Bank from historical data over the period, 1977-1987 (USGLOBEC).
Outputs

- Identification of sources of time series information on chemical and biological components (plankton, fish, marine mammals, and seabirds), and resolution of issues of data quality (e.g. inclusion of effort and gear efficiency changes in analyses of catch data)
- Determination of the characteristic modes of temporal variability of key biological populations, their comparisons among different populations and species to identify system-wide variability, and comparisons with physical variables to identify key forcings
- Analyses of the spatial scales over which these chemical and biological systems are coherent and have significant responses to physical forcings.

Subtask 1.2.3.4 Analyses of palaeoceanographic data

Methodology

Palaeoceanographic data provide the only means of direct measurements of ancient conditions. Analyses of records of fish scales preserved in marine sediments (e.g. Soutar and Isaacs 1974; Baumgartner et al. 1992) have provided unique information on the natural covariability of pelagic fish populations off southern California and their responses to low-frequency climate variations (Figure 8). In addition, analyses of material preserved in marine sediments can provide information on past ocean temperatures and be used to infer changes in circulation and faunistic boundaries. Sediments also preserve micro-organisms such as diatoms, foraminifera, and radiolarians, which could be used to reconstruct historical patterns of food-web and productivity changes. Chemical analyses of this material (organic carbon and nitrogen, trace metals, stable isotope ratios) provide additional information on historical productivity conditions, such as variations in nutrient supplies that may be driven by changes in upwelling. Combining such analyses of food-web and productivity changes with historical growth rates of fish estimated from preserved fish scales or otoliths could lead to determinations of historical growth rates, although with the assumption that feeding behaviours remained unchanged over the period of comparison. Varved sediments provide the highest temporal resolution (0.5–5 years), but occur under particular conditions and require high deposition rates of scales or micro-organisms. Locations with less well-developed sediment laminae (providing 10-15 year resolution) may produce useful information if the sediments are anaerobic with little vertical mixing and disturbance. In all cases, palaeoceanographic data series should be analysed along with palaeo-ecological records from other studies (e.g. tree rings, corals, ice cores) which provide information on historical climate conditions. These activities should be closely coordinated with similar studies occurring within the PAGES- IMAGES (International Marine Past Global Change Study) programme.
California fish scales time series for the Pacific sardine and the northern anchovy. The data are presented in the form of reconstructed biomass (hindcasts) as five year averages which are calibrated to the population sizes estimated in the 20th century. Note that the plotted data are smoothed with a 3-term moving average (equivalent to 15-year smoothing window). These biomass hindcast data are an update of the Baumgartner et al. (1992) series published in CalCOFI reports, with improved chronology and with scale counts at higher resolution from a more recent core sample. The data are also treated somewhat differently (original scale deposition rates are log-transformed before regressing against modern population data) to obtain an improved calibration.
Outputs

• Analyses of existing palaeoceanographic samples for time series of plankton and fish species composition, and analyses of their chemical composition where appropriate, to identify changes in productivity and dominant species
• Comparisons of these patterns of species dominance and productivity with palaeo-ecological indices of historical climate states, e.g., from tree rings, corals
• Comparisons of low-frequency variability from palaeoceanographic data among ecosystems over broad spatial scales to distinguish local from large (spatial) scale processes.

Activity 1.3 Creation of New, Retrospective, Data Sets

Introduction
Existing long time series data sets of marine ecosystem characteristics are rather rare. Most of those that exist cover the instrumental time period of 100–150 years. Conditions conducive to the preservation of signals at the millennial period (>1000 years) are rarer still, and come mostly from palaeoceanographic analyses of anaerobic, varved, sediments. There is an urgent need to expand the number and length of available data series, and their spatial locations, within both time scales. New data sets need to be developed from existing information (for the instrumental time period), and new sample analyses conducted to provide information on both time periods. Emphasis needs to be on indices which provide new climate information, and on new locations for climate information, in order to analyse the spatial extent of the characteristic temporal modes.

Overall objectives
The overall objective of this Activity is to produce new indices of marine ecosystem responses to climate variability and global change, and to expand the spatial distribution of new and existing indices, through:

• Creation of new, long time series data bases by development of new sites of palaeoceanographic and archaeological information
• Detailed biological and chemical analyses of existing and new samples to exploit their information content for analyses of ecosystem responses to climate variability.

The GLO B E C approach
The GLOBEC programme provides an opportunity for extracting new information from previously analysed samples and for collecting new samples possibly extending back hundreds of years in the cases of palaeoceanographic or archaeological information. The analytical and statistical techniques for analyses of these data should follow the recommendations of Tasks 1.2.1. and 1.2.3. Additionally, new sources of information need to be sought to help reduce biases in existing data series, e.g. comparisons of zooplankton data collected during daylight and at night; collection of information on fishing effort in order to standardize fisheries catch data.
Task 1.3.1 Development of new palaeoceanographic data bases

Rationale
Palaeoceanographic data series with fine-scale resolution suitable for analyses of changes in marine ecosystem structure have been developed from relatively few locations world-wide, and most of these to date have been associated with pelagic food-webs in coastal upwelling regions. There is a need to develop new sites for palaeoceanographic analyses of marine systems in other locations around the world.

Specific objectives
• To identify and sample marine sediments in new locations around the world to describe the structure and temporal variability of marine systems on decadal, centennial, and millennial time scales
• To apply modern chemical analyses to these palaeoceanographic samples, particularly of fish scales, to increase information on the past characteristics of the local marine system and their responses to climate variability.

Implementation
This Task is complimentary to the analyses of existing palaeoceanographic data sets (Subtask 1.2.3.4), and focuses on the development of palaeoceanographic samples in new locations. The comments regarding sample analyses and process verification (Task 1.2.3) also apply to this present Task. Initially, the search for new sites will focus on locations likely to have anaerobic, varved, sediments, but should quickly expand to locations with other characteristics which may preserve sedimented material with little disturbance (Figure 9). Analyses conducted on samples from these new sites should include taxonomic identifications, and the suite of chemical analyses proposed in Subtask 1.2.3.4. Adequate spatial coverage related to areas with field programmes and shorter historical data, in addition to appropriate sediment conditions, will be considerations. GLOBEC activities in this Task should be coordinated with the CLIVAR decadal to centennial programme.

Outputs
• Identification of potential locations for new palaeoceanographic data samples
• Development of these new sites and analyses to determine characteristics of the historical marine ecosystems at these locations, and their natural modes of temporal variability
• Co-ordination and collaboration with the CLIVAR - DecCen programme in these analyses.
Location of known (filled circles) and potential (open circles) sites with high-resolution records of ecosystem and ocean-climate variability of the California Current System (and Gulf of California), and in the Peru-Chile Current System. These are all located in coastal or near coastal environments of suboxic deposition. From north to south, in the northern hemisphere, the sites are: Effingham Inlet (British Columbia, Canada), the Santa Barbara Basin (southern California, USA), Soledad Basin (southern Baja California, Mexico), Guaymas slope and Mazatlán slope (Gulf of California, Mexico). In the southern hemisphere the sites are: the shelf off Callao (central Peru), shelf off Pisco (south-central Peru), shelf off Antofagasta (northern Chile), shelf off Concepción (central Chile), and the northernmost fjords in southern Chile. (T.Baumgartner).
Task 1.3.2 Creation of new, retrospective, data through analyses of historical written materials and archaeological sites

Rationale
Locations suitable for the preservation of sedimented marine material are not likely to be found in all the regions of interest to GLOBEC programmes. Many of these GLOBEC study areas, however, have been inhabited by humans over many centuries so that analyses of remains of marine materials used by humans at these locations could provide historical information on past ecosystem characteristics. In addition, many ancient societies have had recorded histories for thousands of years (e.g. Egypt, India, China, Korea (Park 1978a,b). Written records from these societies may contain information about changes in climate and fluctuations in marine resources that could be used to develop time series.

Specific objectives
• Identification of suitable sites for collection of archaeological remains of marine species
• Identification of the remains of species and analyses of their biological characteristics, and their temporal variability
• Collaboration with historians to evaluate historical written materials for information on climate changes and variations in living marine resources.

Implementation
The focus of human activities at these ancient sites is likely to have been on larger marine animals of commercial or subsistence importance, and on animals which were abundant and provided a valuable product. Species with these features are most likely to have been caught and used in sufficient numbers to be preserved. The larger animals will have had large and identifiable remains which will increase their chances of discovery and identification, e.g. salmon, marlin, tuna, marine mammals, and invertebrates such as bivalves. Archaeological materials from these larger, rarer, animals may be extremely important as the only historical sources of their remains. These materials may be used for analyses of biological characteristics, such as length, weight, age (although these measures are likely to be based on modern relationships), growth rates by analyses of regular deposition patterns, and (potentially) genetic composition. Chemical analyses of carbon and nitrogen, and stable isotope ratios, can provide further information on sources of carbon and the trophic position of the material, for reconstruction of past ecosystem structure.

Identification and excavation of archaeological sites will be best accomplished in collaboration with archaeologists. They will also be familiar with the local cultures and their historical utilization of marine animals, thereby providing further information for interpretation of these archaeological samples. Similarly, evaluation of historical written materials for information on climate and marine resource variability (Figure 10) must be done in collaboration with historical and linguistic experts who have access to, and knowledge of, the available materials. There is potential for linkage with LOICZ and PAGES in this work.
**Figure 10**

Historical periods of European herring and sardine fisheries. Open rectangles depict periods when the extensions are not precisely known. Modified after Alheit and Hagen 1997 (From EUROGLOBEC Science Plan 1998).

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**Outputs**

- Collaboration with archaeologists in the identification, excavation, and analyses of sites likely to contain remains of marine animals
- Information on historical distributions and biological characteristics (under the assumption of similarity with modern animals) of medium (food) sized fish and invertebrates, and large vertebrates including marine mammals - information which it is unlikely or difficult to recover by other means
- Collaboration with historians in the evaluation of ancient written records of climate and marine living resources variability.
Task 1.3.3 Genetic analyses of historical samples

Rationale
Most studies of the genetic population structure of marine animals are based on samples taken over a brief period of time, and it has not been possible to estimate the extent of temporal variability on decadal or longer time scales. The analysis of DNA variability in archival, and possibly ancient, samples may provide an assessment of temporal population genetic variability and its association with global changes, particularly those related to climate.

Specific objectives
• To complement genetic studies of existing species to assess levels of historical variability within populations and to discern historical genetic population structures.

Implementation
Genetic methods have been used to complement demographic and ecological studies of marine animals by identifying genetically discrete subpopulations and occasionally by uncovering morphologically cryptic taxa (Bucklin et al. 1996). One way of understanding the effects of past changes on populations is to investigate the genetic architectures of marine animals on appropriate spatial and temporal scales. The analysis of existing populations may sometimes yield indirect information about historical and evolutionary population events that were driven by global change. However, direct information about temporal population changes can only be derived from the analysis of historical or ancient specimens representing ancestral populations. Tissues for analysis may be found in museums, oceanographic and archaeological collections, and possibly in bones and scales recovered from marine sediments. Since proteins degrade quickly, the study of historical genetic variability is possible only by examining sequence variability in DNA. Polymerase chain reaction (PCR) amplification of mitochondrial DNA (mtDNA) for sequencing is the logical first step, because sequences of mtDNA are well-studied in numerous species and because mtDNA has been widely used to examine population variability. Comparisons of haplotype frequency shifts and sequence divergence from present day populations can potentially give temporal resolution of population events thousands or ten of thousands of years in the past, though successful amplification of DNA will tend to decline with age of the sample. The analysis of PCR amplified microsatellite DNA, pseudogenes or introns, all of which have high mutation rates, may resolve population events on shorter time scales of decades or hundreds of years. Since few studies of nuclear DNA have been made of existing species of marine animals, studies of existing populations must accompany historical studies.

Outputs
• The ability to examine directly genetic variability in ancestral populations can give insights into the effects of climatic and oceanographic changes in the abundances and distributions of marine animals that are not possible from the study of existing species.
Task 1.3.4 Development of fish growth histories

Rationale
As a result of their importance to commercial fisheries, data are collected more frequently on fish and shellfish species than they are for plankton. Many of these samples are analysed only cursorily for age and abundance information, and are then archived. These archives therefore provide a valuable source of information on biological characteristics of the fished populations, in particular their growth histories, which can be used to infer variations in growth conditions in the sea.

Specific objectives
• Identification of sources of samples and data from fisheries and marine mammal laboratories that may be used to develop growth histories and infer past productivity conditions
• Analyses of these samples for coherent patterns in space and time indicating variations in growth conditions for these animals.

Implementation
Hard parts of fish, such as scales and otoliths, record growth rings which can often be used to infer seasonal or annual growth rates. These in turn can be used to indicate annual variations in growth conditions. Archives of scales and otoliths exist in many fisheries laboratories, and are often analysed only for age information. These collections also represent potentially valuable sources of marine productivity information, in particular concerning direct impacts on specific marine populations. Comparisons within and among species for the same area can be pursued to broaden the interpretation. Such fish hard parts are also frequently preserved in varved sediments and may be recovered in palaeoceanographic or archaeological investigations. The potentially confounding effect of changes in the abundance of fish on the food available to an individual fish (density-dependent effects) will need to be considered.

Outputs
• Species-specific growth histories for high trophic level carnivores (in the case of vertebrates) and low trophic level invertebrates, from which to infer large-scale changes in oceanic productivity.

Activity 1.4 Development of New Data Sets for Future Comparisons

Introduction
Scientists engaged in retrospective analyses of historical data also have a responsibility to be forward-looking, i.e., a responsibility to support development of new time series data where necessary. Development of new series requires considerable institutional support, and support from the international scientific community. Whereas new data added to existing series can be used immediately to compare with previous trends, the development of new time series requires years of data before analyses of interannual and longer temporal variability can be made.
International GLOBEC activities will increase understanding of marine ecosystem processes and their responses to climate forcing. Detailed process studies and modelling activities will elucidate the mechanisms linking the components of these systems. They will confirm the importance of previously suspected links and identify critical new parameters and critical points in space and time (“pulse points”). These findings need to be incorporated into the evaluation of existing time series and the development of new series.

Overall objectives
The overall objective is to develop new, long time series data collection activities where appropriate. Specifically, this Activity seeks to:

- Develop new long-term time series study locations and variables based on results from present GLOBEC and other programmes, in order to supplement and complement existing long-time series data collection activities
- Coordinate and collaborate closely with GOOS in the continuation and development of these time series activities.

The GLOBEC approach
The outcomes of GLOBEC research will lead to a new understanding of marine ecosystem variability in response to global changes. This new understanding will include new locations and variables to monitor that quickly reflect or capture changes in system structures or functions. Such locations and variables are obvious candidates for new time series studies. In developing new time series locations and activities, broad spatial coverage (world-wide) is desirable, although it must be balanced with consideration of existing long time series locations, knowledge of the climate-marine ecosystem coupling, and significance to ecosystem structures. Time series locations in national waters are expected to be under the jurisdiction of the local state. Time series studies in international waters are likely to require greater international collaboration and coordination - such coordination should be provided by regional marine science organizations (e.g. ICES, PICES) where they exist. In all cases, strong institutional and international scientific support will be necessary for establishing time series programmes in national and international waters. All data should be provided to the appropriate World Data Centre, which may need assistance in designing data systems for biological data and data from new technologies (e.g., acoustical or optical sensors; see Framework Activity, 6.0, below). Again, coordination with the GOOS monitoring programme is essential.

Task 1.4.1 Development of time series studies

Rationale
GLOBEC activities in retrospective analyses, process studies, and modelling will identify new linkages, variables, and/or locations which are critical for the control of and understanding of the responses of marine ecosystems to climate variability. These findings need to be identified and assembled into programmes which will monitor these key variables and locations, thereby providing information for warning of impending global changes and also retrospective analyses of changes after they have occurred.
Specific objectives

• Distillation of results from GLOBEC programmes into key variables and new study sites in order to provide early warnings of climate variations and retrospective analyses after the events.

• Provide support for the establishment and operation of new long time series activities.

Implementation

In collaboration with GOOS and other relevant programmes, the results of GLOBEC investigations need to be distilled to identify the crucial variables and locations to study and develop long time series analyses of climate variability and marine ecosystem responses. Recommendations should be made for a coordinated network of sampling activities to assess ecosystem structure and changes.

Outputs

• Evaluation of GLOBEC programme results and identification of key variables and locations likely to provide warning signals of impending climate changes and ecosystem responses, and to provide the necessary data for retrospective analyses of the events.

• Collaboration with GOOS in the development of these new time series activities.
Figure 11

Flow diagram of the Activities and Tasks detailed in Focus 1 (Retrospective Analyses and Time Series Studies).

Activity 1.1
Preservation of existing long time series studies and data

- Task 1.1.1 Support for on-going time series programs
- Task 1.1.2 Analyses of samples from previous historical surveys
- Task 1.1.3 Rescue and preservation of historical information

Activity 1.2
Analyses of existing retrospective data

- Task 1.2.1 Dissemination of new statistical analysis techniques
- Task 1.2.2 Verification of processes leading to formation of palaeoceanographic data
- Task 1.2.3 Retrospective analyses of available data

Activity 1.3
Creation of new, retrospective, data sets

- Task 1.3.1 Development of new palaeoceanographic databases
- Task 1.3.2 Creation of new, retrospective, data through analyses of historical written materials and archaeological sites
- Task 1.3.3 Genetic analysis of historical samples
- Task 1.3.4 Development of fish growth histories

Activity 1.4
Development of new data sets for future comparisons
FOCUS 2  Process Studies

Introduction
At the small- and mesoscale, population process studies are of critical importance for the understanding of the functioning and thereby the structure of marine ecosystems. Small-scale processes may be influenced by climatic variations but it is large-scale phenomena, such as distribution and timing of stratification and migration patterns, as well as matching in vertical migration and timing of phytoplankton blooms that are likely to be most important. While much recent research has focussed on phytoplankton, particularly through JGOFS, knowledge of the role of zooplankton as grazers, predators and prey is much less well developed. For example, it is only relatively recently that the important distinction between microzooplankton and other zooplankters has been recognized. While the protozoan component of the microzooplankton multiply by cellular division, the larger zooplankton most often undergo complicated life cycles with series of larval stages before sexual maturity is reached. This has major implications for the ability of the two groups to exploit rapidly changing situations in the ocean. Feeding processes and choice of food are critical issues for models. New investigations show that zooplankton are much more versatile in their feeding behaviour than earlier believed and, that if they have the choice, they prefer the more nutritious food sources.

Zooplankton are also a food source for higher trophic levels, and their abundance and species composition may have great implications for the population dynamics of the latter (Cushing 1995). Thus, fish populations may be strongly affected by zooplankton fluctuations, resulting in significant economic consequences. Such fluctuations may be caused by climatic variability or change and/or by human activity, at least in coastal areas, and knowledge of the interrelationships is of fundamental importance for the understanding of when, and where, adverse situations can be predicted.

The process studies in this Focus outline experimental approaches to investigating specific mechanisms which are thought to link ecosystem responses with environmental variability. The design of these studies should be based on, and closely linked to the retrospective studies under Focus 1, and the modelling and observational work detailed in Focus 3. Close integration is essential. Process studies should form an integral part of regional and national programmes, and their crosslinking will be facilitated by the Framework Activities described in this Implementation Plan.

Activity 2.1  Research on Life Histories and Trophodynamics and Their Modelling in Ecosystems

Introduction
Zooplankton are an integral component which mediates phytoplankton production and production of fishes and other animals at higher trophic levels in marine ecosystems (Banse 1995). As a mechanism of production, the population dynamics of each
component zooplankton species is ultimately a product of the rates of reproduction, growth and mortality. Reproduction and growth patterns of zooplankton vary not only between species but also within species, reflecting regional dissimilarities in production cycles and thermal regime. Mortality is largely influenced by a set of predators which varies regionally. Thus, to advance our understanding of the structure and functioning of the global ocean ecosystem and its major subsystems in response to climate change, evaluation of reproduction, growth and mortality rates of major component species of zooplankton of each system and parameters affecting these rate processes is essential.

Overall objectives
The overall objective of this Activity is to assess, at regional and global scales, the processes of population dynamics of dominant zooplankton species. More specifically this Activity will:

- Evaluate reproduction, growth and mortality patterns of dominant zooplankton species, and between-species interactions of the global ocean ecosystem, and major subsystems
- Organize collaborative sampling programmes to determine reproductive, growth and mortality rates of zooplankton species in the field
- Carry out laboratory experiments to evaluate the effect of food availability, temperature, turbulence and other environmental parameters relevant to climate change on the rates of reproduction and growth rates of zooplankton species.

The GLOBEC approach
To achieve global synthesis of population dynamics of dominant zooplankton species in marine food-webs, integration of data gained from on-going Regional Programmes in the Southern Ocean (SO-GLOBEC), Coastal upwelling systems (SPACC), the North Pacific (PICES CCCC), and the North Atlantic (ICES CCC) is essential, together with development of strong process studies in National GLOBEC programmes and other multi-national initiatives such as the Transatlantic Study of Calanus finmarchicus (TASC) and Benguela Environment Fisheries Interaction and Training (BENEFIT).

Task 2.1.1 Zooplankton reproduction, growth and mortality rates

Rationale
Estimates of reproduction, growth rates and mortality rates are critical to understanding the population dynamics of zooplankton and to integrating their dynamics into biophysical models.

In the traditional food chain meso- and macro-zooplankton are intermediate trophic levels between phytoplankton production and production of fish and other animals at higher trophic levels. The important role of the smaller pelagic components, pico-, nano- and particularly the microzooplankton is dealt with under 2.1.4. It is well recognized that the major biological components affecting population dynamics are reproduction, growth and mortality. Reproduction and growth patterns of zoo-
plankton vary not only between species but also within species reflecting regional differences in production cycles and hydrography. Mortality rates are largely influenced by the predator field which also varies regionally. In addition to predation, several other factors, such as parasites, pollutants and toxic phytoplankton may decrease survival rates.

Thus, to advance understanding of the structure and function of the global ocean ecosystem and its major subsystems in response to climate change, coordinated process studies on reproduction, growth and mortality of major zooplankton species of each subsystem are required. These studies will enable population dynamics to be integrated into biological models including physical components.

**Specific objectives**

- To identify key zooplankton species in major ocean ecosystems and subsystems
- To establish population dynamics models for each key zooplankton species based on reproduction, growth and mortality data, and estimate production rates in the field
- To assess impacts of future environmental changes on the critical population dynamics parameters of each key zooplankton species using laboratory studies
- To understand reproductive strategies of eggsac and broadcast spawners in relation to feeding modes
- To investigate the importance of reproductive strategies and diapause for the life history
- To understand the effect of food quality on reproductive rates and egg hatching success
- To understand mortality changes with age.

**Implementation**

The role of food quality in influencing reproduction and growth should be established in a coordinated programme of laboratory experimentation. This will investigate the effect the major components of the diet, of diatoms, dinoflagellates and microzooplankton, on reproduction and also the hatching success of eggs. This work will also help to establish the lifetime fecundity of key zooplankton species as a function of food supply in the physical setting of a range of ecosystems. In conjunction innovative field investigations will be designed and carried out to achieve accurate estimation of growth and mortality of target zooplankton species over the entire range of developmental stages. These will aim to establish the major sources of mortality in the field, both intrinsic (diseases, parasites, etc.) and extrinsic (predation). To complement this research the effect of turbulence on the growth and subsequent mating success of zooplankton will be established in the laboratory. Vertical migration is a major feature of zooplankton behaviour, and this Task will also investigate how vertical migration affects predation risk and predator avoidance, as well as reproduction and growth in zooplankton and vice versa. The proposed work will investigate the plasticity of vertical migration (i.e. how behaviour is influenced by feeding/growth opportunities, temperature, light and predation risk in the water
column) and also the intrinsic or extrinsic cues inducing other key aspects of the life-cycle of some species, diapause or quiescence.

Outputs
• A better understanding of the recruitment rate of zooplankton under a range of environmental conditions
• Definition of the most critical life stages for the maintenance of populations.

Task 2.1.2 Zooplankton trophodynamic strategies

Rationale
Task 2.1.1 addresses the essential components of zooplankton population dynamics, reproduction, growth and mortality. The first two of these are under the direct influence of initial energy input via feeding. Variation in population dynamics of an ecosystem drives the variability in the production of that ecosystem, and thus affects the whole trophic system. Hence process studies on feeding and trophodynamic strategies are important if advances are to be made in ecosystem modelling. To describe or model the system one has to know the variation in the vital rates of each major component. Many important zooplankters are omnivorous, e.g. copepods, euphausiids and salps, and nutritional quality of the food as well as encounter rates for prey organisms have a direct impact on production.

Specific objectives
• To investigate and understand the trophodynamics associated with different populations in major oceanic ecosystems
• To investigate the role of turbulence on predator-prey interaction
• To investigate the level of predation among zooplankton species, as well as the intra- and inter-specific predation processes and pressure.

Implementation
The biological and physical/chemical factors affecting zooplankton feeding will be investigated including, in particular, the influence of predator avoidance behaviour, such as vertical migration, on feeding rates, the role of the biochemical composition of food items essential for reproduction and growth, the effects of temperature, food abundance and composition on reproduction, growth and sex ratio, and quantification of the role of food in larval biology.

Outputs
• Quantification of the factors regulating zooplankton feeding, temperature, phytoplankton biodiversity, food quality and abundance, and their effects mediated via feeding on zooplankton population dynamics
• Improved understanding of zooplankton feeding strategies and their significance, in the context of biological-physical interactions, for production in a range of ecosystems.
Task 2.1.3 Zooplankton-fish interactions

Rationale
Dramatic fluctuations of stocks of small pelagic fishes, which sometimes show basin-wide covariation of well separated stocks (Figure 6) or interbasin alternating variations (Lluch-Belda et al. 1992) are not well understood. Population dynamics of food organisms have been inferred, but substantive evidence is poor or lacking. Changes in large-scale and meso-scale physical parameters seem to play an important role requiring research on the biological-physical coupling of processes and events, e.g. changes in the character of upwelling (persistent or intermittent) may generate a switch from one fish stock to another depending on differences in feeding strategy and thus also in growth rates (for example, sardine versus anchovy).

Specific objectives
• To understand the coupling or decoupling of seasonal progression and success of fish spawning and development of zooplankton communities as regulated by temperature, food abundance and food quality
• To understand the role of small- and mesoscale physical dynamics on zooplankton distribution and abundance and the fate of young fish
• To investigate the coupling of migration and behaviour of fish and zooplankton biomass and distribution patterns
• To understand the predatory effect of planktivorous fish on the structure and dynamics of zooplankton target species communities, and the effect of invertebrate predators such as chaetognaths on ichthyoplankton
• To explore the relationships between the biochemical composition and size fractions of zooplankton influencing fish spawning, larval fish survival and growth.

Implementation
The role of day length, water temperature and food supply for the successful spawning (in terms of egg production), and larval survival of target fish species will be estimated, and nutritional conditions, feeding success and growth rates of larvae and early juveniles taking into consideration intra- and interspecific competition will be investigated. Studies will investigate the implications of target zooplankton behaviour and distribution for zooplankton-fish interaction in relation to advective forces or other physical processes affected by mesoscale features associated with topography, eddy structure, and currents. The role of intensive and selective grazing by selected fish and invertebrate predators on population dynamics and communities of zooplankton target species will require study together with zooplankton predation risk and fish feeding as a function of the optical properties of the water column. Further research should investigate developmental and survival rates of eggs and early fish larvae affected by the physical environment, as well as viability of larvae and predation.

Outputs
• An improved understanding of fish stock fluctuations and their coupling to ocean climate variability and trophic interactions
A long term goal is the possibility of modelling and predicting the response of fish stocks to environmental changes, i.e. to model how changes in recruitment depend on interaction between growth and mortality and how these are coupled to variations in the ocean climate.

Task 2.1.4 Role of microzooplankton in food webs

Rationale
The dominant functional role of microzooplankton in the oceanic food-web has only been relatively recently recognized. Defined as the fraction of zooplankton smaller than 200µm, microzooplankton is divided in two major components with very different biological cycles: larvae of larger zooplankton and unicellular organisms. There is very little information about the role played by the mesozooplankton larvae, nauplii or young stages of small copepods such as Oithona sp and even their abundances are uncertain. There is a major difference between unicellular microzooplankton and larger zooplankters in that the former generally multiply by cellular division while the latter undergo a varying number of larval stages with growth and mortality involved in each individual step. Microzooplankton are important grazers of pico- and nanoplankton and are themselves preyed upon by larger zooplankters. By grazing tiny particles, the microzooplankton actively incorporate particles that might otherwise form a biogeochemical “sink” in the sea.

Specific objectives
• To investigate qualitatively and quantitatively all microzooplankton components, community structure and function, and to study the links between microzooplankton and the conventional food web (copepods to fish)
• To include the microbial food-web in pelagic ecosystem models including large zooplankton and fish.

Implementation
Achievement of these objectives will require coordinated investigation of the composition and the relative role of various components of the microzooplankton community in the food-webs of a range of different ecosystems. There is a requirement to develop new methodologies to quantify microzooplankton ingestion by organisms higher in the trophic system. The resulting quantification of microzooplankton interactions with mesozooplankton, will enable these to be included in trophodynamic and ecosystem models.

Outputs
• Integration of the microbial food-web in models and achievement of a better understanding of the total grazing pressure on phytoplankton, its role for mesozooplankton and fish larval survival, growth and production.
Activity 2.2 Identification and Understanding of Multiscale Physical - Biological Interactions

Introduction
Physical conditions over a broad range of scales, both vertical and horizontal, influence marine ecosystem processes. At the very smallest scales where turbulence is isotropic, from the metre scale down to the Kolmogorov scale of cm - mm, motion is known to influence predator-prey interactions among planktonic organisms. Moving to the mesoscale, encompassing distances of kilometres to tens of kilometres, the possible physical influences on biological processes become more extensive. A major fraction of plankton production and concentration occurs along frontal regions associated with physical phenomena such as shelf break currents, upwelling, topographically steered currents around banks (Figure 12), and transient baroclinic eddies for example Gulf Stream rings. Water motion (upwelling or downwelling) associated with jets or eddies can lead to significant variations in physical and chemical characteristics of the water and in turn lead to changes in prey availability. Finally, large-scale changes in ocean physics, driven by atmospheric phenomena such as ENSO, NAO and Benguela Niños, or driven by atmosphere-ocean interactions such as thermohaline deep water formation in the Nordic Seas are important. These can alter the basic environmental conditions for populations of zooplankton which in turn affect recruitment, growth and mortality of populations at higher trophic levels.

Physical-biological interactions are neither well-documented nor understood in a qualitative sense. As an example, plankton patchiness in space and time has long been known to be characteristic of marine populations. Plankton patchiness is the integral result of the biological production/grazing/predation and migration and physical advection and dispersion, but the interaction between these processes needs increased attention. The same is true for observations of very small-scale interactions. The atmospheric processes are not only important as driving forces for ocean physics, but such processes also have a more direct influence through influences on mixed-layer dynamics and light conditions affecting plankton dynamics. Knowledge of these processes, linked with an observational and a modelling programme (Focus 3), is an essential component of GLOBEC research.

Overall objectives

• To determine the role of multi-scale physical-biological interactions in structuring and fuelling the production of marine ecosystems, and in affecting their response to global change.
Figure 12

Cod and Haddock early life stages on George's Bank; canonical view of the entrainment of the eggs and larvae in the anticyclonic gyre (USGLOBEC).

Cod and Haddock Early Life Stages

(1) Eggs, (2,3) Larvae, (4,5) Pelagic Juveniles, (6) Demersal Juveniles
The GLOBEC approach
Achievement of this objective will require a highly integrated interdisciplinary approach, and it needs interaction with expertise within both marine and atmospheric physics. The approach should include an effort to identify relevant scales, both spatial and temporal, of critical biological and physical processes to better formulate physical-biological coupled multi-scale models. This will require close linkage with the activities of Focus 3 as increased insight into the basic processes needs to be tested and evaluated by modelling, and model results in turn will reveal new aspects of important biological-physical processes.

Task 2.2.1 Ocean physics and basic biological processes of individual organisms

Rationale
Plankton sizes and spatial extent for their activities range from below to above Kolmogorov scales. Strictly speaking small-scale turbulence only occurs down to around lk (Kolmogorov microscale), which in the ocean ranges from 0.7 to 0.07 cm, depending on the energetic conditions. Below this size, water motion is said to be characterized by the remaining laminar shear field derived from the eddies. The term “turbulence” is used in a broad sense, including motions below the Kolmogorov microscale.

Temperature, light conditions, density stratification, buoyancy and turbulence are physical parameters that control feeding, growth, behaviour and distribution of individual organisms in the phytoplankton, zooplankton, and larval fish communities (Figure 13). The variability of these physical parameters is strongly influenced by atmospheric weather phenomena such as cyclone passage. Thus, they vary on a short time scale, but the variability of each parameter is modified as they propagate into the mixed layer of the ocean. Due to the large heat capacity of water the thermal energy of the upper ocean changes considerably more slowly than the kinetic energy. Consequently, temperature varies much more slowly than turbulence and potential energy. On the other hand, light propagates without delay from the atmosphere to the ocean, although the frequency spectrum changes as light propagates with depth. In this way the various physical parameters originating from one weather event start out with a uniform pattern of variability but end with a dispersed variability in the ocean. All parameters influence basic biological processes of individual organisms in different ways. Temperature influences vital rates, stratification and buoyancy influence vertical motion of plankton, light conditions and turbulence are of critical importance for predator-prey interactions. In addition, turbulence also influences chemical diffusion patterns and organized flow structures that organisms may respond to, with physico-chemical control over migration patterns being a possible example. Finally, plankton may undergo behavioural adaptations for swimming at various levels of turbulent intensity. Field data on these very small scale interactions are, at present, insufficient for formulation of any but the most preliminary hypotheses. The optimal values of the physical parameters with respect to individual plankton growth and reproduction vary between plankton species.
Figure 13

Range of feasible values of light, turbulence and the corresponding (successful) ingestion rate (prey sec\(^{-1}\)) for models using two different assumptions of feeding behaviour (upper and lower panels) for larval herring (16 mm) and Cod (6 mm). Modified after Fiksen et al. 1998.
Specific objectives

- To understand the relations between individual plankton and the interacting physical parameters. This involves:
  - Effects of temperature on metabolism and response times in relation to predator-prey interaction
  - The effects of turbulence and light conditions on predator/prey encounter rates, and metabolism, and feeding efficiency
  - Species-specific associations with turbulence and light and their adaptive significance
  - The effects of temperature and turbulence on plankton motion, behaviour and chemical diffusion patterns
  - Behavioural adaptations of plankton swimming at various levels of turbulence
  - The effects of physical variables on competitive interactions between organisms.

Implementation

The research activities under this Task will investigate the effect of physical parameters on behaviour of target species of plankton in the laboratory, in mesocosms and in the field. Experiments will be carried out on the behaviour of zooplankton and fish larvae under controlled physical conditions. This will enable appropriate models to be tested both in the laboratory and in the field. A critical requirement for the field measurements will be to establish a means for simultaneously measuring plankton distributions, light conditions, turbulence and temperature, and this need will be satisfied in conjunction with the work of Focus 3.

Outputs

- Improved understanding of the combined effects of the various physical parameters influencing individual plankton growth and reproduction
- Development of zooplankton behaviour models incorporating physical processes
- Better extrapolation of laboratory obtained rate process data to field populations.

Task 2.2.2 Mesoscale physical-biological interaction

Rationale

Mesoscale hydrographic features in the ocean influence distribution and life cycle success of plankton and fish larvae. The match in residence time of mesoscale features such as eddies, meanders and the upper surface mixed layer with biological patterns is poorly understood at the species and community levels.

Examples of such systems are coastal and shelf break upwellings, transient eddies generated by baroclinic frontal instabilities and stationary topographically trapped gyres above banks and troughs (Figure 14). A characteristic feature of such systems
is the presence of frontal structures where plankton concentrate and trophic transfer rates are high. This is due to the combination of vertical currents which supply nutrients from depth and horizontal currents which give differential patterns of spreading of plankton through convergence and divergence processes. Such physical structures provide local conditions which likely influence demography of zooplankton populations, through direct impact on the reproduction, growth and mortality of successive generations. They may also provide different feeding regimes for juvenile and other small fish. In between such structures, zooplankton tend to be dispersed in mesoscale patches that provide cases of horizontal spatial match and mismatch between predator and prey. This feature influences feeding success, growth and survival in juvenile fish.

Such interactions may have a range of indirect effects on pelagic food webs through effects on phytoplankton communities, and hence zooplankton food quality, through determination of the predominance of the microbial loop and hence the transfer to higher trophic levels, and through the creation of transition zones or boundaries which in turn may be important sites of zooplankton aggregation and production.

Specific objectives

- Provide input data for mesoscale circulation models and trophodynamic models
- To develop sampling strategies for observing biological processes in relation to physical structures for key target species, and to develop sampling and observation techniques needed for rational in situ field experiments allowing direct measurement of population demography characteristics, patterns and rate process
- To identify and understand physical-biological mesoscale interactions, e.g. for organisms performing diel migration and encountering different water masses in the water column
- Develop statistical methods for handling large data series and complex relationships and produce data, algorithms and conceptual models for implementation in numerical models
- To understand the potential interactions of surface ocean dynamics on species dispersal, predator-prey encounter rates, and reproductive success
- Identify advection routes and retention areas and quantify dispersal ranges during larval drift
- Determine the mortality rates attached to particular juvenile stages, and determine the earliest possible stage for a reasonable measure of year class strength
- Identify the factors that favour low larval mortality and maximize year class strength
- Determine the effect of physical processes on favouring the predominance of classical vs. microbial energy pathways.
Examples of mesoscale oceanographic features illustrated by satellite remote sensing. 

**Upper left panel**: SeaWiFS image of the Western Approaches of the English Channel for 20 September 1998, showing high chlorophyll associated with the tidal front (a), and also elevated chlorophyll associated with the shelf-break front (b).

**Upper right panel**: SeaWiFS image of the west coast of the Iberian Peninsula (Spain and Portugal) for 18 July 1998, showing a phytoplankton filament associated with coastal upwelling (c), and the coastal upwelling region itself (d).

**Lower panel**: AVHRR image of the region south of Iceland for 9 July 1998, showing complex mesoscale features revealed by reflectance of surface waters due to coccoliths; a distinct mesoscale eddy is indicated (e). SeaWiFS and AVHRR images are captured and archived by the N ERC Satellite Receiving Station, Dundee, and processed by the Remote Sensing Group, CCMS-Plymouth Marine Laboratory. SeaWiFS data courtesy of the NASA SeaWiFS Project and Orbital Science Corporation.
Implementation
This Task will establish programmes and technologies to investigate simultaneously zooplankton rate processes and distribution and behaviour and mesoscale hydrological dynamics. To a larger extent than previously, plankton sampling needs to be conducted spatially with a higher resolution in order to match physical sampling and resolve relevant structures. It is also important to resolve temporal changes with a high resolution as the shape of the mesoscale features continuously distorts. Predator/prey behavioural and physiological responses to mesoscale hydrodynamics will also be studied. A key element will be to relate species life cycle strategy and demography of target species to dynamics in the physical field, and to include results in appropriate scaled models to determine critical parameters and associated rates for predicting the biological response on physical forcing. The research will involve the investigation of the spatial and temporal dimension of the demography and trophic relationship in the mesoscale system generating new production in the upper pelagic zone.

Outputs
• A better understanding of how key zooplankton species are distributed in mesoscale structures in relation to fish distribution
• More accurate measurements of the biomass of key species to improve secondary production estimations, particularly concentrating on accurate abundance estimates of target species (for per capita rates)
• Conceptual models of the fluxes of energy within and from mesoscale ecological processes
• Development of climatically driven physical ocean models with appropriate biological components resulting in a better understanding of the effects of global change, mediated through mesoscale features, on the biology of the ocean.

Task 2.2.3 Large-scale physical-biological interaction

Rationale
Climate variability may result in variability in water masses and currents which could affect zooplankton communities and fish populations via altered life history patterns. For example, overwintering strategies, migration routes, and the timing and location of spawning grounds are likely to be sensitive to climatically related changes in large-scale circulation on a basin-wide scale. Basin-scale circulation features of the oceans are always strongly linked to atmospheric features. For example the ENSO is caused by the coupled effects of changes in the equatorial wind system and large-scale circulation in the tropical Pacific. It influences the upwelling dynamics along the American west coasts and the mesoscale features in the region. Similarly, Benguela Niños in the South Atlantic strongly influence the upwelling system off Southwest Africa. The atmospheric pressure variation of the Icelandic Low and the Azores High, the North Atlantic Oscillation, causes strong variations in the Gulf Stream and in the thermal regime of the entire North Atlantic. Zooplankton are adapted to the historical large-scale circulation system. For example, the copepod *Calanus finmarchicus* is distributed in the entire Subarctic Gyre of the North Atlantic, while *Calanus helgolandicus* occupies larger parts of the North Atlantic to the south of
the Subarctic Gyre (Fomentin and Planque 1996). A major issue is to determine how
the large scale circulation pattern transports and redistributes individuals within the
system so that successive generations experience different environmental conditions
in the different regions they are transported to, and the degree of temporal and spa-
tial overlap between predators and prey. Research on large-scale physical-biological
interactions is an important activity for GLOBEC, and the analysis of long-term time
series as a basis for understanding the driving forces, the mechanisms and the proc-
eses, and will be an important issue of this Task jointly with Focus 1

Marine speciation is related to large-scale ocean water mass transport. To allow for
speciation, circulation patterns have to result in isolation of ocean basins from the
rest of the world ocean. Only modern molecular techniques can identify the occur-
rence of genetic recent time scale. Biological productivity in the pelagic zone is mo-
tile, characterized by advection of organisms at lower trophic levels, and by migra-
tion of animals at higher trophic levels. As the potential energy of stored biomass is
transferred by the trophic levels up the food-web, the time scale for transfer between
levels increases from seasonal to multiannual scales. Numerical modelling is still in
its infancy in trying to develop predictive models of processes up to the herbivore
level. Models are not yet at the stage where interfacing with commercial fish popula-
tion models is possible. Much effort in applied fisheries science has been directed to
developing multi-species models that can be evolved into models that give input of
year class formation and recruitment to each individual stock. GLOBEC should
build on these models and contribute to the means of interfacing with coupled
physical-biological models.

Specific objectives

• Investigate how ecosystem dynamics of mesoscale features are linked to the
  physics of basin-scale variations

• To develop long term pelagic time series in combination with targeted short
term investigations

• To identify population diversity at the molecular level and to demonstrate inter
  population exchange.

Implementation

The ecological effects of basin-wide physical variations need to be investigated in
close cooperation with climatologists and atmospheric scientists. Analysis of long-
term time series of marine organisms and climate will be an important tool to under-
stand the underlying processes. To study large-scale physical-biological interactions
it will clearly be extremely valuable to mount research focussed on the molecular
 genetics of the GLOBEC target species, and also to develop an evolutionary scheme
for such species and their distribution in the world ocean on geological time scales.

Outputs

• Establish the links of upwelling ecosystems, frontal regions and other mesoscale
  regions of high plankton productivity to the basin-scale physical processes
Improved understanding of how climate variability through changes in water mass properties and current structure could have a profound influence on zooplankton communities and fish populations via altered life history patterns.

Deliver year class predictions and input to stock assessment models.

**Activity 2.3  Responses of Marine Ecosystems to Fishing and Species Introductions**

**Introduction**

Human activities cause major changes in marine as well as terrestrial ecosystems. Marine ecosystems are affected directly by activities such as fishing or species introductions and indirectly by alterations to nutrient cycles and climate. Most of the world’s fish stocks are heavily exploited - in some cases more than 60% are caught every year. Such removals might be expected to have considerable significance for the prey species of fish (e.g. zooplankton) and also for their predators and competitors (e.g. birds and marine mammals). In addition species introductions resulting from human activities may have profound, and unpredictable effects, on marine ecosystem structure.

Major international programmes are already underway to evaluate the consequences of human activities such as fishing and species transfer and to propose regulations and remedial action. Several of the scientific activities proposed for the GLOBEC programme will complement such programmes and should be designed to contribute to them. The contribution of GLOBEC will be specifically in the context of interaction with changes in climatic regimes.

**Overall objectives**

- To contribute to understanding the direct and indirect impacts of human activities on the marine ecosystem in the context of global change.

**The GLOBEC approach**

Since the aim is to complement existing programmes in this area, the approach will be to identify particular scientific strengths within GLOBEC and seek ways to apply them in cooperation. Some of this cooperation may be through the activities of the regional cosponsors, or in the case of SPACC with agencies dealing with the fisheries for small pelagic species.

**Task 2.3.1  Impacts of fishing**

**Rationale**

Fish occupy the mid- to upper trophic levels in marine ecosystems. They form schools in the upper ocean where biological activity is the greatest, and from which human beings have taken portions of the fish population. Fish biomass has fluctuated through time due to fishing as well due to natural changes in ecosystems.
Fishing has significant potential impacts on marine ecosystems. The major direct one is via mortality on target species, and indirectly on other species as by-catch. By-catch as a result of fishing activities provides food for seabirds and other scavenging species. Heavy gear may damage organisms on the seabed, and passive gears such as gill nets may inadvertently catch marine mammals and seabirds. Towed gears will disturb the seabed resulting in changes in benthic communities. In the long term such direct impacts of fishing may result in indirect impacts such as changes in trophic interactions.

Ecological considerations suggest that the removal of fish by large-scale fishing will result in changes in food web structure: e.g., reduced grazing pressure of fish on large zooplankton would allow the large zooplankton to increase rapidly, which would then in turn have effects on the small zooplankton community: a cascade effect of fishing through food web structure. Intensive fishing as well as climate and/or environmental change is also considered as a main cause of the species replacement among fishes when fisheries persistently focus on specific species.

In commercial groundfisheries, the oldest and largest members of long-lived species are the first target of fishermen, so that many exploited fish populations show truncated age and size structures. The number of offspring should therefore decrease in this case, since the larger sizes produce a major portion of egg masses. Also, if the fish school has a migratory behaviour through its life cycle, the truncated populations might use different habitats compared to those before fishing, and develop new behavioural strategies to adapt to the new habitats. For short-lived fish species, overfishing might also cause changes in fecundity and growth.

**Specific objectives**

- To contribute to an evaluation of the impact of fishing on particular ecosystems of relevance to GLOBEC, and on the interactions between components of these ecosystems.
- To contribute to the development of indices of overall system performance, and to evaluate their value in summarising information about the state of marine ecosystems
- To understand how fisheries alter the food web structure including target species, and to provide quantitative data for the cascade hypothesis as well as species replacement in marine ecosystem.

**Implementation**

Development of this research area within GLOBEC will be in close cooperation with existing and ongoing initiatives, for example within ICES, and the work of the SCOR Working Group 105 on “The impact of world fisheries harvests on the stability and diversity of marine ecosystems”. The aim will be to contribute specific GLOBEC expertise to these efforts, particularly in relation to ecosystems of interest to the Regional Programmes.
Outputs

- A better understanding of the impacts of fishing on marine ecosystems as a contribution to the evaluation of the effects of global change on these systems
- Stimulating interdisciplinary research between fishery scientists and biological oceanographers.

Task 2.3.2 Effects of introduced species

Rationale

Compared to knowledge of terrestrial species introduction, data on the dynamics of marine species introduction are scarce, and predictive models of their potential effect on marine ecosystem structure are not possible. Rates of introductions of non-native species have been increasing dramatically, either as a consequence of ballast water discharge, or commercial aquaculture. A recent example is that of the ctenophore *Mnemiopsis leidyi* (Shiganova 1998). This was introduced accidentally some years ago from the eastern seaboard of the United States into the Black Sea where this active predator rapidly proliferated, reaching densities of 30 individuals per cubic metre, and has been implicated in the rapid collapse of the pelagic fisheries. Knowledge of the biology and population dynamics of introduced species remains limited. In addition to transport in ballast water marine species may potentially be moved by tens or even hundreds of kilometers per generation, and nearshore oceanographic process may have particular significance for transport and recruitment dynamics.

Specific objectives

- Carry out comparative studies on the ecology and population dynamics of introduced species in the area of introduction in comparison with their area of origin
- To quantify the impact of species introductions on marine ecosystem structure
- To contribute predictive models of the dispersal rates of introduced organisms.

Implementation

As with Task 2.3.1, the aim will be for GLOBEC to cooperate closely with existing and ongoing initiatives, for example within ICES and the International Maritime Organization (IMO). In particular, close interaction is envisaged with the developing SCOR-IOC initiative on, “The Global Ecology and Oceanography of Harmful Algal Blooms” (GEOHAB). The work should contribute particular GLOBEC expertise to these efforts, and not overlap with them. Specific studies should be focussed on species and ecosystems of interest to GLOBEC programmes, for example the Black Sea.

Outputs

- A contribution to better understanding of the effects of anthropogenically introduced species on marine ecosystem structure in relation to the evaluation of the effects of global change on these systems.
Figure 15

Flow diagram of the Activities and Tasks detailed in Focus 2 (Process Studies).

Activity 2.1
Research on life histories and trophodynamics and their modelling in ecosystems

Task 2.1.1 Zooplankton reproduction, growth and mortality rates
Task 2.1.2 Zooplankton trophodynamic strategies
Task 2.1.3 Zooplankton-fish interactions
Task 2.1.4 Role of micozoooplankton in food webs

Activity 2.2
Identification and understanding of multiscale physical-biological interactions

Task 2.2.1 Ocean physics and basic biological processes of individual organisms
Task 2.2.2 Mesoscale physical-biological interaction
Task 2.2.3 Large-scale physical-biological interaction

Activity 2.3
Responses of marine ecosystems to fishing and species introductions

Task 2.3.1 Impacts of fishing
Task 2.3.2 Effects of introduced species
FOCUS 3 Predictive and Modelling Capabilities

Background
GLOBEC has the goal of understanding and ultimately predicting how populations of marine animal species respond to natural and anthropogenic changes in global climate. This goal will be achieved through collection of information from a series of coordinated interdisciplinary process and modelling studies. Development of diagnostic and prognostic models is required to elucidate ecosystem dynamics and responses on a range of time scales, including major climatic fluctuations. The concept is that predictive capabilities are achievable only if observations and modelling are designed and developed together with the aim of predicting marine ecosystem parameters at different time scales. Key variables of interest for GLOBEC must be chosen carefully, and will be dictated in part by special regional aspects (e.g., target species), and will likely evolve as GLOBEC results are obtained. However, fundamental physical (e.g., meteorology, currents, temperature, salinity, etc.) and biological (e.g., phytoplankton and zooplankton biomass distributions and rate processes) observations will form the GLOBEC core measurements and must be modelled with high fidelity. During recent years, the GLOBEC Sampling and Observational Systems Working Group (SOS-WG) and Numerical Modelling Working Group (NM-WG) have prepared reports individually (GLOBEC Reports No. 3 and 6) and jointly (GLOBEC Special Contribution No. 2). These documents provide the basis for development of Focus 3. The objectives of Focus 3 consist of activities that will facilitate advances in sampling and observational systems (Activity 3.1), modelling (Activity 3.2), and coupled modelling-observational systems (Activity 3.3) that can be used to address the scientific questions of GLOBEC.

General approach
Develop models that interface with interdisciplinary observational systems so that the coupled model-observation system has the capability to examine the responses of selected marine ecosystems, up to the level of zooplankton and fish populations, to physical forcing and biological interactions. The modelling component will provide assistance in the design of field studies and the dynamical interpretation of field measurements. Close links between Focus 3 and the Regional Programmes, and research on Retrospective Studies (Focus 1) and Process Studies (Focus 2) will be critical to success. A number of general activities relevant to this Focus are included in the Framework Activity relating to methods standardization and model comparisons, which are of direct interest to all component GLOBEC programmes. Other Activities and Tasks of this Focus will be core components of individual regional and national programmes (for example, it is not expected that all national GLOBEC programmes will choose, or be able to develop, new technologies). Participation in GLOBEC provides the advantage that new methods and technologies developed in one programme or region may be readily transferred to other programmes and regions (for example through GLOBEC workshops, working groups, laboratory visits).
Activity 3.1  Design and Testing of Relevant Sampling and Observational Systems

Introduction
There have been several recent breakthroughs in the area of new technologies which may be used for observing variability in marine biological, chemical, and physical processes. Many of these are of direct relevance to GLOBEC. This Activity also has strong links to the process studies (Focus 2) in the sense of providing a means to bridge the scales from highly localized process work to broader population level factors. It also is clearly linked to the modelling work as shown in the section on Activity 3.1.

General objective
• Utilize new sampling and in situ optical, video, and acoustical methods and systems, and satellite remote sensing, to provide comprehensive measurements of ecosystem properties on time scales from minutes to years and on space scales from less than millimetres to the global scale.

The GLOBEC approach
One of the great challenges of GLOBEC is to use effective observations that span roughly ten orders of magnitude in spatial and temporal domains (Figure 16) to understand variability in physical and biological environments. GLOBEC will rely on synoptic descriptions (Figure 17) and predictions which require nested sampling strategies and nested numerical models with data assimilation capabilities. A major aim will be to make modelling techniques and models widely and openly available to as many teams and countries as possible. The Framework Activities 5.2 and 8.3 are in particular intended to help with this.

Task 3.1.1 Design test-bed experiments to improve interpretation and utilization of new acoustical and optical data as well as to develop new techniques and methodologies

Rationale
Acoustical and optical technologies provide opportunities for increasing the volume and broadening the range of biological data (Holliday and Pieper 1994; Schultze et al. 1992). However, interpretation of these data remain difficult. Studies that allow comparison of a variety of instruments and platforms (a testbed) can be used to develop the understanding needed and approaches for melding the many types of data. Oversampling will be necessary initially to determine minimal sampling resolutions. Concurrent, co-located sampling using nets (Figure 18), acoustics (e.g., multi-frequency and Acoustic Doppler Current Profiler [ADCPs]), videos, optics, etc. will be valuable for this Task. Behavioural observations may be obtained as part of testbed and process-oriented studies. These are important for quantifying feeding, swimming, spawning, and predator-prey behaviours as well as for studying biological-physical interactions on small scales (e.g., questions concerning the roles of turbulence, internal gravity waves, etc.). Innovative sampling methodologies could be deployed via the testbeds.
Figure 16

Suggested relation between size and growth rate of major groups in the plankton showing size ranges potentially covered by acoustic and optical instrumentation considered in Focus 3. (T. Dickey).
Figure 17

Broad-Scale Survey station positions on George’s Bank, illustrating the synoptic mesoscale sampling approach used (USG LO BEC).

Georges Bank Broad-scale stations sampled on Oceanus 319
Figure 18

Instrumentation and sampling gear used on the Broad-Scale Survey on George’s Bank (see Figure 17) (US GLOBEC).
**Specific objectives**

- To design testbed experiments to compare performance of new instruments and to intercalibrate existing technologies
- To capitalize on new technologies and modelling capabilities for the experiments
- To establish optimal sampling designs for each region.

**Implementation**

New instrument performance and comparisons with existing technologies will obviously form a significant component of the development of new technologies. Similarly, appropriate sampling designs need to be developed for each region, and for each technology. Comparisons of designs among regions or GLOBEC programmes should be conducted as part of the activities of the sampling and modelling working group (see Framework Activity 5) or other relevant workshops.

**Outputs**

- Reports providing guidance for future GLOBEC sampling and modelling activities
- International testbed experiment project coordinated by the GLOBEC Working Group or a GLOBEC-sponsored workshop.

**Task 3.1.2** Explore new means for processing and utilizing high bandwidth, rapidly sampled data (e.g., video, optical, and acoustical) as well as analyzing complex interdisciplinary data sets

**Rationale**

Multi-frequency optical and acoustical data and video imagery can now be obtained. These data are highly detailed, but challenging in terms of their volume and interpretation.

**Specific objectives**

- To develop new methodologies and approaches to process optimally and utilize these important types of data
- To review methods for the analysis and interpretation of these data, including geostatistics and spatial analysis, and facilitate development of new methods as needed.

**Implementation**

To examine and recommend processing and statistical methodologies and approaches. For some situations, new techniques may need to be developed and made available to the GLOBEC and marine science research community generally, for example, as reports which would give full details of the methods including sample datasets. Dissemination would be enhanced through use of a web page to discuss technologies and exchange methods. Training in these new technologies and meth-
ods is also an important issue. The sampling and modelling working group of GLOBEC or a GLOBEC-sponsored workshop is recommended to initiate this Task.

**Outputs**
- Review and recommendation of appropriate methods for analyses of complex, multi-disciplinary, data sets deriving from new technologies.

**Task 3.1.3**

*Identify biotechnology which may be used for identification of different populations of targeted species.*

**Rationale**
Population dynamics is a prime focus for GLOBEC. Without the ability to distinguish discrete stocks or populations of target organisms, attempts to develop models of their population dynamics will be confounded by exchanges of individuals among populations. Conversely, the ability to identify individuals from different stocks or populations may enable estimates of exchange rates among populations to be determined. Further, new biotechnology might be useful for quick taxonomic identification of mixed plankton samples, which would reduce processing time immensely and allow taxonomic discrimination at time and space scales currently sampled only for physical characteristics. New genetic marker methods should be utilized for this Task.

**Specific objectives**
- To identify different populations and larval-stage development using new genetic methodologies

**Implementation**
Development of new biotechnologies is expected to be carried out in only some of the national or regional GLOBEC programmes. However, as with development of new sampling technologies, it is important that new developments in biotechnologies be made available widely and rapidly to the marine science community. A special subcommittee of the GLOBEC sampling and modelling working group could be formed to summarize relevant work in this area and report on progress and likely breakthroughs. Note that the US GLOBEC programme has discussed new biotechnology in their Report No.3.

**Outputs**
- Report to the GLOBEC community on biotechnology and new methodologies appropriate for deployment in the GLOBEC field programmes.
Activity 3.2 Develop Relevant Modelling Capabilities

Introduction
Modelling is central to GLOBEC research. The purpose of GLOBEC modelling is to synthesize understanding of how mesoscale physics modulates interactions between small- and large-scale ecosystem processes and to develop predictive capabilities. The goal is to predict the effects of climate change on marine populations and communities.

Modelling activities within GLOBEC will be directed at elucidating the mechanisms linking biological and physical components of marine ecosystems and understanding the responses of ecosystems, particularly targeted populations of higher trophic levels, to various types of physical forcing and biological interactions. This will require the development of a hierarchy of models that will be coupled with the GLOBEC process and observational programmes. GLOBEC will need to use multiscale models that are capable of assimilating physical, biological and chemical data. The development of such models poses novel scientific and methodological issues and as a result provides GLOBEC with an opportunity to advance the state-of-the-art in marine ecosystem modelling. The goal is to develop ecosystem models which can predict the ecosystem responses at time scales from a few days to years. Such predictions will be possible if coupled physical-biological interaction models are developed and data assimilation techniques for initialization and updating with multivariate data are carried out.

Overall objectives
- To model the response of marine ecosystems to various types of physical forcing and biological interactions and to predict marine ecosystem response to climate fluctuations
- To develop biological models that are appropriate for describing marine ecosystems, including zooplankton, ichthyoplankton, and other top predator (e.g. Antarctic penguins) species of interest
- To develop coupled physical-biological models that can be used to study the response of zooplankton populations to physical forcing
- To develop data assimilation techniques for coupled physical-biological models
- To define parameterization of physical and biological processes at different scales.

The GLOBEC approach
Modelling efforts within the GLOBEC programme will of necessity be diverse, will focus on a selected range of time and space scales (e.g., consistent with field efforts), and will consider interactions that occur on a variety of physical and biological time and space scales (Figure 19). To foster the development of models that can be used to address the GLOBEC scientific objectives will require a multi-faceted approach that will include conceptual modelling studies of simplification and predictability, prototype models of biological processes in idealized environments, and site-specific coupled physical-biological predictive models. A major aim will be to make modelling techniques and models widely and openly available to as many teams and countries as possible. The Framework Activities 5.2 and 8.3 are in particular intended to help with this.
Figure 19

Finite element grid used in modelling the circulation on George's Bank; levels of resolution vary in different regions of the study area (Modified from McGillicuddy et al. 1998).
Task 3.2.1 To develop biological models capable of describing selected ecosystems and which include relevant zooplankton and ichthyoplankton species

Rationale
The GLOBEC focus is on herbivores and primary carnivores. These groups exhibit many varied adaptive strategies, and have a wide range of food resources. The approaches for modelling higher trophic levels are fundamentally different from those used for modelling nutrients and phytoplankton. Higher organisms exhibit complex behavioural responses to their environment and other organisms, and include a wide range (orders of magnitude) of individual body size within their life cycle (Figure 16). Structured population models (SPMs) and individual based models (IBMs) are approaches for modelling higher trophic levels, depending upon the specific objectives. The SPMs are appropriate for simulating space and time distributions of successive cohorts of targeted species with multistage development. Coupling of SPMs with spatially resolved ecosystem models provides time varying spatial distributions of the populations studied. Major research challenges for SPMs include parameterization of the processes that determine cohort growth and mortality and coupling of these models with circulation models so that the scales of the two models types are compatible. The IBMs track individuals of specific species through time and provide predictions of individual growth and survival probability as determined by ambient environmental conditions. Major research challenges in the development of spatially explicit IBMs include formulation of individual survival probability, and feedback between population density and individual survival. Individual based modelling is applicable to modelling the early life history dynamics of ichthyoplankton since techniques (e.g., otolith microstructure) exist for determining individual growth histories. Thus, it is possible to parameterize and test models in a field setting. Multi-species models may be constructed from combinations of bulk-biomass representations, SPMs and IBMs. In these models, mortality remains a key process variable of population dynamics to be estimated.

Specific objectives
- To develop models of lower trophic levels that include the diversity of major potential food species utilized by the selected zooplankton and ichthyoplankton target species, i.e. phytoplankton, microzooplankton
- To develop models of higher trophic levels using IBM or SPM approaches, as appropriate
- To develop modelling approaches that emphasize critical developmental stages i.e., those with high mortality rates or particular behaviour
- To develop formulations and parameterizations for biological processes (vital rates) and their links to physical (light, turbulence, temperature) and biological (food quality, food quantity) parameters at the level of individuals that can be extended for inclusion in structured population models.
Implementation
Integration of present knowledge on zooplankton biology and definition of approaches for including important, but not well known, processes needs to be conducted in collaboration with the research under Focus 2 (Process Studies). In addition, strong ties should be maintained between GLOBEC modelling, process, and monitoring studies (Focus 1). Further ties between empiricists and modellers will be maintained through workshops that bring the two communities together to discuss biological processes, and through the sampling and modelling working group. The variety of models must be compared through a model intercomparison study (Framework Activity, 5.2 below) in order to understand their similarities and differences, in particular with the view towards synthesis of GLOBEC results (see the Integrating Activity on programme synthesis). The model comparisons should include results from laboratory, mesocosm, and regional scale efforts.

Outputs
• Development of detailed mechanistic models for key zooplankton species
• Report(s) describing results of model intercomparison studies.

Task 3.2.2 Develop regional and mesoscale coupled physical-biological models

Rationale
Although global in scope, the GLOBEC programme is composed of several distinct mesoscale and regional programmes which are linked through their focus on the overall science questions of GLOBEC. The GLOBEC modelling component provides the framework for integrating the results of the regional programmes. It is envisioned that the mesoscale and regional models (Figure 20) will be capable of interfacing with larger (e.g., basin) or smaller (e.g., coastal) interdisciplinary models.

Specific objectives
• To predict the effects of physical forcing on ecosystem dynamics at selected spatial and temporal scales
• To develop a suite of approaches rather than searching for a generic model.

Implementation
Circulation models must be developed and implemented that contain the dynamics and space-time resolutions that are necessary for addressing issues related to biological production problems. Parameterizations need to be developed that will allow the transfer of results from fine scale coupled physical-biological models to larger scale models (e.g., regional to basin scale). Further, approaches for the assimilation of physical, biological and chemical data into a range of coupled physical-biological models are required in order to link directly with the on-going process and monitoring studies. To test model implementation and performance, and to support field
programmes, these models will be provided to field and laboratory researchers in such a way that they can be used to aid in sampling design and data analysis. Similarly, these models need to be available to Focus 1 researchers so they can be used for diagnostic studies with historical data sets. The development of models that can be used in a manner similar to the community models used in meteorology and physical oceanography is encouraged.

Outputs
• Development and evaluation of circulation models that can be used for coupling with biological models. This could be achieved through a workshop and workshop report
• Provide a variety of models to the broader community for use. This would further the development of parameterizations and data assimilation approaches.

Task 3.2.3 Basin scale ecosystem models

Rationale
These models should give the necessary boundary conditions for regional/mesoscale models and should encompass the relevant phytoplankton and zooplankton dynamics at the scale of the open ocean or general circulation. Most of the mesoscale and/or coastal ecosystems depend strongly upon such an embedding environment, certainly from the point of view of physical interactions, and probably also for biological processes. Due to the coarseness of the spatial grid, such models should develop adequate ecosystem closure sub-models and parameterizations of sub-grid scale processes. To downscale to regional/mesoscale models, techniques should be developed and one-way/two-way nesting explored. This step will contribute to the spatial and temporal dynamical interpolation of observational data to the large scale, in order to advance towards the goal of predicting global ecosystem variability in relation to climate change.

Outputs
• Development and evaluation of circulation models that can be used for coupling with biological models. This could be achieved through a workshop and workshop report
• Provide a variety of models to the broader community for use. This would further the development of parameterizations and data assimilation approaches.
Observed and predicted distribution of *Calanus finmarchicus* on George’s Bank using a data assimilation modelling approach (McGillicuddy and Runge, US GLO BEC).
Specific objectives
• To develop ecosystem models at the scale of ocean basins
• To develop one-way/two-way nesting between different scales and structured ecosystem models
• To develop closure sub-models and parameterizations of sub-grid scale ecosystem processes in large-scale ecosystem models.

Implementation
Large-scale ecosystem models should describe in sufficient detail the functioning of the pelagic ecosystem. Consideration should be given to the linkage between phytoplankton and zooplankton components while connections with the benthic subsystem may be parameterized. Levels of aggregation of ecosystem variables should be considered and closure hypothesis and schemes developed. Nesting procedures and concepts involving both spatial scales and biochemical parameters to connect with mesoscale/regional models should be developed and sensitivity of the mesoscale/regional models to such hypotheses will be tested. These large-scale ecosystem models should be generic in contrast to the mesoscale/regional models, which may consider details of regionally relevant species for phytoplankton and zooplankton components.

Outputs
• Large scale ecosystem models with nesting techniques to regional/mesoscale models.

Task 3.2.4 Develop models of small-scale processes and parameterizations

Rationale
Interactions between a predator and its prey occur at the scale of the individual and as a result small scale turbulent processes are of considerable importance in mediating this interaction. Models provide an approach for theoretical investigation of these predator-prey interactions, and experiments that can validate and test the results of these models should be developed.

Specific objectives
• To develop model formulations and parameterizations for zooplankton feeding on various prey species in realistic hydrodynamical conditions
• To develop model formulations on organism behaviour and other interactions (organism-environment)
• To develop approaches for representing predator-prey interactions at scales relevant to individuals (i.e. micrometers-centimetres) at the typical resolution scales of most coupled physical-biological models (1–20 km).
Implementation
Models of zooplankton feeding behaviour that provide predictions of secondary production resulting from theoretically-derived turbulent flow fields need to be developed. Testing predictions of these feeding behaviour models in the laboratory and in the field also needs to be done in close collaboration with Process Studies (Focus 2).

Outputs
• Provide formulations of small scale processes to include in population models.

Task 3.2.5 Prognostic models of long-term changes in zooplankton and fish stocks

Rationale
Understanding long-term shifts in marine zooplankton and ichthyoplankton populations will require models that consider climatic time scales and are capable of using retrospective and historical measurements. Simulations of long-term changes in the population dynamics of commercial species resulting from natural variability and anthropogenic activity are needed. The development of these models will require close interaction between modellers and those focusing on analyses of historical and retrospective data sets (Focus 1).

Specific objectives
• To increase understanding of long-term climate-mediated (natural and anthropogenic) changes in marine ecosystems through hindcasting zooplankton and ichthyoplankton population changes
• To use models in the analysis of historical and retrospective data sets.

Implementation
Development of climate-biological models that can be used to predict responses of zooplankton populations and fish stocks to long-term environmental change will require interactions among climatologists, physical oceanographers, and lower and upper trophic level modellers. There are potential linkages with the modelling activities of CLIVAR and JGOFS.

Task 3.2.6 Development of new approaches and techniques in modelling

Rationale
Scientific progress in GLOBEC is possible only if the modelling and experimental/observational programmes are fully unified and integrated. Models with the space and time resolution needed by GLOBEC can be achieved only through the integration of models and data. The development of data assimilative physical-biological models poses unique and challenging research possibilities. Also, comparison of model outputs with large volumes of data from the many sensor types envisioned for the testbeds will require new and innovative approaches.
Specific objectives

- To identify a suite of problems, especially coupled physical-biological problems, that can be addressed with idealized process models (or models in idealized domains) and use these problems to develop data assimilative methods for physical-biological models.
- To develop new techniques for comparison of field measurement and model predictions.

Implementation

Concepts for data assimilative methods in physical-biological models will be developed as part of the activities of the sampling and modelling working group (see also GLOBEC Report No. 6). This should include investigation and assessment of the developing field of virtual reality for visualization of model-data comparison. Reports and recommendations for implementation of the concepts, and comparisons of models, will be required.

Outputs

- Data assimilative models that can be used in real time with data obtained from field programmes and monitoring sites.

Task 3.2.7 Development of data assimilation techniques for ecosystem models

Rationale

To achieve predictive capabilities, deterministic ecosystem models should be initialized and updated with biological, chemical and physical data at relevant space-time scales. Experiments should be conducted to check on the relevant parameters to be updated in the different models; one of the most useful aspects of data assimilation is to help set biological parameters. Appropriate data extrapolation techniques should be determined. These will enable vertical distribution and other model variables to be inferred from surface data using multivariate statistical techniques. This approach will simplify the complex and multivariate assimilation problem in a relevant subspace. Models and data assimilation schemes developed should be used to evaluate data collection schemes and their importance in the assimilation procedure. This Task is strongly linked with Activity 3.3 and it will be dependent upon the availability of synoptic scale multiparameter data and a hierarchy of ecosystem models. Careful recognition will be given to the fact that once models and data are merged together, they are no longer independent.
Specific objectives

- To develop techniques for updating and initializing ecosystem models and assessing them in a predictive mode.
- To develop a hierarchy of data assimilation tools coupled to observing systems and model complexity.
- To determine the intrinsic predictability time scales applicable to ecosystems and the limiting factors.
- To develop the necessary infrastructure for continuous predictions of marine ecosystem variability at short, medium (mesoscale) and long time scales (climate).

Implementation

Data assimilation techniques can include simple nudging, simplified or reduced order Kalman filtering (Optimal Interpolation) for several biological and chemical parameters and adjoint modelling. Testing of methods includes the use of multidisciplinary synoptic data (in situ and satellite) and most probably mesoscale resolution models. Predictability studies will consider Monte Carlo experiments or ensemble forecasting techniques.

Outputs

- Provide data assimilation methods and schemes to update and initialize ecosystem models for predictions.
- Assessment of the predictability time scale of the biological parameters coupled with the physical environment.

Activity 3.3 Development of Coupled Modelling- Observational Capabilities and Applications

Introduction

This Activity brings together observational and modelling initiatives within GLOBEC to progress towards project synthesis. GLOBEC will utilize coupled modelling and physical/biological observational systems. The approach will involve nested and parameterized models, coupled with coordinated field data collection, in order to determine the ecosystem interactions of interest and to simulate the influence of global change on these interactions.

Specific objectives

- Develop modelling capabilities with interdisciplinary, coupled modelling-observational systems.
The GLOBEC approach
Development of multiscale biological-physical dynamical models taking account of spatial and temporal nesting, formulation and adequate parameterization of biological processes, and consistency and correspondence between data and models. These Tasks will be conducted by national or regional programmes. Comparisons of experiences among programmes, and transfer of technologies and models to programmes not directly developing these Tasks.

Task 3.3.1 Development of coupled model/observational systems will be promoted using testbeds

Rationale
The design and implementation of sampling and modelling systems will require coordination and considerable planning and communication among modellers and field researchers. Subgrid scale parameterizations and development of empirical relations are necessary. Testbeds can be used effectively for these purposes. The testbeds should be thought of as comprehensive arrays of sampling platforms, including in situ and remote (satellite) systems.

Specific objectives
• To coordinate the design and implementation of both sampling and modelling activities
• To plan and coordinate near real-time data telemetry and assimilation of data into models.

Implementation
Development of coupled model and observational systems should be encouraged in a few well selected testbed locations. Experiences gained through these pilot studies can then be expanded to other locations and projects. Design and development of these coupled testbed systems should be coordinated through the sampling and modelling working group of GLOBEC.

Outputs
• Development of appropriate subgrid scale parameterizations and empirical relations which can be applied elsewhere
• Reports on testbed results and experience which can be utilized for major GLOBEC observational and modelling studies and for developing GOOS.

Task 3.3.2 Execution of “Observational System Simulation Experiments” (OSSEs)

Rationale
Determining the optimal mix of sampling platforms and sensors will require execution of OSSEs. Testbeds may logically be used for OSSEs. These should precede GLOBEC process studies and deployment of large scale (e.g., regional and basin-scale) sampling arrays.
Specific objectives

- Utilize testbeds for development of OSSEs
- Perform OSSEs prior to major field campaigns.

Implementation

Implementation of this Task is incremental from the results obtained in other testbed activities (e.g. Activity 3.1), and is based upon results from pilot studies on appropriate sampling designs (e.g. Task 3.3.1). Analyses of these experiences and recommendations for action and selection of appropriate sites will be coordinated through the sampling and modelling working group.

Outputs

- Reports to GLOBEC on OSSE results.

Task 3.3.3

Make available the observational and modelling methodologies for development of the Global Ocean Observing System (GOOS), particularly, the Living Marine Resources (LMR) module

Rationale

The GOOS-LMR can benefit from GLOBEC research, especially in the areas of observational networks and modelling. In turn, development of the GOOS-LMR, Health of the Ocean (HOTO), and Coastal modules should be valuable for GLOBEC in that particular opportunities for collaborative sampling should arise as GOOS evolves. In addition, capacity building through GOOS could benefit GLOBEC activities.

GLOBEC can contribute to the design of GOOS by providing information on critical parameters to be measured and on time and space scales that are best suited for predictive capabilities in such a system. GLOBEC is also concerned with continuing development of technology suitable for continuous sampling of biological and chemical parameters in the ocean, and these should also be of interest to GOOS, especially its modules on LMR and HOTO.

Specific objectives

- Establish effective linkages with, and information transfer to, relevant programmes such as GOOS.

Implementation

The design and implementation of GOOS will depend in large part on the results and analyses from GLOBEC. Linkages between GLOBEC and GOOS need to be established early, both to develop a history of information flow and to evaluate potential GOOS protocols, locations, and sampling designs. Oversight of this Task should be conducted by the GLOBEC IPO, in consultation with the GLOBEC SSC.
Figure 21

Flow diagram of the Activities and Tasks detailed in Focus 3 (Predictive and Modelling Capabilities).

Activity 3.1
Design and testing of relevant sampling and observational systems

Activity 3.2
Develop relevant modelling capabilities

Activity 3.3
Development of coupled modelling-observational capabilities and applications

Task 3.1.1
Design testbed experiments to improve interpretation and utilization of new acoustical and optical data as well as to develop new techniques and methodologies.

Task 3.1.2
Explore new means for processing and utilising high bandwidth, rapidly sampled data (e.g., video, optical, and acoustical) as well as analysing complex interdisciplinary data sets. Identify biotechnology which may be used for identification of different populations of targeted species.

Task 3.1.3
To develop biological models capable of describing selected ecosystems and which include zooplankton and ichthyoplankton species

Task 3.2.2
Develop regional and mesoscale coupled physical-biological models

Task 3.2.3
Basin scale ecosystem models

Task 3.2.4
Develop models of small-scale processes and parameterisations

Task 3.2.5
Prognostic models of long-term changes in zooplankton and fish stocks

Task 3.2.6
Development of new approaches and techniques in modelling

Task 3.2.7
Development of data assimilation techniques for ecosystem models

Task 3.3.1
Coupled model/observation systems development of using testbeds.

Task 3.3.2
Execution of Observational Systems Simulation Experiments (OSSEs)

Task 3.3.3
Make available observational and modelling methodology for development of the Global Ocean Observing System (GOOS), particularly, the Living Resources (LMR) module
FOCUS 4  Feedbacks from Changes in Marine Ecosystem Structure

Background
The general objective of Focus 4 as outlined in the GLOBEC Science Plan is:

- To cooperate with other ocean, atmosphere, terrestrial and social global change research programmes to estimate feedback from changes in marine ecosystem structure to the global earth system with emphasis on the following three activities:
  - Select appropriate topics for interaction, for example, carbon fluxes, in consultation with other programmes, particularly with JGOFS and LOICZ
  - Predict scenarios of altered marine ecosystem structure and their impact on important stocks, and potential feedback to the global system
  - Draw on the results of other international programmes involved in modelling of climate change and its impacts.

The first three Foci of GLOBEC consider the influences of physical and biological processes on trophodynamic interactions, with the emphasis on zooplankton-fish interactions. One hypothesis is that the population dynamics of zooplankton and lower trophic levels exert the major, non-anthropogenic influence on variability in fish stock production. This is, for example, seen in the observed variability in abundances of small pelagic fish stocks in major upwelling areas of the world oceans (see the description of the GLOBEC regional programme SPACC, see below). The relationships between cod stocks fluctuations and zooplankton production in the North Atlantic are also a fundamental concern of another GLOBEC regional programme, the CCC programme coordinated by ICES (see below). The ways in which the population dynamics of zooplankton may be influenced through feedback from the higher and lower trophic levels are key issues for understanding marine ecosystem change in a wider context. These aspects of the structure and functioning of marine ecosystems, and of the dynamic relationships among the trophic levels within them, are not being addressed in any other marine global change programme.

For the purposes of implementation, some of the activities above, as defined in the GLOBEC Science Plan, will be developed in cooperation with other IGBP programmes. They have been redefined in a more scientific context:

Activity 4.1 Ecosystem-Climate Interactions on Multiple Scales and their Influences on Basic Biological Processes throughout the Food Web
Activity 4.2 Earth System Impacts from Changes in Marine Ecosystems
Activity 4.3 Social Impacts of Changes in Marine Ecosystems

All three activities comprise components which will require expertise from beyond the GLOBEC science community; they will require further elaboration through extensive interdisciplinary effort with other global change programmes, i.e. physical programmes (related to Activity 4.1), programmes on trophic transfers (related to
Activity 2) and social sciences programmes (related to Activity 4.3). These parts of the activities will be considered in the subsequent sections on Integrating Activities and Scientific Networking.

Activity 4.1 involves the consideration of physical processes, which, through their actions on multiple spatial and temporal scales, influence trophodynamics through climate variability and change. Thus, climate change may have a direct influence on trophodynamics through its impacts on zooplankton-fish interactions, or through indirect pathways involving primary productivity, top predators and human influences. These indirect impacts of climate change on trophic relationships may be as significant as the more direct ones.

It is generally accepted that smaller spatial scales and shorter temporal scales mainly influence the dynamics of lower trophic levels, and that larger and longer scales influence higher trophic levels. However, we now see that the larger spatial scales and the longer temporal scales may also have a significant influence on the dynamics of the primary and secondary producers, especially in their decadal-scale population variability. Climate change not only influences the individual physical and biological processes at trophic levels, it also influences the ecosystem itself by large-scale advection of water masses and the resultant displacement of zoogeographical regions.

The ENSO phenomenon is the most prominent example of the effect of basin-scale, interannual to decadal-scale physical variability that not only affects higher trophic levels, but has an impact on all levels down to the primary producers. Analysis of the long time series from the CPR in the North Atlantic indicates that the observed interannual to decadal-scale variations in phytoplankton and zooplankton abundances are linked to the basin-scale NAO. From this it is to be expected that the feedback from the trophic level below, and possibly also above the level of zooplankton-fish interactions, will affect the target trophic levels of interest to GLOBEC.

Activity 4.1 must take advantage of the synthesis emerging from the results of the World Ocean Circulation Experiment (WOCE) and GLOBEC must be certain to establish links to the new programme on Climate Variability and Predictability (CLIVAR) (see 7.5.2. below). CLIVAR will emphasize the dominant role of decadal-scale climate variability which coincides with GLOBEC’s interest in such time scales from an ecosystem perspective. GLOBEC will also develop strong ties to the LMR component of GOOS which has identified the need for environmental data in the management of fish stocks.

Activity 4.2 is based on the premise that changes in the structure of marine ecosystems and in the biogeochemical flows among system components, will have significant impacts on the functioning of the entire Earth system. Zooplankton are assumed to be an important component in the drawdown of CO₂ through grazing on phytoplankton and production of faecal pellets. These processes, in turn, contribute to primary production through the recycling of nutrients and the resultant regenerated production. The timing and magnitude of zooplankton spawning is assumed to be strongly dependent on primary production. The dynamics of these processes have specific features in each of the major oceanic areas selected for study in the regional GLOBEC programmes. For example, in the upwelling regions that are a concern of the SPACC programme, the dynamics of lower trophic interactions are very
different from the interactions seen in spring bloom-dominated ecosystems like those of the North Atlantic (CCC) and of the North Pacific (CCCC).

On the other hand, we see that human activities such as fishing and hunting impact on the higher trophic levels of marine ecosystems may be of equal or even greater significance than natural influences or climatic effects on the lower trophic levels. Examples of important topics to address in this context are the consequences of sea bird mass mortalities due to El Niño events, deaths of fur seals in Benguela Niños, the removal of whales as top predators in the Southern Ocean, and the occasional mass starvation and mortality of seals in the Nordic Seas.

Many of these aspects of Activity 4.2 will require close integration of GLOBEC and two other IGBP programmes, JGOFS and LOICZ. These can provide important support to GLOBEC for understanding the energy flows at lower trophic levels from zooplankton grazing, production of faecal pellets, CO₂ drawdown and the issues of new versus regenerated production.

For the higher trophic levels, three IGBP programmes LOICZ, the Global Analysis, Interpretation and Modelling (GAIM) and Global Change and Terrestrial Ecosystems (GCTE) provide support and potential for interaction when considering these feedback mechanisms.

Under Activity 4.3, the socio-economic impacts of changes in marine ecosystems on local coastal communities as well as on the international fishing industry are considered. Such changes are often linked to basin-scale climate events such as the El Niños and the NAO, but fish populations often undergo dramatic changes without any apparent triggering from climatic events. There may be feedback to marine ecosystems from changes in social conditions. For example, fishing effort may be redirected to other locations, target species, or seasons which may have deleterious and unexpected impacts on marine ecosystems.

Progress on Activity 4.3 will require interaction with the Global Environmental Change and Human Security (GECHS) Project of the International Human Dimensions Programme on Global Environmental Change (IHDP) (see 7.5.1). This programme focuses particularly on how human security in the broad context is influenced by natural and man-made changes in environmental conditions and natural resources and how human communities respond to such changes.

Activity 4.1 Ecosystem-Climate Interactions on Multiple Scales and their Influences on Basic Biological Processes throughout the Food Web

Introduction
Changes in ocean climate occur on multiple temporal and spatial scales and marine ecosystems respond to these changes over a similar range of scales. Among such changes there are fluctuations of a highly periodic nature, like diurnal and seasonal changes to which organisms and populations seem to be perfectly adapted. Other changes of a more stochastic character may result in large changes in populations
and in the ecosystem structure of which they are a part. Although the apparently stochastic changes in ocean climate and in marine ecosystems seem to dominate on longer time scales, there are also large non-periodic changes on short time scales, e.g. on the time scale of synoptic meteorology, which might influence marine populations by acting on critical life stages such as larval fish.

At the level of individual organisms there are basically three environmental factors which influence feeding and metabolism: temperature, light and turbulence. In turn, these three factors are linked to the climate and to the weather system on specific scales of variations and they propagate from the atmosphere to the ocean on different time scales due to different response times. Temperature shows much smaller temporal variation and usually smaller spatial variation than the turbulence and light conditions do because of the large heat capacity of water which does not allow for rapid variations in temperature. Similarly there is less temporal and spatial variability in turbulence than in light conditions due to the time lag in transport of momentum from the atmosphere to the ocean. Thus each parameter has its specific modes of variation in the atmosphere and in the sea.

These three key factors temperature, light conditions and turbulence, in turn influence individual organisms at different trophic levels in varying degrees. While temperature is important on all trophic levels from phytoplankton to marine mammals, the effects of turbulence are mainly confined to the planktonic levels. Light conditions are most important to lower trophic levels although this parameter also has an effect higher up in the food web. Thus we see that the ways in which signals in the climate system, or a specific climatic events, such as the passage of a low pressure system, influence marine populations are very different depending on the trophic level and species involved.

The understanding of climate change and its impacts on ecosystems requires insight into a wide range of fluctuations and oscillations on temporal scales from the seasonal to interannual, decadal and longer. The most prominent climate impact on marine ecosystems, as we have experienced them up to the present time, is not the long-term anthropogenically generated climate change, but those phenomena linked to ocean climate fluctuations of interannual to decadal-scale fluctuations, such as ENSO with a dominant period of about five years and NAO with its dominant period in the ocean climate of about 10 years (Figure 22). The understanding of longer-term climate change depends on understanding these climate fluctuations and oscillations with shorter time scales. Similarly, understanding long-term changes in marine ecosystems depends on understanding ecosystem shifts and fluctuations on shorter time scales, for example those which are relevant to populations of small pelagic fish in upwelling ecosystems.

There are indications that the spatial basin-scale and temporal interannual to decadal-scale climate phenomena of the various ocean basins are more or less interlinked, although the mechanisms behind the linkages are presently poorly understood. For example, it is apparent that the ENSO has manifestations in higher latitudes through teleconnections within the atmosphere. In the North Pacific ENSO variability is found in the Pacific/North American (PNA) pattern and the NP index (Figure 22), but is best seen when averages are taken over the five winter months. The deepened Aleutian Low during ENSO events results in a characteristic SST pattern (Trenberth and Hurrell 1995; Niebauer 1988). There is evidence that ENSO vari-
ability is correlated with a dipole like structure in the SST anomaly field in the western North Atlantic.

It is, however, becoming increasingly evident that the interactive processes between the atmosphere and the ocean are forcing the large-scale fluctuations described above. Principally, it is evident that Sea Surface Temperature (SST) anomalies influence Sea Level Pressure (SLP), but attempts to reproduce the observed correlations in atmospheric General Circulation Models (GCMs) forced with the prescribed SST anomalies have been inconclusive. While these problems are important issues for international climate research programmes, and are very relevant to GLOBEC’s interests, they fall outside the range of GLOBEC’s expertise. However, some of these climate research topics in particular require GLOBEC’s interaction with these climate research programmes:

1. The interannual to decadal-scale variations in ocean climate which display some of the most powerful influences on productivity fluctuations in the marine ecosystems. Examples of such events are the impacts of: a) ENSO fluctuations on the productivity at the coast off Chile-Peru; b) the “Benguela Niños” on the productivity off the coast of Angola and Namibia; c) the NAO in the northeast and north-west parts of the North Atlantic; d) oscillations in the North Pacific system.

2. The links and possible correlations between specific climate processes and single climate parameters which influence basic biological processes (see Focus 2) in the marine ecosystem are important. These are temperature, light conditions and turbulent intensity.

3. The correlation between climate parameters in the various marine ecosystems, e.g. the correlation between temperature and wind-induced turbulence and the correlation between light (cloud) conditions and temperature.

4. The characteristic periods of temporal and spatial variation in the climate parameters mentioned in paragraphs 2 and 3 above. For example, due to the enormous heat capacity of sea water compared to that of the air masses the sea temperature shows much slower fluctuations than the atmospheric temperature as do all other climate parameters linked to the atmosphere, e.g. the wind-induced turbulence.
Figure 22

Indices of large scale atmospheric patterns. **Upper panel:** the North Atlantic Oscillation (NAO) Index – Winter, based on the differences of normalized sea level pressures between Lisbon, Portugal and Reykjavik, Iceland from 1864-1998. **Middle Panel:** The North Pacific (NP) Index, the area-weighted sea level pressure over the region 30°N-65°N, 160°E-140°W. **Lower Panel:** The Southern Oscillation Index (SOI), computed using monthly sea level pressures at Tahiti and Darwin.
There are basic differences in how climate fluctuations influence the production in marine ecosystems. This will also determine GLOBEC’s interactions with the climate research programmes. As hypothesized by Bakun (1990), variations in the production of upwelling systems are believed to be caused by changes in the kinetic energy transfer from the atmosphere to the ocean, by influencing upwelling intensity, supply of nutrients, and phytoplankton production.

In Arctic and sub-Arctic marine ecosystems, like the North Pacific and the North Atlantic, where many species live at their lower range of temperature tolerance, it is believed that the impact of climate works mainly through its influence on changes in thermal energy transfer as the seawater temperature strongly influences metabolic rates of organisms on all trophic levels. However, in sub-Arctic regions changes in the kinetic energy transfer from the atmosphere to the ocean may be an additional important factor regulating the production of the ecosystem.

The major climate events of the world ocean ecosystems are defined in various ways. The El Niño events are quantitatively monitored by a Multivariate ENSO Index, the so-called MEI Index which is composed of six climate parameters over the tropical Pacific (sea level pressure, zonal and meridional components of surface wind, sea surface temperature, air surface temperature, and total cloudiness fraction of the sky). After spatially filtering the individual fields into clusters, the MEI is calculated as the first unrotated Principal Component of all six observed fields combined. The NAO is quantified by the NAO Index (see Figure 22) which is the normalized anomaly in the sea level pressure difference (usually calculated during the winter months) between Ponta Delgado in the Azores and Akureyri, Iceland. This index represents the variation in the relative strength of the Icelandic Low and the Azores High of the North Atlantic. The NAO Index is positive when the Icelandic Low is deep and strong and negative when the Icelandic Low is relatively weak. In upwelling regions the anomaly in climate is often quantified by calculating the Upwelling Index which is the long-shore cubed wind velocity component over the region.

This demonstrates that the indices for the major climate events which impact marine ecosystems are, to varying degrees, proxy data which do not necessarily represent the climate parameters functionally related to the ecosystem processes.

**General objectives**

The objective of Activity 4.1 is to develop a framework for the application of climate indices, other proxy climate data, traditional synoptic meteorological data, and derived climate model results in the study of basic biological processes and in trophodynamic modelling. This demands that the functional relations between climate parameters and trophodynamic processes be identified and that the proper temporal and spatial scales be defined for each of the climate parameters in relation to the actual trophodynamic processes, and will in turn result in additional and improved climate indices in marine ecosystem research.

**The GLOBEC approach**

Identifying functional relationships between climate parameters and ecosystem processes and the proper temporal and spatial scales of such processes will be a part of all four Foci of GLOBEC, and particularly of Focus 2 and Focus 3. The intersec-
tions between these Foci have the potential to reveal functional relationships between basic biological processes and physical parameters. The effort should be coordinated with international climate research programmes, particularly CLIVAR which has identified as an important research topic the study of decadal-scale variations and the major climate events of the world ocean such as the ENSO and NAO. Feedback to CLIVAR of important parameters and the relevant scales of these events should lead to the development of novel climate indices. Statistical downscaling is a method used in climate modelling to represent processes and parameters on a smaller scale than those resolved by the climate model. This should also be applied to identify physical processes of importance to ecosystem processes.

Task 4.1.1 Identify how typical weather events in specific regions influence light conditions, wind-driven mixing, advection and sea temperature

Rationale
Ocean climate parameters such as temperature, wind stress and light conditions which influence basic biological processes have different modes of variability, and the individual basic processes are of differing importance in the various marine ecosystems. In Arctic and sub-Arctic ecosystems weather patterns and energy input to the ocean are dominated by frequently occurring low pressure systems passing by, and this is associated with particular patterns of spatio-temporal variation in the climate parameters. The annual light cycle in these regions dominates the primary production as well as productivity of the higher trophic levels. In upwelling regions, which are usually located at lower latitudes, production is controlled by other mechanisms and therefore is influenced by other climate parameters. In high latitude ecosystems, where the majority of species live at the low end of the temperature range, seawater temperature is the most important factor. However, this dominant role of temperature masks the effects of other climate parameters which vary in much the same way. In upwelling ecosystems the weather pattern has different characteristics with less spatial variation, but with high frequency temporal variations. The effects of ocean temperature are generally the opposite of those in Arctic regions; high temperatures are associated with a reduced rate of upwelling (and therefore of nutrient supply), with detrimental effects on production.

Specific objectives
- Describe the significant weather patterns for each of the major marine ecosystems
- Determine the spatial and temporal modes of variation of the climate parameters associated with these weather patterns
- Investigate the significance of each climate parameter for basic biological processes and overall ecosystem production.

Implementation
Global and regional databases in meteorology and oceanography comprise the major sources of data for the analysis of interrelationships between climate parameters and marine ecological processes (Figure 23). In order to analyse such data sets, local
knowledge of hydrography, physical and biological processes and an understanding of the climate parameters controlling the important biological processes will be necessary. Numerical models of ocean circulation will be an important tool in investigating the sensitivity of large-scale variability in the climate parameters on a local scale. The GLOBEC community will have to utilize the expertise within CLIVAR and other international climate research programmes in the analysis. The study of the influence of the climate parameters on basic biological processes will be done in close collaboration with Focus 2.

**Outputs**

- Establish an understanding of the relationships between weather patterns, trophic transfers and marine ecosystem production.

**Task 4.1.2** Analyse the frequency spectra of long-term temporal and spatial variation of large-scale weather events

**Rationale**

The understanding to be developed in Task in 4.1.1 will form the basis for prediction of ocean climate and its effects on marine ecosystems. A necessary condition for ecosystem prediction is to understand the basic mechanisms behind responses and how climate parameters influence them. This will form the guidelines for what type of climate predictions are needed, *i.e.* the controlling climate parameters and the required accuracy of the values, the spatial resolution and the time frame of the predictions. Presently, it is uncertain how far into the future predictions of climate are reliable, but modelling efforts are being developed in CLIVAR and other international climate research programmes. These include dynamical coupled models, statistical models and expert systems. Generally, climate predictions for marine ecosystem management do not require the same detailed spatial and temporal resolution as do today’s public meteorological services. Trends, rather than absolute values, and regional spatial scales, rather than local and detailed scales, would be of great value in this context. On the other hand, the accuracy of the time frame of the prediction is much higher, as predictions for seasons and years would be of great interest. In particular, the behaviour of the large-scale weather events such as the ENSO, the NAO and Benguela Niños is important for prediction.

**Specific objectives**

- Analyse the interannual to decadal-scale frequency spectra of regional and basin-scale climatic events
- Develop appropriate climate indices for predicting reproduction and growth in marine ecosystems.
Figure 23

Position of biological time series (with at least 20 years of zooplankton sampling and fish stock estimates) and atmospheric centres of action. **Top panel:** Time series of zooplankton sampling and fish stock estimates. 1) Gulf of Alaska, 2) Northeast U.S. Continental shelf, 3) California Current, 4) Gulf of Mexico, 5) Panamanian Shelf, 6) Humboldt Current, 7) Norwegian Shelf, 8) North Sea, 9) Iberian Coastal, 10) Adriatic Sea, 11) Black Sea, 12) Benguela Current, 13) Barents Sea, 14) Sea of Okhotsk. **Bottom panel:** Annually combined scheme of location of atmospheric centres of action (COAs). AL- Aleutian Low; HH- Hawaiian High; SPH- South Pacific High; IL- Icelandic Low; AH- Azores High; SAH- South Atlantic High; SH- Siberian High; IOH- Indian Ocean High. (Piontkovski S., Hameed, S., and Conversi, A.).
Implementation
The further development of coupled dynamic ocean-atmosphere models will be a product of the CLIVAR programme and will be needed for GLOBEC implementation. For ocean climate predictions, further development of statistical models will also be an important contribution as it seems that the longer-term oscillations are more dominant in the ocean than in the atmosphere where short-term signals can have an impact. A third type of forecasting is climate expert systems which make use of a large number of rules which can be changed as detailed knowledge develops. In the management of living marine resources we are now at the stage where we can move from single species models and traditional multispecies models to models which incorporate environmental data.

Outputs
• Provide a basis for applying a new generation of climate forecasts to marine ecosystem prediction
• Methods developed for applying environmental data in the management of marine living resources.

Activity 4.2 Earth System Impacts from Changes in Marine Ecosystems

Introduction
Changes in the structure of marine ecosystems, and in the flows and pathways of elements and energy among system components, that result from global environmental change will have broad impacts both within marine ecosystems and to the total natural Earth system. For example, changes in the timing of zooplankton life cycles and abundance can affect the characteristics (duration, amplitude) of spring blooms of phytoplankton, either directly through grazing on phytoplankton (as in the North Atlantic) or indirectly by grazing on microzooplankton (as in the North Pacific). Changes in zooplankton life cycle timing can also impact the feeding and growth of fish, as embodied in the match-mismatch concept (Cushing 1982). Major shifts in the timing of zooplankton and fish life cycles, abundance, distribution, or species composition can all have dramatic effects on the highest trophic levels. Examples that have been well described include mass mortalities of seabirds associated with El Niño events, and mass starvations and mortalities of pinnipeds in the Nordic Seas.

Changes in atmospheric systems and land-use policies can also severely impact regional marine ecosystems. For example, changes in precipitation patterns, regulation (timing changes) of river flows due to dams, and/or reduction of river flows due to removal of water for other uses (irrigation, industrial) can impact the dynamics of the coastal ocean into which the river flows. Such reduction or changes in fresh water inputs can affect the coastal hydrography, circulation, nutrient and sediment loading, the use of estuarine and coastal habitats as fish nursery areas, and potentially the socio-economic structures of the local area. The effects can be far-reaching, extending far beyond the local coastal ocean such that, for example, a decreasing salinity in the North East Pacific has been ascribed to seasonal timing changes of flow resulting from dams on the Columbia River.
Overall objective
• The overall objective of this Activity is to identify the potential impacts to the broad natural Earth system resulting from changes in marine ecosystems.

The GLOBEC approach
Foci 1-3 of this Implementation Plan are centred primarily on the specifics of regional ecosystems and the processes and components of those ecosystems. Both Focus 1 (Retrospective Analyses) and Focus 3 (Modelling) do have an integrative function over space and time, but they are primarily centred on the local marine ecosystem. There is, therefore, a need to consider system components broader than the local marine ecosystem, such as marine mammals (which may or may not be considered as an integral part of the local study), marine birds, the cycling of elements among all system components, and large spatial scales that integrate over multiple ecosystems (which may include long-distance migration of mammals, birds, etc.). Comparisons among local marine ecosystems will take place within each of the Regional GLOBEC programmes, but they will not necessarily consider multiple systems outside of their particular region. SPACC will compare properties among the various upwelling systems that it investigates, and the PICES CCC programme will compare properties among the 12 regional ecosystems that it has identified. ICES CCC compares the dynamics of growth and recruitment of the 25 cod stocks in the northern North Atlantic. However, there remains a need for analysis and synthesis of regional marine ecosystems on a global scale, which should be a major feature of the GLOBEC approach.

Task 4.2.1 Comparisons of changes in ecosystem structure and biogeochemical pathways resulting from global change

Rationale
The majority of national and regional GLOBEC programmes are focused on the processes and dynamics of their particular marine systems. There is a need to consider how changes in these systems affect the natural environment beyond the local marine ecosystem. There is also a need to identify how changes in system components (state variables) influence the pathways and flows of energy and materials to other components or state variables.

Specific objectives
• To facilitate ecosystem comparisons for each regional programme and to identify principal pathways of energy and materials, their differences among ecosystems, and their restructuring in response to global changes in external forcing
• To include the top (often highly migratory) trophic levels in these comparisons, and to evaluate their responses to the redistribution of energy, species composition, etc., in the various global systems.

Implementation
Most major Regional GLOBEC programmes are expected to have some activity directed towards comparing biogeochemical cycling among trophic components. The objective of this Task is to stimulate scenarios of qualitative changes in external forc-
ing (wind, temperature, freshwater input, changes in species composition, etc.) to identify substantive changes in ecosystem structure and material cycling. The impact of such changes on upper trophic levels such as birds and mammals is also a priority, especially for regions such as the Antarctic and North Pacific, although they should be included for all areas. Workshops need to be convened to compare the regional models to determine differences due to model structure, then to evaluate substantive changes in flows and pathways resulting from forcings that might be expected with global change scenarios. The explicit consequences to top trophic levels should be a major part of these workshops, in particular comparisons among Antarctic and North Pacific components.

**Outputs**

- Workshop publications evaluating and comparing responses of a variety of regional ecosystems to changes in large-scale forcings, including the effects of system structure, changes in biogeochemical pathways, and the consequences to upper trophic levels.

**Activity 4.3 Social Impacts of Changes in Marine Ecosystems**

**Introduction**

Substantial changes in the abundance, distribution, and/or species composition of marine ecosystems are expected to have significant impacts on human communities. In the past, sudden, major, changes in the structures of marine ecosystems have had serious and substantial social and economic effects. Recent major examples are provided by the collapse of the Peruvian anchoveta in the 1970’s, and by the collapse of the Atlantic cod populations in the NW Atlantic in the early 1990’s. The resulting moratorium on the eastern Canadian cod fishery caused the loss of 40,000 jobs in Newfoundland and devastated many communities where fishing is the only livelihood.

The social implications of El Niño events are extensive as they influence communities directly through the weather and indirectly through ecosystem effects. However, the social implications of changes in the production of marine resources go far beyond their influence on local coastal fishing communities. Changes in anchovy catches influenced world fish meal prices, and changes in harvestable kelp influenced the production of alginates on the world market. Less dramatic examples, although still important, can be cited for changes in species composition on Georges Bank and the North Sea in the 1970’s and 1980’s, and between finfish and invertebrates as major fishery components in the Gulf of Alaska and the Bering Sea. At the very least, such qualitative changes in abundance and composition will cause redistribution of fishing fleets to other locations (increasing fishing pressure there) or to other species, which are often under-utilized and therefore poorly studied. The most recent collapse of the Norwegian spring-spawning herring in the late 1960s contributed indirectly to the start of the Atlantic salmon farming industry in Norway as many of the purse seine fishing vessel owners, who lost their herring quotas, invested in fish farming. There is an urgent need to develop new ways of incorporat-
ing the expanding knowledge of marine ecosystems that will result from GLOBEC programmes into management policies and activities relating to marine ecosystems and fisheries. In order to do this, GLOBEC must build bridges to the social science community through the IHDP.

**Overall objectives**

- To develop methods to incorporate formal consideration of marine ecosystem status and functioning into marine ecosystem (and fisheries) management activities.

**The GLOBEC approach**

The focus of the majority of GLOBEC studies is, and should remain, on investigating the responses of natural marine ecosystems to global changes. However, the broad implications of such changes to the functioning of the total Earth system also need to be recognized. Specifically, major changes in marine ecosystems will have significant impacts on social and economic systems, and these, in turn, will affect marine ecosystems locally and elsewhere, for example, by the redeployment of displaced fishing power to other species or other areas. Understanding the broad implications of changes in marine ecosystems needs to include the human dimension; these activities should be further coordinated with the developing IHDP (see the Framework Activity on Networking) because they require types of expertise not traditionally found in the GLOBEC science community.

There is an additional need, and a responsibility, to develop formal methods to incorporate the new knowledge of marine ecosystem functioning and potential responses to global change, into ecosystem (and fisheries) management strategies. The needs may be most important in situations where substantial changes in productivity or species composition are predicted, which will cause the altered system to be so unlike its previous state that prior management assumptions become inappropriate. Application of information derived from GLOBEC programmes will be instrumental in identifying such changes, and in describing the extent to which new ecosystem structures may resemble previous ones.

**Task 4.3.1 Methods for the application of marine ecosystem information into the management of marine resources**

**Rationale**

Effective management strategies for whole marine ecosystems are non-existent at present. The reasons are, in part, institutional, with responsibility for managing the marine environment often dispersed among (competing) agencies regulating marine transportation, pollution, non-renewable resource extraction, and fisheries. Even within the fisheries agencies, the exploitation of many species is not actively managed, and when there is active management it rarely recognizes the multi-species or multi-trophic level connections of real ecosystems. The focus of GLOBEC on marine ecosystems provides the opportunity, and indeed the requirement, to assist with the development of approaches to incorporate ecosystem concepts and realities into the management of marine resources.
Specific objectives
- To develop frameworks for the inclusion of marine ecosystem concepts and structures, and their potential changes resulting from global change, into the management of marine resources.

Implementation
Research on marine resource management issues is presently on-going around the world, usually associated with large, single species fisheries. Attempts are being made in several locations to develop multi-species management models, with progress in the ICES area being most notable. It is recommended that each of the Regional GLOBEC programmes should have at least one component project with the objective of developing relationships with marine resource managers in order to incorporate ecosystem information into management frameworks and activities. This will encourage a variety of mechanisms by which such environmental information may be applied in Antarctic, North Pacific, North Atlantic, and upwelling regions. Other areas in great need of multi-species and ecosystem approaches to resource management are tropical and coral reef habitats, and interactions with managers of these habitats should be encouraged for relevant programmes. Workshops need to be convened to discuss and compare ecosystem approaches to marine resource management, and to facilitate dialogue amongst fundamental and applied marine science researchers, and marine resource managers.

Outputs
- Frameworks for including marine ecosystem and multi-species information into the management of marine resources, with case studies for the principle GLOBEC Regional programmes
- Workshops to compare such ecosystem approaches to marine resource management, and to facilitate interactions with marine managers
- Transfer of GLOBEC products (including technology, models and data-bases) to agencies responsible for providing scientific management advice.
Figure 24

Flow diagram of the Activities and Tasks detailed in Focus 4 (Feedbacks from Changes in Marine Ecosystem Structure).

Activity 4.1
Ecosystem-climate interactions on multiple scales and their influences on basic biological processes throughout the food web

Task 4.1.1 Identify how typical weather events in specific regions influence light conditions, wind driven mixing, advection and sea temperature.

Task 4.1.2 Analyse the frequency spectra of long-term temporal and spatial variation of large-scale weather events.

Activity 4.2
Earth system impacts from changes in marine ecosystem

Task 4.2.1 Comparisons of changes in ecosystem structure and biogeochemical pathways resulting from global change

Activity 4.3
Social impacts of change in marine ecosystem

Task 4.3.1 Methods for the application of marine ecosystem information into the management of marine resources.
Framework Activities are the “cross-cutting” activities which will require attention from all components of the international GLOBEC project and will fall under the direct oversight of the international SSC. These are the efforts which will truly demonstrate the “value added” of a coordinated international programme – those things which could not be achieved by any single national programme acting alone. Framework activities, for example, the development of ecosystem comparisons, or of agreements on measurement protocols and data exchange policies will ensure that, at the end of the GLOBEC programme, results from all of the regional studies and national programmes, can be compared and integrated to obtain the global synthesis which is the ultimate goal of the project.

The GLOBEC SSC has identified four such Framework Activities:

- Sampling and models: protocols and intercomparisons
- Data management
- Scientific networking
- Capacity building.

A schematic summary of these Framework Activities is given in Figure 25.
Schematic summary of the Framework Activities described in the GLOBEC Implementation Plan

**FRAMEWORK ACTIVITIES**

### Sampling and models
- Core sampling protocols
- Sampling and observational technological capabilities and needs
- Sampling networks and platforms
- Ships of opportunity
- Emerging technologies
- Model inter-comparison

### Data Management

### Scientific Networking
- GLOBEC research networks
- Focus Working Groups
- GLOBEC publications
- Open Science Meetings
- Interactions with GECHS
- Interactions with CLIVAR
- Interactions with other climate change programmes

### Capacity building
- Scientific training
- Development of scientific infrastructure
- Interdisciplinary training
ACTIVITY 5.0 Sampling and Models: Protocols and Intercomparisons

Introduction
A wide array of Activities, Tasks and sub-Tasks are described in this Implementation Plan. These will be implemented within a range of regional and national programmes, some of which are described below. To achieve global synthesis there is a need to ensure that the data collected, and the models used for their interpretation and analysis, are comparable.

Effective GLOBEC synthesis and modelling will be optimized by careful attention to standards, protocols, and methods, both for sampling and observational systems, and models. This Framework Activity sets guidelines, and suggests mechanisms for working towards a practical element of standardization of methods and models within the GLOBEC programme.

Overall objectives
- Ensure that measurements made by, and models used in, GLOBEC are as comparable as is practically possible, thus aiding global synthesis.

The GLOBEC approach
A coordinated initiative is required to ensure comparability of data and models in the various research Tasks envisaged. In some cases, well defined, internationally agreed upon methods exist and where appropriate these will be adopted and recommended for use by GLOBEC. Such methods cover a variety of basic parameters, particularly those developed as core protocols for JGOFS. In other cases no such standardized methods exist, and from time to time it may prove necessary for GLOBEC to develop such methods to ensure that data are collected in a uniform manner throughout the programme. The absence of such standards would cause major problems for synthesis.

Task 5.1 Core Sampling Protocols and Methods Intercomparison

Rationale
Global synthesis requires that the data collected by GLOBEC programmes are as comparable as possible, through the use of agreed sampling techniques and measurement protocols. This critical Task will ensure that opportunities for comparison and combination of data from the regional and national research programmes are optimized. Intercomparison of data and establishment of long-term trends in marine ecosystems require standardized, data.
Specific objectives

• To evaluate and compare sampling and measurement techniques with a view to recommending methods for use in GLOBEC studies.

Implementation

This Task will be accomplished through a series of workshops under the guidance of the Sampling and Modelling Working Group. These will consider issues of measurement standards, protocols and methods specifically in the context of the needs of the four GLOBEC Research Foci and the Regional Programmes. This Activity will lead to agreement on the recommendation of existing established methodologies, or identify those which require further development and intercomparsion before recommendation for use by GLOBEC. ICES through their Working Group on Zooplankton Ecology (WGZE) are developing a Zooplankton Methodology Manual, and this initiative is highly relevant to this Task.

Outputs

• Workshop reports on methods and measurement issues for the four Foci and the Regional Programmes
• Information on standard GLOBEC protocols disseminated through the IPO (web-site and hard-copy).

Subtask 5.1.1 Provide an updated account of sampling and observational technological capabilities and needs

Rationale

GLOBEC Report No. 3 provided an extensive summary of sampling capabilities that were available as of early 1993. Several advances in sampling technology have been made since that time. Also, there remain gaps in sampling capabilities which need to be identified and approaches for eliminating these will be required. Examples of advances in sampling technology that can be used to obtain biologically relevant information include the use of Acoustic Doppler Current Profiling (ADCP) meters to measure vertical velocity and free-fall Conductivity Temperature Depth (CTD) systems to obtain routine small scale turbulence measurements. Areas where research in sampling methodology needs to be done are in obtaining higher size resolution and improved identification (by species) of phytoplankton and zooplankton as well as higher trophic level organisms including fish, and determination of in situ mortality, grazing, and predation rates in collaboration with Focus 2. GLOBEC needs to adopt sampling systems that provide real-time reporting of high-rate data that can be incorporated in data assimilation models to provide regional and global scale information.

New instrumentation and methodologies are essential for the execution of GLOBEC objectives. Many of the new approaches are highly advantageous because they will provide large volumes of data for many biological variables. However, interpretation and calibration of the data are quite complex. Thus, “ground-truthing” using traditional sampling will be important, especially in the early stages of application.
Programmes like GLOBEC will always be inherently data poor because of undersampling of the vast ocean environment where variability in space and time spans over ten orders of magnitude. Further exacerbating the problem is the diversity and range of important biological and chemical variables. In many cases, it will be more important to obtain large volumes of data than to obtain a limited number of measurements with high resolution and accuracy, a lesson well documented by the physical oceanographic community. Hence, a careful blend of data which are numerous, but less accurate or precise, and a more limited subset which is high in quality will be necessary.

Specific objectives

- New sampling and observational technologies (particularly since 1993) need to be summarized and evaluated for GLOBEC needs so as to achieve optimal deployment in GLOBEC programmes.

Implementation

A workshop should be convened and a brief report should update GLOBEC Report No. 3.

Outputs

- Report on advances in moorings, drifters, vertical profilers, towed bodies (both dedicated for research and deployed from ships of opportunity), remotely operated vehicles (ROVs), neutrally buoyant floats (e.g., simulating organism behaviours through buoyancy adjustments), shore-based radar and acoustical systems, and autonomous underwater vehicles (AUVs) as well as sensors which have been made within the past few years. The report should also include information on new communication and observational satellites, as well as advances in remote sensing (for example, surface temperature, ocean colour, and altimetry deserve particular attention).

Subtask 5.1.2 Summarize existing/continuing/planned sampling networks and remote sensing platforms. Special attention should be given to means of obtaining a nearly continuous spectrum of sampled scales

Rationale

The cost of obtaining data continues to increase and the number of dedicated platforms is decreasing, thus every effort needs to be made to capitalize on available data. In addition, modelling efforts can be used to optimize sampling. An important research area is development of subgrid scale parameterizations for models. Observations (e.g., turbulence, mesoscale, etc.), likely obtained through process-oriented studies of Focus 2, will be needed for this.

Specific objectives

- Develop collaborations with GOOS efforts, especially those of LMR and Coastal modules
• To utilize physical and biological (e.g., HOTO) data sets being obtained for other purposes.

Implementation
Establish, and maintain, good communications with related coordinating groups.

Outputs
• Document information and provide to the GLOBEC IPO for dissemination to the Regional and National GLOBEC programmes.

Subtask 5.1.3 Explore new schemes for obtaining data utilising ships of opportunity

Rationale
There is great potential for using ships of opportunity for GLOBEC observations. These ships include weather stations, ferries and commercial ships. They provide the possibility of obtaining observations at times and places not available to research ships. They are essential for the continuation and establishment of new long term observational and monitoring programmes such as those of the CPR survey (see Focus 1).

This approach has proven successful for physical oceanography. Many merchant ships now routinely obtain upper-ocean currents from ADCP measurements, and the backscatter information from these measurements may be useful for determining zooplankton biomass. Similarly, routine shipboard echosounder data may be utilized. However, special methods of interpreting these data will be necessary. Use of towed bodies (e.g., CPRs, Video Plankton Recorders [VPRs], Optical Plankton Counters [OPCs], Undulating Oceanographic Recorders [UORs], etc.) and perhaps expendable probes on ships of opportunity (including regular shipping and ferry routes) should be explored.

Specific objectives
• Determine how to capitalize effectively on routine measurement programmes.

Implementation
Contact representatives of various ship-of-opportunity programmes to explore opportunities for interaction and collaboration with GLOBEC.

Outputs
• Report information to GLOBEC IPO for dissemination.
Subtask 5.1.5  Expand the availability and application of relevant emerging sampling and observational technologies

Rationale
Many of the most promising acoustical and optical technologies are available to only a few research scientists. Because of their importance and abilities to obtain large volumes of relevant data, these need to be mass produced to reduce cost and in turn increase the volume of critical data. Interestingly, the ADCP, which began as a research instrument has become commonly used on commercial vessels. Similarly, several optical systems have been produced in relatively large numbers because of their value in ecological studies and environmental monitoring. An important outcome of this Task will be directed towards making such technologies more readily available in developing countries involved in GLOBEC research.

Specific objectives
• To identify the most promising technologies for GLOBEC
• To explore means to increase availability of the new technologies for deployment in the GLOBEC Regional and National programmes.

Implementation
Gather relevant information on emerging technologies which have potential for mass production

Outputs
• Report to the GLOBEC community on expansion of availability of new, relevant technologies.

Task 5.2  Model Intercomparison

Rationale
Modelling is central to GLOBEC and a broad range of simple to complex models is needed (Focus 3). Because of the sparseness of data, data assimilation methods will be crucial. Modularity and portability of models are important attributes of GLOBEC models. The modelling component of GLOBEC will rely on interdisciplinary OSSEs to plan and optimize sampling programmes. Clearly, a strong interlinking of model and observation components is of great importance. To date, the SOS- and NM-WGs have been well coordinated and it is anticipated that this arrangement will continue to ensure the maximum utilization of GLOBEC observational and modelling resources.

On-going observational and modelling programmes should be incorporated into GLOBEC modelling activities because integrated data collection and modelling efforts are costly and relatively few in number. These programmes can be used as building blocks and the experiences gained from them can be useful for future GLOBEC modelling. The emphasis within GLOBEC on zooplankton dynamics complements the JGOFS focus on primary production. The requirement in GLOBEC for realistic circulation models makes exploitation of the results of WOCE and other
physical oceanography modelling efforts desirable.

**Specific objectives**

- Identify regional programmes and modelling efforts that are ongoing in areas where GLOBEC-type projects are being developed and request that these programmes consider accommodating measurements and models that would be beneficial to GLOBEC
- Evaluate previous modelling results in an effort to determine critical space and time requirements in support of the development of monitoring/sampling strategies that would benefit GLOBEC
- Coordinate and collaborate closely with modelling activities in these on-going programmes.

**Implementation**

Convene a workshop, if appropriate, to bring together modelling components of major programmes, such as JGOFS and WOCE, to foster exchange of information and ideas. Models will likely use data obtained from different platforms, and this should be in standardized format wherever possible. Provide GLOBEC representation at modelling workshops and working groups supported by other programmes

**Outputs**

- Model results will be used in planning field programmes
- Better integration of GLOBEC approaches and ideas in other programmes.
**ACTIVITY 6.0 Data Management**

**Introduction**
There are large data management concerns for GLOBEC. Some of the challenges include:

1. Data rescue/data recovery
2. Exchange and archival of time series data, including palaeoceanographic data and summarized data series products
3. Data exchange amongst researchers participating in integrated process studies
4. Specifications of meta-data requirements for existing and emerging data types to allow for proper archival and retrieval of data
5. Preparation of standardized datasets to force, test and validate numerical models
6. Assuring the GLOBEC legacy through the submission of data to organizations that can assure long-term data stewardship.

Many of these problems will also be faced by the Regional and national GLOBEC programmes. The international GLOBEC programme can contribute substantially to the resolution of these data problems by recommending common approaches and standards for data formats, archival, etc. Ultimately, success of GLOBEC through the synthesis of results will depend in large part on success in implementing common data conventions. This important issue is also addressed in the Framework Activity on, “Sampling and models: protocols and inter-comparisons” (Activity 5.0, above).

**Overall objectives**
- To develop and recommend policies on the management of data from GLOBEC programmes, to facilitate access and understanding, and to enable synthesis of results.

**The GLOBEC approach**
GLOBEC will use a decentralized data management and distribution system. The centralized components (for example, centralized under the supervision of the IPO, will be a comprehensive inventory of GLOBEC and GLOBEC-like data holdings with pointers to their locations and key contact persons. Within-project (during the funded lifetime of GLOBEC programmes) data management and data exchange is an important component of each national and Regional GLOBEC programme, and should be addressed in detail within the implementation plan of each GLOBEC programme. Each GLOBEC programme/project should create an inventory of data and data products. These inventories will be collated by the IPO to build the centralized database of meta-data and pointers to actual data locations. Each GLOBEC programme should address the long term archival of observational data and data products in order to ensure a lasting contribution to marine science. Note that there are several national and international data agencies that may be able to contribute to the archiving of data that will derive from typical GLOBEC programmes.
Data sharing and exchange is an essential component of GLOBEC interdisciplinary studies. The collective value of data is greater than its dispersed value. All investigators should be prepared to share their data and data products and should recognize the ‘proprietorship’ (‘rights to first publication/authorship’) of data acquired from other investigators. GLOBEC investigators retain the primary responsibility for data quality control and assurance. Investigators, in particular those using data from other researchers, should be prepared to track updates, corrections and dataset versions.

Implementation

Implementation of the GLOBEC policies for data management will require interactions among the individual GLOBEC programmes and other international agencies established for the long-term archiving of data (e.g. World Oceanographic Data Centres, the IGBP Data and Information Systems Project [IGBP-DIS] etc.). In order to coordinate these activities and policy developments, consideration will be given to forming a Data Management Working Group (DMWG) to review existing GLOBEC data management systems, issues and problems and recommend specific strategies to deal with the shortcomings of existing systems. Requirements for data products or related data issues should be forwarded to the DMWG by other working groups. These data issues will place a strong responsibility on the IPO, which will be advised by the DMWG.

The IPO should provide active leadership in developing and implementing quality control procedures, with the goal of incorporating these procedures into the national and regional data distribution systems. The IPO should provide an inventory, and data access procedures to non-GLOBEC data sources that are of importance to GLOBEC participants. The IPO should identify and recommend mechanisms to create required “linkages” and data exchanges with other appropriate programmes (within the IGBP, and others). This should include (but not be limited to) links with JGOFS, PAGES, CLIVAR and GOOS. Further, the IPO (advised by the DMWG) should monitor progress of data migration to permanent archives and advise the SSC on any problem areas. Clearly, the role of the IPO is critical, and the SSC should keep a careful watch to ensure that the IPO has adequate resources to discharge its data responsibilities.

The IPO should construct and maintain an inventory of GLOBEC (and GLOBEC-relevant) data and data products. In this work the IPO should cooperate with the following organizations:

• Existing World Data Centres (WDCs) and related organizations particularly to ensure the long-term stewardship of GLOBEC data
• National GLOBEC programme offices and/or national data management offices
• Regional programme data management efforts.

The IPO and GLOBEC SSC should ensure close collaboration between the DMWG and the Numerical Model/Observation Systems Working Group to establish:

• Metadata requirements for new observation technologies
• Data archival requirements for new observation technologies
• Standardized data sets for testing, forcing and validation of numerical models.

Close links should be maintained with IGBP-DIS activities, particularly FOCUS 2 which is developing a meta-data inventory within IGBP together with an IGBP-specific web search engine.

GLOBEC national and regional programmes need to identify their data management strategies, addressing the issues of data standardization, within-project data exchange, inventories and migration to permanent archives.
ACTIVITY 7.0 Scientific Networking

Introduction
GLOBEC encompasses a considerable number of different disciplines such as climatology, marine geology, physical oceanography, marine chemistry, planktology and fisheries biology. GLOBEC researchers are involved in retrospective investigations using long-term data series, in field studies collecting data and samples or taking in-situ measurements and in modelling activities. GLOBEC research is carried out on all continents, including Antarctica, and close cooperation is continuously required between scientists working in counties far away from each other. In view of this interdisciplinary nature of research and the multi-disciplinary cooperation which includes developing as well as developed counties GLOBEC must provide mechanisms for rapid transfer of information to the GLOBEC research community to ensure successful cooperation and to meet its objectives. GLOBEC must also develop strong links with other international global change research programmes with related interests and it must provide some of the scientific understanding required by the groups planning GOOS.

Since GLOBEC is still in its development and planning phase, many individual scientists, national institutions and countries, particularly developing ones, are not well informed about the international programme. The SSC anticipates much broader interest in the GLOBEC programme, especially from small coastal states where local fisheries form a significant economic base. There is an international responsibility to ensure that information about the GLOBEC programme is disseminated to these countries for which it has such relevance and to assist all scientists to become involved in GLOBEC to the greatest extent possible. The results of the GLOBEC research effort must be accessible to the global scientific community, both in the developed and the developing countries.

Overall objectives
• Rapid transfer of information to the GLOBEC research community
• Establish new communication links with scientists, institutions and countries outside of the present GLOBEC community
• Open avenues of communication with other global change core programmes of IGBP, WCRP, and IHDP.

The GLOBEC approach
GLOBEC will establish different types of networks to serve different needs. At the level of individual scientists, the IPO must ensure that all GLOBEC researchers are informed in a timely way on general matters and new developments concerning GLOBEC.

Like other global change programmes, GLOBEC is structured into major sub-programmes (CCC, SPACC, CCCC, SO-GLOBEC) and a large number of regional and national programmes/projects of differing nature and organization, all contributing in some measure to meeting the international GLOBEC objectives. All of these initia-
tives will develop their own networking structure according to their different needs. The task of the GLOBEC IPO is to build an international network across these regional and national initiatives and to establish effective information links between them.

Internationally, information must flow in two directions: the IPO should, of course, provide a constant flow of information on the international GLOBEC programme. At the same time, the IPO should be receiving information on the many local, national and regional research efforts around the world and distilling this for use by the SSC and GLOBEC working groups. Thus, through the efforts of the IPO, news, data and information can also flow between the national programmes and from them to individual GLOBEC researchers.

Task 7.1 Establishment of GLOBEC Research Networks

Rationale
The efficient and timely flow of information is crucial if the efforts of all individual GLOBEC researchers and the different national and regional initiatives are to be harmonized around the four research Foci so as to meet the GLOBEC objectives.

Specific objectives
- The establishment, expansion and maintenance of networks linking of GLOBEC scientists at all relevant levels: international, within GLOBEC sub-programmes, regional and national
- Specialist networks for specific purposes.

Implementation
The rapid expansion of the Internet makes scientific networking feasible on a scale that would not have been possible a decade, or even five years ago. Access to electronic mail and the World Wide Web is now becoming wide-spread, although gaps still exist in some countries, especially on the African continent. While GLOBEC must exploit this new resource, the IPO will remain sensitive to the inability of some researchers to participate in networks which are entirely electronically-based and will ensure that they have other means of receiving information about GLOBEC. Dual use of both electronic, and conventional means of communication will ensure that the widest possible community is served effectively.

The IPO will develop and maintain contacts with all of the national GLOBEC programmes and with individual researchers in those countries where no formal national programme exists. These contacts should be used to develop, enlarge and maintain both electronic and traditional mailing lists for the distribution of information.

The GLOBEC web-site is another important tool for the provision of information on the international programme. In order to make it as effective as possible, and to facilitate the exchange of information between national programmes and other groups
relevant to GLOBEC, the IPO can provide an important service to the community by identifying and placing on the web-site appropriate electronic links to as many related activities as possible. To be informative, the web-site will require regular updating.

Consideration will be given to exploiting, and working with, existing IGBP Core Project Impact Centres to provide regional training in support of regional networking.

**Outputs**
- Functioning GLOBEC research networks
- GLOBEC web-site as a common communication resource for the programme
- Data base of GLOBEC activities, programmes and scientists
- Regional training courses in cooperation with regional Impact Centres.

### Task 7.2 Establishment of Focus Working Groups

**Rationale**
The implementation of the research activities of the four Foci described in this Implementation Plan will require coordination and international leadership. These Foci derive from the GLOBEC Science Plan, and in turn have their origins in a series of successful GLOBEC workshops held under the auspices of Working Groups (see below for list of GLOBEC Reports). In some cases the GLOBEC SSC has already taken steps to re-constitute particular Working Groups, and careful attention will be given to this issue at future meetings.

**Specific objectives**
- To ensure that the international research of each of the four research Foci is led and coordinated effectively by appropriate specialist Focus Working Groups with wide representation.

**Implementation**
The GLOBEC SSC will consider establishing Focus Working Groups for each of the four Foci elaborated in this Implementation Plan. Additionally, other Working Groups may be considered to tackle particular issues of importance to the development of the GLOBEC project. As GLOBEC completes it’s Implementation Plan, and moves into a mature research phase, it is expected that the structure of the SSC should move to reflect the activities of the research Foci.

**Outputs**
- Effective Working Groups to lead and coordinate research under the four Foci.
Specialist networks will be established across the sub-programmes and regional/ national initiatives. These will link closely with the Focus Working groups on particular issues, e.g. retrospective investigational, modelling, data banking work.

Task 7.3   GLOBEC Publications

Rationale
Notwithstanding the increased use of electronic communication, there are many reasons to use traditional means of publication to distribute information about GLOBEC. Reports and newsletters in “hard copy” provide a permanent record of GLOBEC’s progress, one which can be catalogued in libraries and which will be available for reference even after the programme is complete. Such reports, and other informative pieces about the GLOBEC programme can easily be sent to decision makers and managers as needed. Printed documents change hands easily, thereby helping to expand the international GLOBEC network.

There is a need to inform the steadily growing GLOBEC research community on new developments in GLOBEC organization and results. Traditional tools, as well as electronic ones, are important to the success of this effort.

Specific objectives
• Ensure the speedy transfer of information on general GLOBEC matters and research meetings, plans, activities and results.

Implementation
The IPO will maintain a regular publication schedule for the GLOBEC Newsletter which will be distributed to all GLOBEC researchers, national GLOBEC committees and interested national and international institutions and agencies as a hard copy and on the web-site.

The GLOBEC Report Series will be the forum for the timely distribution of the results of relevant working group meetings and for information on international scientific activities.

Outputs
• GLOBEC Newsletter
• GLOBEC Reports.

Task 7.4   GLOBEC Open Science Meetings

Rationale
GLOBEC needs a forum where researchers of the different sub-programmes and regional/national initiatives can gather to exchange ideas and experience, to present data and new hypotheses and to integrate results. Such meetings, open to the entire GLOBEC community, provide an opportunity for direct feedback to the SSC on the
progress of the international programme. “Mid-course corrections” of programme planning and implementation may result. No other forum allows for face-to-face contacts between the international SSC and the community it serves and such “town meetings”, while requiring significant funding and organizational effort, are an important benefit of an internationally coordinated programme. These meetings also provide an excellent opportunity for building links to other international programmes related to GLOBEC objectives and, as appropriate, may be organized jointly with such programmes. The first Open Science Meeting (OSM) was held in Paris, 17-20 March 1998, and was central to the development of this Implementation Plan. A collection of papers presented at the OSM has been published in *Fisheries Oceanography* 7:179-390.

**Specific objectives**

- Present GLOBEC to the international research community and to national and international funding agencies
- Present and integrate results of sub-programmes and regional/national initiatives
- Review GLOBEC research activities, re-focus on relevant themes, if required and re-direct objectives if appropriate
- Provide a forum for open and direct contacts between GLOBEC researchers at all levels.

**Implementation**

The IGBP requires its core projects to convene OSMs on a regular basis. Whereas the IPO is responsible for their organization, the SSC will outline the scientific programme for such meetings. These meetings will be open, on a self-funding basis, to all interested scientists and representatives of national and international institutions and agencies. The broadest possible participation will be sought.

**Outputs**

- Periodic review and revision of GLOBEC research objectives and activities
- Publication of research results in peer-reviewed international journals
- Regional and global syntheses of GLOBEC research results.
Task 7.5 Interactions with other Global Change Research Programmes

Subtask 7.5.1 Interactions with the Global Environmental Change and Human Security (GECHS) Project to examine the human dimensions of changes in marine ecosystems

Rationale
Large, abrupt, and even cyclical changes in marine ecosystems leading to changes in fish population abundance, distribution, and composition can have significant human impacts. Substantial social disruptions were caused by the collapse of the Peruvian anchoveta fishery in the 1970’s and the collapse of the NW Atlantic cod stocks in the 1990’s. International conflicts have arisen because of disagreements on the area of a nation’s fishing territory, e.g. between Iceland and the U.K. over demersal fisheries in the Icelandic Sea in the early 1970s; between Canada and Spain over demersal fishing in the NW Atlantic late 1980s; and in the North Pacific relating to high-seas drift net fishing. Major changes in species composition, such as the collapse of herring populations on George’s Bank in the 1980’s and the collapse of crustacean populations in the Gulf of Alaska and Bering Sea, caused substantial changes in fishing strategies and in the deployment of fishing power. Highly migratory stocks like the Atlanto-Scandian herring in the Norwegian Sea are causing conflicts about how to share the stocks between nations. The extent to which common themes can be found to these social disruptions, potential solutions or mitigating actions, and their resulting impacts to marine ecosystems (e.g. increased exploitation of previously under-exploited species) is an important topic for GLOBEC. It is also a topic that is central to the developing IHDP Global Environmental Change and Human Security (GECHS) project. Linkages between GLOBEC and GECHS on this topic are essential to develop a future management structure for marine resources which not only considers total allowable catch (TAC) of single species and their geographical distribution, but also gives background information on responses at other trophic levels in the marine ecosystem, effects on alternative fishing methods, interaction with decisions concerning land-based industry and communities which rely on marine resources. As stated in the GECHS Science Plan “the overall research question addressed by GECHS is simply, what is the relation between global environmental change and human security?”. More specifically, GECHS identifies six key questions which all have more or less direct links to the Tasks of GLOBEC:

- What is the present extent of insecurity?
- Which regions are most insecure?
- What types of environmental change threaten human security?
- How does environmental change threaten human security?
- Why are some regions more vulnerable to specific environmental changes than others?
- Can we predict future insecurity?
Specific objectives
• To interact with the GECHS Project to identify:
  - how large changes in marine ecosystems affect human security globally, and in coastal communities;
  - why some regions and communities are more vulnerable than others to large changes in marine ecosystems;
  - indicators of changes in marine ecosystems which are likely to have major impacts on human security;
  - to identify social responses to large changes in marine ecosystems that may have further deleterious impacts to these ecosystems.

Implementation
GLOBEC programmes involved in Foci 1–3 need to identify changes that may result in qualitative changes in abundance and species composition, such that fishing activities and local communities may be severely affected (either positively or negatively). These will set the stage for recognising changes that may affect social systems. In the problems described in the Rationale above national authorities are seeking advice from expertise separately, e.g. from fisheries biologists, from fisheries economists, or expertise in social sciences. These kinds of problems should, however, be approached in a more holistic way, not only from a management point of view but also from a scientific point of view. The emerging IHDP provides an opportunity to start joint studies of social scientists and ecologists in order to examine the entire consequences of major changes in marine ecosystems, particularly the GECHS project. Such studies should include common elements to the disruptions, any solutions that were found, and any mitigating social actions that could have further consequences for the marine ecosystem. Such consequences could include redistribution of fishing to new species, new areas, new gear types (i.e. displaced fishing effort), or delaying social changes to wait for the ecosystem to recover to its former state (which may simply displace intense fishing effort in time). The term “Human Security” in the GECHS project comprises a wide range of problems with four interacting main components: physical security, economic security, health security and environmental security. The working definition of Human Security established in the GECHS Science Plan is: “1) ensuring the existence of options to mitigate or adapt to threats to human, environmental and social rights; and 2) ensuring the freedom of those affected to exercise the options”. Through the GLOBEC objectives to explore marine ecosystem variability and change, GLOBEC will contribute to the understanding of environmental security and sustainable development which are both major components of the broad term Human Security of GECHS.

Outputs
• Identification of “warning signals” for typical marine ecosystems globally that suggest the possibility of substantive changes in abundance or composition sufficient to cause social disruptions
• Understanding of the responses of human social systems to substantive changes in marine ecosystems, and their potential for further deleterious impacts on marine systems.
Subtask 7.5.2 Interactions with the World Climate Research Programme (WCRP) on Climate Variability and Predictability (CLIVAR) to examine the influence of global climate change on marine ecosystems

Rationale
An important rationale for development of the CLIVAR Programme has been the output from the Tropical Ocean and Global Atmosphere (TOGA) Programme and the World Ocean Circulation Experiment (WOCE). A key issue of CLIVAR is that the understanding of seasonal to centennial climate variability depends on understanding the coupled ocean-atmosphere processes. Both the time and spatial scales focused in CLIVAR are to a large extent similar to the scales of marine ecosystem variability focused in GLOBEC. The overall objectives of CLIVAR are to:

- Describe and understand the physical processes responsible for climate variability and predictability on seasonal, interannual, decadal and centennial time scales, through the collection and analysis of observations and the development and application of models of the coupled climate system, in cooperation with other relevant climate research and observing programmes
- Extend the record of climate variability over the time scales of interest through the assembly of quality-controlled palaeoclimatic and instrumental data sets
- Extend the range and accuracy of seasonal to interannual climate prediction through the development of global coupled predictive models
- Understand and predict the response of the climate system to increases of radiatively active gases and aerosols and compare these predictions to the observed climate record in order to detect the anthropogenic modification of the natural climate signal.

Of the three main components of CLIVAR, Global Ocean Atmosphere Land System (GOALS), Decadal to Centennial Climate System (DecCen) and Anthropogenic Climate Change (ACC), the two first components focus on climate processes of great importance for GLOBEC. They, respectively, focus on seasonal to interannual and decadal to centennial climate variability with emphasis on the coupled climate system. The nine research areas identified in GOALS and DecCen focus on specific problems that link directly to each of the regional GLOBEC Programmes.

Six of the research areas have importance for the dynamics of the marine ecosystems considered in SPACC. Thus G1. “Extending and improving predictions based on ENSO”, G2. “Variability of the Asian-Australian monsoon”, G3. “Variability of the American monsoon systems”, G4. “African climate variability”, D2. “Tropical Atlantic variability” and D4. “Pacific and Indian Oceans decadal variability”. They all focus on lower to middle latitude climate processes of great importance to address the questions of what causes variability in the dynamics of typical upwelling ecosystems. Three of these research areas have also direct importance to CCCC. These are G1, G3 and D4 which consider processes that have implications on a larger scale and demonstrate the importance of teleconnections. Two of the research areas have particular interest to CCC. The processes of D1, “The North Atlantic Oscillation (NAO)” and D3 “Atlantic thermohaline circulation” consider the key elements of what is be-
lieved to influence the fluctuations of North Atlantic cod stocks and their prey species. One of the research areas, D5. “Southern Ocean thermohaline circulation”, has particular interest for Southern Ocean GLOBEC as it addresses both variability of the Antarctic Circumpolar Current, coupled ice-ocean-atmosphere interaction and deep water formation.

Specific objectives

- To utilize results obtained on climate variability within the CLIVAR Programme to interpret and predict marine ecosystem variability
- To provide feedback to the CLIVAR Programme on climate processes of major importance to understanding marine ecosystem variability.

Implementation

The interaction with CLIVAR will be most effective at the regional programme level. SPACC, CCC, CCCC and SO GLOBEC should establish contacts with the nine research areas of GOALS and DecCen in CLIVAR in order to link the climate processes of the various regions directly to ecosystems. The results of Activity 4.1 and Activity 4.2 in Focus 4 will provide important feedback to CLIVAR by informing interacting scientific communities on climatic influences on trophic transfer.

Outputs

- Understand how climate variability forces changes in marine ecosystems
- Provide a system for prediction of marine ecosystem variability and change.

Subtask 7.5.3 Interaction with other ecosystem and climate change programmes

In addition to the GECHS and the CLIVAR Projects there are also other international programmes on climate change which more or less have interlinking objectives with GLOBEC. Many of them are within the IGBP, while other relevant climate change programmes are found under the World Climate Research Programme jointly sponsored by ICSU, the World Meteorological Organization (WMO) and IOC.

GLOBEC should utilize the large number of data sets and time series collected during earlier and existing programmes. GLOBEC should cooperate with the IGBP programmes JGOFS and LOICZ. This will provide important support to GLOBEC for understanding the energy flow at lower trophic level from zooplankton grazing, production of faecal pellets and CO₂ draw down and the issues of new versus regenerated production. At higher trophic levels the three IGBP programmes LOICZ, GAIM and GCTE provide support in considering feedback mechanisms.

GLOBEC also needs to utilize the results of the major WCRP programmes other than CLIVAR. WOCE which is now in its terminating phase has provided an important background for the CLIVAR Programme and important basin-scale oceanography time series have been established. The LMR component of GOOS has high relevance to GLOBEC as it focuses on the need for environmental data in management of fish stocks.
Currently interdecadal data sets on plankton which have been assembled are restricted to a few geographical regions predominantly in the northern hemisphere. Examples are CPR data, CalCOFI, Gulf of Alaska, and Gulf of Maine. An extended inventory, assembly and data analysis are required for other regions, especially for example for the Arctic Basin, the Indian Ocean, and the Mediterranean Basin. Interdecadal plankton-fish-climate linkages are still poorly known for these parts of the globe. However, data are potentially available, from archives, cruise reports and some publications. GLOBEC should contribute to the process of making data available through bridging and coordination of regional GLOBEC programmes in such areas on one hand and through interaction with key representatives running the regional non-GLOBEC programmes on the other hand.
ACTIVITY 8.0 Capacity Building

Introduction

Capacity building is a very important objective of GLOBEC which is most likely to be lead initially through the SPACC regional programme. Many GLOBEC research goals cannot be achieved without the fullest possible international participation in the programme. Eight of the ten most important commercial fish species by volume on a global scale are small pelagic fish. These fish stocks are exploited primarily within the Exclusive Economic Zones (EEZ) of coastal states, many of which are also developing countries. In most of these coastal and small island states, the fisheries are an important economic resource and fish are a significant source of protein in the diet. Scientists in these countries have an important part to play in GLOBEC research by contributing their knowledge to the local marine resource management process. Their involvement will benefit the international programme as a whole by broadening its geographic coverage, bringing new viewpoints, regional expertise and understanding. Without assuming the responsibility to foster a healthy and truly mutually beneficial collaboration with their colleagues in developing countries, GLOBEC scientists from the developed world might expect problems in applying for permission to conduct research within the EEZs of these countries.

The SPACC Programme is being carried out in a large number of ecosystems around the world, in the Americas, Africa and Europe and will soon be extended into Asia. Thus, SPACC provides an important opportunity to involve marine scientists in a number of developing countries in research of direct relevance to them. In some regions, particularly in the developing world, the ability to conduct research is hampered by a lack of scientific expertise and adequate technological infrastructure. Consequently, capacity building will be a major programme element of GLOBEC and SPACC in particular. To assure world-wide participation in its comparison of ecosystems, SPACC will emphasize inexpensive core measurements that can be made in most countries, while at the same time where possible promoting the use of advanced technologies (see Activity 5.0).

Overall objectives

- Encourage scientists and institutions in developing countries to become fully involved in GLOBEC
- Involve scientists from developing countries in adopting modern research methods
- Develop capacity and research infrastructure in developing countries.

The GLOBEC approach

SPACC is unique among the programme elements of GLOBEC because of its global coverage, the participation of many developing as well as developed countries and its emphasis on capacity building, education and training. It will mobilize scientific manpower and resources in developing countries to address regional and global scientific questions concerned with global change. SPACC not only enhances north/south cooperation, but also provides a forum for south/south communication, as
some of the most important ecosystems for small pelagic fishes are in the southern hemisphere.

**Task 8.1 Scientific Training**

**Rationale**
GLOBEC can meet its objective to understand the impact of climate variability through ecosystem comparison only, if well-trained scientists from the widest network of countries have good opportunities to become involved in cooperative research.

**Specific objectives**
- Organize training courses
- Enhance short-term exchange of scientists between developing and developed countries.

**Implementation**
A number of organizations for international cooperation such as SCOR, IOC-UNESCO, Global Change System for Analysis Research and Training (START) SADC or the Inter-American Institute (IAI) as well as national agencies for technical cooperation have a strong interest in fostering capacity building for global change research in developing countries. Consequently, they may be prepared to assist in organising courses and to contribute to funding them. Regional courses would be particularly appropriate for joint development by GLOBEC and START.

Such courses can offer training in appropriate methodologies for GLOBEC measurements, but will be worthless if the “students” return to laboratories and institutions which do not possess the instruments or facilities required to make these measurements. GLOBEC will give careful consideration to matching the training it offers to efforts improve the capabilities of the participating institutions. At sea training opportunities will also be provided on GLOBEC research cruises whenever possible.

The experience of other programmes, and especially JGOFS, is instructive. Regional training courses in the interpretation of remotely-sensed ocean colour data have been matched to local scientific interests and to the acquisition of funds for relatively inexpensive SeaWIFS data receiving stations to be located at institutes in the region. The design of training courses in modelling techniques should not exceed the potential of local researchers to apply these techniques, or should be linked to the acquisition of new computing capabilities. When the research vessels of developed nations are operating in the waters of a developing country, high priority should be given to providing berths for local scientists who are unlikely to have access to well-equipped ships.

**Output**
- Improvement of research capabilities of scientists from developing countries
- Increased geographic coverage, especially for regional programmes such as SPACC.
Task 8.2  Development of Scientific Infrastructure and Enhancement of Capacity Building in Developing Countries

Rationale
There is a need for improvement of scientific and technical capabilities and of research infrastructure in developing countries to enhance sustainable development.

Specific objectives
- Enhance mutual assistance between researchers from developing and developed countries in GLOBEC projects
- Full participation of developing countries in SPACC, and other developing regional programmes.

Implementation
A whole suite of procedures will be incorporated into GLOBEC to meet these specific objectives. SPACC will organize field campaigns involving scientists and technicians from both developing and developed countries. A by-product of these international campaigns is “training on the job”. Long-term exchange of researchers between developing and developed counties will be promoted. A particularly useful tool for enhancing institutional or regional capacity is twinning between research institutions from developing and developed counties. Communication between scientists from developing countries will be supported especially to initiate south/south cooperation. SPACC is particularly suited for such an undertaking as SPACC researchers in South America and Northern and Southern Africa share similar research problems as they work in ecosystems dominated by the same fish communities and sharing the same physical forcing processes.

Task 8.3  Interdisciplinary Training of Students and Especially Post-Doctoral Fellows in Both Observational and Modelling Methods

Rationale
A major GLOBEC thrust needs to be in the area of training of students and post-doctoral fellows in techniques relevant to the challenging research tasks posed by GLOBEC. In particular, researchers of GLOBEC problems will be most effective if they are well grounded in both observational and modelling areas, a relatively rare combination today. Special means, such as short courses, exchange programmes, etc., need to be developed to satisfy this need. In accord with this recommendation, international networking among GLOBEC students and researchers is now feasible and highly desirable as a tool for education as well as research. Through these means, exchange of state-of-the-art methodologies, data, and models can be facilitated. Further, intercomparisons of regional studies can be accomplished. To under-
score the importance of this GLOBEC activity, other evolving and future programmes (e.g., GOOS-LMR) will likely base some of their observational methodologies and standards as well as modelling components upon the framework of the GLOBEC programme.

Few students are provided with truly interdisciplinary training. Most academic structures necessitate making a choice between pursuing training in biology or physics, modelling or observational studies. Thus, relatively limited numbers of young oceanographers are capable of contributing to the execution of the Tasks outlined under Activity 3 unless given special educational opportunities. Also, the broader oceanographic community is sometimes unaware of what has been learned via modelling and what can be accomplished with this approach.

**Specific objectives**

- To train students and post-doctoral fellows in observational and modelling areas relevant to GLOBEC
- Convene workshops/training activities that will allow exposure of the larger oceanographic community to the use of interdisciplinary models.

**Implementation**

Summer internships and postdoctoral fellowships should be provided for use at institutions which are active in collaborations involving interdisciplinary observational and modelling studies in collaboration with the Regional programmes. In addition, short courses, summer courses and workshops on interdisciplinary modelling, will be organized and sponsored.

**Outputs**

- GLOBEC reports on the impact of training programmes, and the dissemination of trained personnel into the field programmes.
FRAMEWORK ACTIVITIES

Framework Activities are the “cross-cutting” activities which will require attention from all components of the international GLOBEC project and will fall under the direct oversight of the international SSC. These are the efforts which will truly demonstrate the “value added” of a coordinated international programme – those things which could not be achieved by any single national programme acting alone. Framework activities, for example, the development of ecosystem comparisons, or of agreements on measurement protocols and data exchange policies will ensure that, at the end of the GLOBEC programme, results from all of the regional studies and national programmes, can be compared and integrated to obtain the global synthesis which is the ultimate goal of the project.

The GLOBEC SSC has identified four such Framework Activities:

- Sampling and models: protocols and intercomparisons
- Data management
- Scientific networking
- Capacity building.

A schematic summary of these Framework Activities is given in Figure 25.
Figure 25

Schematic summary of the Framework Activities described in the GLOBEC Implementation Plan

FRAMEWORK ACTIVITIES

Sampling and models

- Core sampling protocols
- Sampling and observational technological capabilities and needs
- Sampling networks and platforms
- Ships of opportunity
- Emerging technologies
- Model inter-comparison

Data Management

Scientific Networking

- GLOBEC research networks
- Focus Working Groups
- GLOBEC publications
- Open Science Meetings
- Interactions with GECHS
- Interactions with CLIVAR
- Interactions with other climate change programmes

Capacity building

- Scientific training
- Development of scientific infrastructure
- Interdisciplinary training
ACTIVITY 5.0 Sampling and Models: Protocols and Intercomparisons

Introduction
A wide array of Activities, Tasks and sub-Tasks are described in this Implementation Plan. These will be implemented within a range of regional and national programmes, some of which are described below. To achieve global synthesis there is a need to ensure that the data collected, and the models used for their interpretation and analysis, are comparable.

Effective GLOBEC synthesis and modelling will be optimized by careful attention to standards, protocols, and methods, both for sampling and observational systems, and models. This Framework Activity sets guidelines, and suggests mechanisms for working towards a practical element of standardization of methods and models within the GLOBEC programme.

Overall objectives
- Ensure that measurements made by, and models used in, GLOBEC are as comparable as is practically possible, thus aiding global synthesis.

The GLOBEC approach
A coordinated initiative is required to ensure comparability of data and models in the various research Tasks envisaged. In some cases, well defined, internationally agreed upon methods exist and where appropriate these will be adopted and recommended for use by GLOBEC. Such methods cover a variety of basic parameters, particularly those developed as core protocols for JGOFS. In other cases no such standardized methods exist, and from time to time it may prove necessary for GLOBEC to develop such methods to ensure that data are collected in a uniform manner throughout the programme. The absence of such standards would cause major problems for synthesis.

Task 5.1 Core Sampling Protocols and Methods Intercomparison

Rationale
Global synthesis requires that the data collected by GLOBEC programmes are as comparable as possible, through the use of agreed sampling techniques and measurement protocols. This critical Task will ensure that opportunities for comparison and combination of data from the regional and national research programmes are optimized. Intercomparison of data and establishment of long-term trends in marine ecosystems require standardized, data.
Specific objectives

- To evaluate and compare sampling and measurement techniques with a view to recommending methods for use in GLOBEC studies.

Implementation

This Task will be accomplished through a series of workshops under the guidance of the Sampling and Modelling Working Group. These will consider issues of measurement standards, protocols and methods specifically in the context of the needs of the four GLOBEC Research Foci and the Regional Programmes. This Activity will lead to agreement on the recommendation of existing established methodologies, or identify those which require further development and intercomparsion before recommendation for use by GLOBEC. ICES through their Working Group on Zooplankton Ecology (WGZE) are developing a Zooplankton Methodology Manual, and this initiative is highly relevant to this Task.

Outputs

- Workshop reports on methods and measurement issues for the four Foci and the Regional Programmes
- Information on standard GLOBEC protocols disseminated through the IPO (web-site and hard-copy).

Subtask 5.1.1 Provide an updated account of sampling and observational technological capabilities and needs

Rationale

GLOBEC Report No. 3 provided an extensive summary of sampling capabilities that were available as of early 1993. Several advances in sampling technology have been made since that time. Also, there remain gaps in sampling capabilities which need to be identified and approaches for eliminating these will be required. Examples of advances in sampling technology that can be used to obtain biologically relevant information include the use of Acoustic Doppler Current Profiling (ADCP) meters to measure vertical velocity and free-fall Conductivity Temperature Depth (CTD) systems to obtain routine small scale turbulence measurements. Areas where research in sampling methodology needs to be done are in obtaining higher size resolution and improved identification (by species) of phytoplankton and zooplankton as well as higher trophic level organisms including fish, and determination of in situ mortality, grazing, and predation rates in collaboration with Focus 2. GLOBEC needs to adopt sampling systems that provide real-time reporting of high-rate data that can be incorporated in data assimilation models to provide regional and global scale information.

New instrumentation and methodologies are essential for the execution of GLOBEC objectives. Many of the new approaches are highly advantageous because they will provide large volumes of data for many biological variables. However, interpretation and calibration of the data are quite complex. Thus, “ground-truthing” using traditional sampling will be important, especially in the early stages of application.
Programmes like GLOBEC will always be inherently data poor because of undersampling of the vast ocean environment where variability in space and time spans over ten orders of magnitude. Further exacerbating the problem is the diversity and range of important biological and chemical variables. In many cases, it will be more important to obtain large volumes of data than to obtain a limited number of measurements with high resolution and accuracy, a lesson well documented by the physical oceanographic community. Hence, a careful blend of data which are numerous, but less accurate or precise, and a more limited subset which is high in quality will be necessary.

**Specific objectives**

- New sampling and observational technologies (particularly since 1993) need to be summarized and evaluated for GLOBEC needs so as to achieve optimal deployment in GLOBEC programmes.

**Implementation**

A workshop should be convened and a brief report should update GLOBEC Report No. 3.

**Outputs**

- Report on advances in moorings, drifters, vertical profilers, towed bodies (both dedicated for research and deployed from ships of opportunity), remotely operated vehicles (ROVs), neutrally buoyant floats (e.g., simulating organism behaviours through buoyancy adjustments), shore-based radar and acoustical systems, and autonomous underwater vehicles (AUVs) as well as sensors which have been made within the past few years. The report should also include information on new communication and observational satellites, as well as advances in remote sensing (for example, surface temperature, ocean colour, and altimetry deserve particular attention).

**Subtask 5.1.2**

Summarize existing/continuing/planned sampling networks and remote sensing platforms. Special attention should be given to means of obtaining a nearly continuous spectrum of sampled scales.

**Rationale**

The cost of obtaining data continues to increase and the number of dedicated platforms is decreasing, thus every effort needs to be made to capitalize on available data. In addition, modelling efforts can be used to optimize sampling. An important research area is development of subgrid scale parameterizations for models. Observations (e.g., turbulence, mesoscale, etc.), likely obtained through process-oriented studies of Focus 2, will be needed for this.

**Specific objectives**

- Develop collaborations with GOOS efforts, especially those of LMR and Coastal modules.
To utilize physical and biological (e.g., HOTO) data sets being obtained for other purposes.

**Implementation**
Establish, and maintain, good communications with related coordinating groups.

**Outputs**
- Document information and provide to the GLOBEC IPO for dissemination to the Regional and National GLOBEC programmes.

**Subtask 5.1.3 Explore new schemes for obtaining data utilising ships of opportunity**

**Rationale**
There is great potential for using ships of opportunity for GLOBEC observations. These ships include weather stations, ferries and commercial ships. They provide the possibility of obtaining observations at times and places not available to research ships. They are essential for the continuation and establishment of new long term observational and monitoring programmes such as those of the CPR survey (see Focus 1).

This approach has proven successful for physical oceanography. Many merchant ships now routinely obtain upper-ocean currents from ADCP measurements, and the backscatter information from these measurements may be useful for determining zooplankton biomass. Similarly, routine shipboard echosounder data may be utilized. However, special methods of interpreting these data will be necessary. Use of towed bodies (e.g., CPRs, Video Plankton Recorders [VPRs], Optical Plankton Counters [OPCs], Undulating Oceanographic Recorders [UORs], etc.) and perhaps expendable probes on ships of opportunity (including regular shipping and ferry routes) should be explored.

**Specific objectives**
- Determine how to capitalize effectively on routine measurement programmes.

**Implementation**
Contact representatives of various ship-of-opportunity programmes to explore opportunities for interaction and collaboration with GLOBEC.

**Outputs**
- Report information to GLOBEC IPO for dissemination.
**Subtask 5.1.5 Expand the availability and application of relevant emerging sampling and observational technologies**

**Rationale**
Many of the most promising acoustical and optical technologies are available to only a few research scientists. Because of their importance and abilities to obtain large volumes of relevant data, these need to be mass produced to reduce cost and in turn increase the volume of critical data. Interestingly, the ADCP, which began as a research instrument has become commonly used on commercial vessels. Similarly, several optical systems have been produced in relatively large numbers because of their value in ecological studies and environmental monitoring. An important outcome of this Task will be directed towards making such technologies more readily available in developing countries involved in GLOBEC research.

**Specific objectives**
- To identify the most promising technologies for GLOBEC
- To explore means to increase availability of the new technologies for deployment in the GLOBEC Regional and National programmes.

**Implementation**
Gather relevant information on emerging technologies which have potential for mass production

**Outputs**
- Report to the GLOBEC community on expansion of availability of new, relevant technologies.

**Task 5.2 Model Intercomparison**

**Rationale**
Modelling is central to GLOBEC and a broad range of simple to complex models is needed (Focus 3). Because of the sparseness of data, data assimilation methods will be crucial. Modularity and portability of models are important attributes of GLOBEC models. The modelling component of GLOBEC will rely on interdisciplinary OSSEs to plan and optimize sampling programmes. Clearly, a strong interlinking of model and observation components is of great importance. To date, the SOS- and NM-WGs have been well coordinated and it is anticipated that this arrangement will continue to ensure the maximum utilization of GLOBEC observational and modelling resources.

On-going observational and modelling programmes should be incorporated into GLOBEC modelling activities because integrated data collection and modelling efforts are costly and relatively few in number. These programmes can be used as building blocks and the experiences gained from them can be useful for future GLOBEC modelling. The emphasis within GLOBEC on zooplankton dynamics complements the JGOFS focus on primary production. The requirement in GLOBEC for realistic circulation models makes exploitation of the results of WOCE and other...
physical oceanography modelling efforts desirable.

Specific objectives
- Identify regional programmes and modelling efforts that are ongoing in areas where GLOBEC-type projects are being developed and request that these programmes consider accommodating measurements and models that would be beneficial to GLOBEC
- Evaluate previous modelling results in an effort to determine critical space and time requirements in support of the development of monitoring/sampling strategies that would benefit GLOBEC
- Coordinate and collaborate closely with modelling activities in these on-going programmes.

Implementation
Convene a workshop, if appropriate, to bring together modelling components of major programmes, such as JGOFS and WOCE, to foster exchange of information and ideas. Models will likely use data obtained from different platforms, and this should be in standardized format wherever possible. Provide GLOBEC representation at modelling workshops and working groups supported by other programmes

Outputs
- Model results will be used in planning field programmes
- Better integration of GLOBEC approaches and ideas in other programmes.
ACTIVITY 6.0 Data Management

Introduction
There are large data management concerns for GLOBEC. Some of the challenges include:

1. Data rescue/data recovery
2. Exchange and archival of time series data, including palaeoceanographic data and summarized data series products
3. Data exchange amongst researchers participating in integrated process studies
4. Specifications of meta-data requirements for existing and emerging data types to allow for proper archival and retrieval of data
5. Preparation of standardized datasets to force, test and validate numerical models
6. Assuring the GLOBEC legacy through the submission of data to organizations that can assure long-term data stewardship.

Many of these problems will also be faced by the Regional and national GLOBEC programmes. The international GLOBEC programme can contribute substantially to the resolution of these data problems by recommending common approaches and standards for data formats, archival, etc. Ultimately, success of GLOBEC through the synthesis of results will depend in large part on success in implementing common data conventions. This important issue is also addressed in the Framework Activity on, “Sampling and models: protocols and inter-comparisons” (Activity 5.0, above).

Overall objectives
• To develop and recommend policies on the management of data from GLOBEC programmes, to facilitate access and understanding, and to enable synthesis of results.

The GLOBEC approach
GLOBEC will use a decentralized data management and distribution system. The centralized components (for example, centralized under the supervision of the IPO, will be a comprehensive inventory of GLOBEC and GLOBEC-like data holdings with pointers to their locations and key contact persons. Within-project (during the funded lifetime of GLOBEC programmes) data management and data exchange is an important component of each national and Regional GLOBEC programme, and should be addressed in detail within the implementation plan of each GLOBEC programme. Each GLOBEC programme/project should create an inventory of data and data products. These inventories will be collated by the IPO to build the centralized database of meta-data and pointers to actual data locations. Each GLOBEC programme should address the long term archival of observational data and data products in order to ensure a lasting contribution to marine science. Note that there are several national and international data agencies that may be able to contribute to the archiving of data that will derive from typical GLOBEC programmes.
Data sharing and exchange is an essential component of GLOBEC interdisciplinary studies. The collective value of data is greater than its dispersed value. All investigators should be prepared to share their data and data products and should recognize the ‘proprietorship’ (‘rights to first publication/authorship’) of data acquired from other investigators. GLOBEC investigators retain the primary responsibility for data quality control and assurance. Investigators, in particular those using data from other researchers, should be prepared to track updates, corrections and dataset versions.

Implementation

Implementation of the GLOBEC policies for data management will require interactions among the individual GLOBEC programmes and other international agencies established for the long-term archiving of data (e.g. World Oceanographic Data Centres, the IGBP Data and Information Systems Project [IGBP-DIS] etc.). In order to coordinate these activities and policy developments, consideration will be given to forming a Data Management Working Group (DMWG) to review existing GLOBEC data management systems, issues and problems and recommend specific strategies to deal with the shortcomings of existing systems. Requirements for data products or related data issues should be forwarded to the DMWG by other working groups. These data issues will place a strong responsibility on the IPO, which will be advised by the DMWG.

The IPO should provide active leadership in developing and implementing quality control procedures, with the goal of incorporating these procedures into the national and regional data distribution systems. The IPO should provide an inventory, and data access procedures to non-GLOBEC data sources that are of importance to GLOBEC participants. The IPO should identify and recommend mechanisms to create required “linkages” and data exchanges with other appropriate programmes (within the IGBP, and others). This should include (but not be limited to) links with JGOFS, PAGES, CLIVAR and GOOS. Further, the IPO (advised by the DMWG) should monitor progress of data migration to permanent archives and advise the SSC on any problem areas. Clearly, the role of the IPO is critical, and the SSC should keep a careful watch to ensure that the IPO has adequate resources to discharge its data responsibilities.

The IPO should construct and maintain an inventory of GLOBEC (and GLOBEC-relevant) data and data products. In this work the IPO should cooperate with the following organizations:

- Existing World Data Centres (WDCs) and related organizations particularly to ensure the long-term stewardship of GLOBEC data
- National GLOBEC programme offices and/or national data management offices
- Regional programme data management efforts.

The IPO and GLOBEC SSC should ensure close collaboration between the DMWG and the Numerical Model/Observation Systems Working Group to establish:

- Metadata requirements for new observation technologies
- Data archival requirements for new observation technologies
• Standardized data sets for testing, forcing and validation of numerical models.

Close links should be maintained with IGBP-DIS activities, particularly FOCUS 2 which is developing a meta-data inventory within IGBP together with an IGBP-specific web search engine.

GLOBEC national and regional programmes need to identify their data management strategies, addressing the issues of data standardization, within-project data exchange, inventories and migration to permanent archives.
ACTIVITY 7.0 Scientific Networking

Introduction
GLOBEC encompasses a considerable number of different disciplines such as climatology, marine geology, physical oceanography, marine chemistry, planktology and fisheries biology. GLOBEC researchers are involved in retrospective investigations using long-term data series, in field studies collecting data and samples or taking in-situ measurements and in modelling activities. GLOBEC research is carried out on all continents, including Antarctica, and close cooperation is continuously required between scientists working in counties far away from each other. In view of this interdisciplinary nature of research and the multi-disciplinary cooperation which includes developing as well as developed counties GLOBEC must provide mechanisms for rapid transfer of information to the GLOBEC research community to ensure successful cooperation and to meet its objectives. GLOBEC must also develop strong links with other international global change research programmes with related interests and it must provide some of the scientific understanding required by the groups planning GOOS.

Since GLOBEC is still in its development and planning phase, many individual scientists, national institutions and countries, particularly developing ones, are not well informed about the international programme. The SSC anticipates much broader interest in the GLOBEC programme, especially from small coastal states where local fisheries form a significant economic base. There is an international responsibility to ensure that information about the GLOBEC programme is disseminated to these countries for which it has such relevance and to assist all scientists to become involved in GLOBEC to the greatest extent possible. The results of the GLOBEC research effort must be accessible to the global scientific community, both in the developed and the developing countries.

Overall objectives
• Rapid transfer of information to the GLOBEC research community
• Establish new communication links with scientists, institutions and countries outside of the present GLOBEC community
• Open avenues of communication with other global change core programmes of IGBP, WCRP, and IHDP.

The GLOBEC approach
GLOBEC will establish different types of networks to serve different needs. At the level of individual scientists, the IPO must ensure that all GLOBEC researchers are informed in a timely way on general matters and new developments concerning GLOBEC.

Like other global change programmes, GLOBEC is structured into major sub-programmes (CCC, SPACC, CCCC, SO-GLOBEC) and a large number of regional and national programmes/projects of differing nature and organization, all contributing in some measure to meeting the international GLOBEC objectives. All of these initia-
tives will develop their own networking structure according to their different needs. The task of the GLOBEC IPO is to build an international network across these regional and national initiatives and to establish effective information links between them.

Internationally, information must flow in two directions: the IPO should, of course, provide a constant flow of information on the international GLOBEC programme. At the same time, the IPO should be receiving information on the many local, national and regional research efforts around the world and distilling this for use by the SSC and GLOBEC working groups. Thus, through the efforts of the IPO, news, data and information can also flow between the national programmes and from them to individual GLOBEC researchers.

Task 7.1 Establishment of GLOBEC Research Networks

Rationale
The efficient and timely flow of information is crucial if the efforts of all individual GLOBEC researchers and the different national and regional initiatives are to be harmonized around the four research Foci so as to meet the GLOBEC objectives.

Specific objectives
- The establishment, expansion and maintenance of networks linking GLOBEC scientists at all relevant levels: international, within GLOBEC sub-programmes, regional and national
- Specialist networks for specific purposes.

Implementation
The rapid expansion of the Internet makes scientific networking feasible on a scale that would not have been possible a decade, or even five years ago. Access to electronic mail and the World Wide Web is now becoming wide-spread, although gaps still exist in some countries, especially on the African continent. While GLOBEC must exploit this new resource, the IPO will remain sensitive to the inability of some researchers to participate in networks which are entirely electronically-based and will ensure that they have other means of receiving information about GLOBEC. Dual use of both electronic, and conventional means of communication will ensure that the widest possible community is served effectively.

The IPO will develop and maintain contacts with all of the national GLOBEC programmes and with individual researchers in those countries where no formal national programme exists. These contacts should be used to develop, enlarge and maintain both electronic and traditional mailing lists for the distribution of information.

The GLOBEC web-site is another important tool for the provision of information on the international programme. In order to make it as effective as possible, and to facilitate the exchange of information between national programmes and other groups
relevant to GLOBEC, the IPO can provide an important service to the community by identifying and placing on the web-site appropriate electronic links to as many related activities as possible. To be informative, the web-site will require regular updating.

Consideration will be given to exploiting, and working with, existing IGBP Core Project Impact Centres to provide regional training in support of regional networking.

Outputs
• Functioning GLOBEC research networks
• GLOBEC web-site as a common communication resource for the programme
• Data base of GLOBEC activities, programmes and scientists
• Regional training courses in cooperation with regional Impact Centres.

Task 7.2 Establishment of Focus Working Groups

Rationale
The implementation of the research activities of the four Foci described in this Implementation Plan will require coordination and international leadership. These Foci derive from the GLOBEC Science Plan, and in turn have their origins in a series of successful GLOBEC workshops held under the auspices of Working Groups (see below for list of GLOBEC Reports). In some cases the GLOBEC SSC has already taken steps to re-constitute particular Working Groups, and careful attention will be given to this issue at future meetings.

Specific objectives
• To ensure that the international research of each of the four research Foci is led and coordinated effectively by appropriate specialist Focus Working Groups with wide representation.

Implementation
The GLOBEC SSC will consider establishing Focus Working Groups for each of the four Foci elaborated in this Implementation Plan. Additionally, other Working Groups may be considered to tackle particular issues of importance to the development of the GLOBEC project. As GLOBEC completes it’s Implementation Plan, and moves into a mature research phase, it is expected that the structure of the SSC should move to reflect the activities of the research Foci.

Outputs
• Effective Working Groups to lead and coordinate research under the four Foci.
Specialist networks will be established across the sub-programmes and regional/national initiatives. These will link closely with the Focus Working groups on particular issues, e.g. retrospective investigational, modelling, data banking work.

**Task 7.3 GLOBEC Publications**

**Rationale**
Notwithstanding the increased use of electronic communication, there are many reasons to use traditional means of publication to distribute information about GLOBEC. Reports and newsletters in “hard copy” provide a permanent record of GLOBEC’s progress, one which can be catalogued in libraries and which will be available for reference even after the programme is complete. Such reports, and other informative pieces about the GLOBEC programme can easily be sent to decision makers and managers as needed. Printed documents change hands easily, thereby helping to expand the international GLOBEC network.

There is a need to inform the steadily growing GLOBEC research community on new developments in GLOBEC organization and results. Traditional tools, as well as electronic ones, are important to the success of this effort.

**Specific objectives**
- Ensure the speedy transfer of information on general GLOBEC matters and research meetings, plans, activities and results.

**Implementation**
The IPO will maintain a regular publication schedule for the GLOBEC Newsletter which will be distributed to all GLOBEC researchers, national GLOBEC committees and interested national and international institutions and agencies as a hard copy and on the web-site.

The GLOBEC Report Series will be the forum for the timely distribution of the results of relevant working group meetings and for information on international scientific activities.

**Outputs**
- GLOBEC Newsletter
- GLOBEC Reports.

**Task 7.4 GLOBEC Open Science Meetings**

**Rationale**
GLOBEC needs a forum where researchers of the different sub-programmes and regional/national initiatives can gather to exchange ideas and experience, to present data and new hypotheses and to integrate results. Such meetings, open to the entire GLOBEC community, provide an opportunity for direct feedback to the SSC on the
progress of the international programme. “Mid-course corrections” of programme planning and implementation may result. No other forum allows for face-to-face contacts between the international SSC and the community it serves and such “town meetings”, while requiring significant funding and organizational effort, are an important benefit of an internationally coordinated programme. These meetings also provide an excellent opportunity for building links to other international programmes related to GLOBEC objectives and, as appropriate, may be organized jointly with such programmes. The first Open Science Meeting (OSM) was held in Paris, 17-20 March 1998, and was central to the development of this Implementation Plan. A collection of papers presented at the OSM has been published in *Fisheries Oceanography* 7:179-390.

**Specific objectives**

- Present GLOBEC to the international research community and to national and international funding agencies
- Present and integrate results of sub-programmes and regional/national initiatives
- Review GLOBEC research activities, re-focus on relevant themes, if required and re-direct objectives if appropriate
- Provide a forum for open and direct contacts between GLOBEC researchers at all levels.

**Implementation**

The IGBP requires its core projects to convene OSMs on a regular basis. Whereas the IPO is responsible for their organization, the SSC will outline the scientific programme for such meetings. These meetings will be open, on a self-funding basis, to all interested scientists and representatives of national and international institutions and agencies. The broadest possible participation will be sought.

**Outputs**

- Periodic review and revision of GLOBEC research objectives and activities
- Publication of research results in peer-reviewed international journals
- Regional and global syntheses of GLOBEC research results.
Task 7.5 Interactions with other Global Change Research Programmes

Subtask 7.5.1 Interactions with the Global Environmental Change and Human Security (GECHS) Project to examine the human dimensions of changes in marine ecosystems

Rationale

Large, abrupt, and even cyclical changes in marine ecosystems leading to changes in fish population abundance, distribution, and composition can have significant human impacts. Substantial social disruptions were caused by the collapse of the Peruvian anchoveta fishery in the 1970’s and the collapse of the NW Atlantic cod stocks in the 1990’s. International conflicts have arisen because of disagreements on the area of a nations fishing territory, e.g. between Iceland and the U.K. over demersal fisheries in the Icelandic Sea in the early 1970s; between Canada and Spain over demersal fishing in the NW Atlantic late 1980s; and in the North Pacific relating to high-seas drift net fishing. Major changes in species composition, such as the collapse of herring populations on George’s Bank in the 1980’s and the collapse of crustacean populations in the Gulf of Alaska and Bering Sea, caused substantial changes in fishing strategies and in the deployment of fishing power. Highly migratory stocks like the Atlanto-Scandian herring in the Norwegian Sea are causing conflicts about how to share the stocks between nations. The extent to which common themes can be found to these social disruptions, potential solutions or mitigating actions, and their resulting impacts to marine ecosystems (e.g. increased exploitation of previously under-exploited species) is an important topic for GLOBEC. It is also a topic that is central to the developing IHDP Global Environmental Change and Human Security (GECHS) project. Linkages between GLOBEC and GECHS on this topic are essential to develop a future management structure for marine resources which not only considers total allowable catch (TAC) of single species and their geographical distribution, but also gives background information on responses at other trophic levels in the marine ecosystem, effects on alternative fishing methods, interaction with decisions concerning land-based industry and communities which rely on marine resources. As stated in the GECHS Science Plan “the overall research question addressed by GECHS is simply, what is the relation between global environmental change and human security?”. More specifically, GECHS identifies six key questions which all have more or less direct links to the Tasks of GLOBEC:

- What is the present extent of insecurity?
- Which regions are most insecure?
- What types of environmental change threaten human security?
- How does environmental change threaten human security?
- Why are some regions more vulnerable to specific environmental changes than others?
- Can we predict future insecurity?
Specific objectives

• To interact with the GECHS Project to identify:
  - how large changes in marine ecosystems affect human security globally, and in coastal communities;
  - why some regions and communities are more vulnerable than others to large changes in marine ecosystems;
  - indicators of changes in marine ecosystems which are likely to have major impacts on human security;
  - to identify social responses to large changes in marine ecosystems that may have further deleterious impacts to these ecosystems.

Implementation

GLOBEC programmes involved in Foci 1–3 need to identify changes that may result in qualitative changes in abundance and species composition, such that fishing activities and local communities may be severely affected (either positively or negatively). These will set the stage for recognising changes that may affect social systems. In the problems described in the Rationale above national authorities are seeking advice from expertise separately, e.g. from fisheries biologists, from fisheries economists, or expertise in social sciences. These kinds of problems should, however, be approached in a more holistic way, not only from a management point of view but also from a scientific point of view. The emerging IHDP provides an opportunity to start joint studies of social scientists and ecologists in order to examine the entire consequences of major changes in marine ecosystems, particularly the GECHS project. Such studies should include common elements to the disruptions, any solutions that were found, and any mitigating social actions that could have further consequences for the marine ecosystem. Such consequences could include redistribution of fishing to new species, new areas, new gear types (i.e. displaced fishing effort), or delaying social changes to wait for the ecosystem to recover to its former state (which may simply displace intense fishing effort in time). The term “Human Security” in the GECHS project comprises a wide range of problems with four interacting main components: physical security, economic security, health security and environmental security. The working definition of Human Security established in the GECHS Science Plan is: “1) ensuring the existence of options to mitigate or adapt to threats to human, environmental and social rights; and 2) ensuring the freedom of those affected to exercise the options”. Through the GLOBEC objectives to explore marine ecosystem variability and change, GLOBEC will contribute to the understanding of environmental security and sustainable development which are both major components of the broad term Human Security of GECHS.

Outputs

• Identification of “warning signals” for typical marine ecosystems globally that suggest the possibility of substantive changes in abundance or composition sufficient to cause social disruptions

• Understanding of the responses of human social systems to substantive changes in marine ecosystems, and their potential for further deleterious impacts on marine systems.
Subtask 7.5.2 Interactions with the World Climate Research Programme (WCRP) on Climate Variability and Predictability (CLIVAR) to examine the influence of global climate change on marine ecosystems

Rationale
An important rationale for development of the CLIVAR Programme has been the output from the Tropical Ocean and Global Atmosphere (TOGA) Programme and the World Ocean Circulation Experiment (WOCE). A key issue of CLIVAR is that the understanding of seasonal to centennial climate variability depends on understanding the coupled ocean-atmosphere processes. Both the time and spatial scales focused in CLIVAR are to a large extent similar to the scales of marine ecosystem variability focused in GLOBEC. The overall objectives of CLIVAR are to:

- Describe and understand the physical processes responsible for climate variability and predictability on seasonal, interannual, decadal and centennial time scales, through the collection and analysis of observations and the development and application of models of the coupled climate system, in cooperation with other relevant climate research and observing programmes
- Extend the record of climate variability over the time scales of interest through the assembly of quality-controlled palaeoclimatic and instrumental data sets
- Extend the range and accuracy of seasonal to interannual climate prediction through the development of global coupled predictive models
- Understand and predict the response of the climate system to increases of radiatively active gases and aerosols and compare these predictions to the observed climate record in order to detect the anthropogenic modification of the natural climate signal.

Of the three main components of CLIVAR, Global Ocean Atmosphere Land System (GOALS), Decadal to Centennial Climate System (DecCen) and Anthropogenic Climate Change (ACC), the two first components focus on climate processes of great importance for GLOBEC. They, respectively, focus on seasonal to interannual and decadal to centennial climate variability with emphasis on the coupled climate system. The nine research areas identified in GOALS and DecCen focus on specific problems that link directly to each of the regional GLOBEC Programmes.

Six of the research areas have importance for the dynamics of the marine ecosystems considered in SPACC. Thus G1. “Extending and improving predictions based on ENSO”, G2. “Variability of the Asian-Australian monsoon”, G3. “Variability of the American monsoon systems”, G4. “African climate variability”, D2. “Tropical Atlantic variability” and D4. “Pacific and Indian Oceans decadal variability”. They all focus on lower to middle latitude climate processes of great importance to address the questions of what causes variability in the dynamics of typical upwelling ecosystems. Three of these research areas have also direct importance to CCCC. These are G1, G3 and D4 which consider processes that have implications on a larger scale and demonstrate the importance of teleconnections. Two of the research areas have particular interest to CCC. The processes of D1, “The North Atlantic Oscillation (NAO)” and D3 “Atlantic thermohaline circulation” consider the key elements of what is be-
lieved to influence the fluctuations of North Atlantic cod stocks and their prey species. One of the research areas, D5. “Southern Ocean thermohaline circulation”, has particular interest for Southern Ocean GLOBEC as it addresses both variability of the Antarctic Circumpolar Current, coupled ice-ocean-atmosphere interaction and deep water formation.

**Specific objectives**

- To utilize results obtained on climate variability within the CLIVAR Programme to interpret and predict marine ecosystem variability
- To provide feedback to the CLIVAR Programme on climate processes of major importance to understanding marine ecosystem variability.

**Implementation**

The interaction with CLIVAR will be most effective at the regional programme level. SPACC, CCC, CCCC and SO GLOBEC should establish contacts with the nine research areas of GOALS and DecCen in CLIVAR in order to link the climate processes of the various regions directly to ecosystems. The results of Activity 4.1 and Activity 4.2 in Focus 4 will provide important feedback to CLIVAR by informing interacting scientific communities on climatic influences on trophic transfer.

**Outputs**

- Understand how climate variability forces changes in marine ecosystems
- Provide a system for prediction of marine ecosystem variability and change.

**Subtask 7.5.3 Interaction with other ecosystem and climate change programmes**

In addition to the GECHS and the CLIVAR Projects there are also other international programmes on climate change which more or less have interlinking objectives with GLOBEC. Many of them are within the IGBP, while other relevant climate change programmes are found under the World Climate Research Programme jointly sponsored by ICSU, the World Meteorological Organization (WMO) and IOC.

GLOBEC should utilize the large number of data sets and time series collected during earlier and existing programmes. GLOBEC should cooperate with the IGBP programmes JGOFS and LOICZ. This will provide important support to GLOBEC for understanding the energy flow at lower trophic level from zooplankton grazing, production of faecal pellets and CO$_2$ draw down and the issues of new versus regenerated production. At higher trophic levels the three IGBP programmes LOICZ, GAIM and GCTE provide support in considering feedback mechanisms.

GLOBEC also needs to utilize the results of the major WCRP programmes other than CLIVAR. WOCE which is now in its terminating phase has provided an important background for the CLIVAR Programme and important basin-scale oceanography time series have been established. The LMR component of GOOS has high relevance to GLOBEC as it focuses on the need for environmental data in management of fish stocks.
Currently interdecadal data sets on plankton which have been assembled are restricted to a few geographical regions predominantly in the northern hemisphere. Examples are CPR data, CalCOFI, Gulf of Alaska, and Gulf of Maine. An extended inventory, assembly and data analysis are required for other regions, especially for example for the Arctic Basin, the Indian Ocean, and the Mediterranean Basin. Interdecadal plankton-fish-climate linkages are still poorly known for these parts of the globe. However, data are potentially available, from archives, cruise reports and some publications. GLOBEC should contribute to the process of making data available through bridging and coordination of regional GLOBEC programmes in such areas on one hand and through interaction with key representatives running the regional non-GLOBEC programmes on the other hand.
ACTIVITY 8.0 Capacity Building

Introduction
Capacity building is a very important objective of GLOBEC which is most likely to be lead initially through the SPACC regional programme. Many GLOBEC research goals cannot be achieved without the fullest possible international participation in the programme. Eight of the ten most important commercial fish species by volume on a global scale are small pelagic fish. These fish stocks are exploited primarily within the Exclusive Economic Zones (EEZ) of coastal states, many of which are also developing countries. In most of these coastal and small island states, the fisheries are an important economic resource and fish are a significant source of protein in the diet. Scientists in these countries have an important part to play in GLOBEC research by contributing their knowledge to the local marine resource management process. Their involvement will benefit the international programme as a whole by broadening its geographic coverage, bringing new viewpoints, regional expertise and understanding. Without assuming the responsibility to foster a healthy and truly mutually beneficial collaboration with their colleagues in developing countries, GLOBEC scientists from the developed world might expect problems in applying for permission to conduct research within the EEZs of these countries.

The SPACC Programme is being carried out in a large number of ecosystems around the world, in the Americas, Africa and Europe and will soon be extended into Asia. Thus, SPACC provides an important opportunity to involve marine scientists in a number of developing countries in research of direct relevance to them. In some regions, particularly in the developing world, the ability to conduct research is hampered by a lack of scientific expertise and adequate technological infrastructure. Consequently, capacity building will be a major programme element of GLOBEC and SPACC in particular. To assure world-wide participation in its comparison of ecosystems, SPACC will emphasize inexpensive core measurements that can be made in most countries, while at the same time where possible promoting the use of advanced technologies (see Activity 5.0).

Overall objectives
- Encourage scientists and institutions in developing countries to become fully involved in GLOBEC
- Involve scientists from developing countries in adopting modern research methods
- Develop capacity and research infrastructure in developing countries.

The GLOBEC approach
SPACC is unique among the programme elements of GLOBEC because of its global coverage, the participation of many developing as well as developed countries and its emphasis on capacity building, education and training. It will mobilize scientific manpower and resources in developing countries to address regional and global scientific questions concerned with global change. SPACC not only enhances north/south cooperation, but also provides a forum for south/south communication, as
some of the most important ecosystems for small pelagic fishes are in the southern hemisphere.

Task 8.1 Scientific Training

Rationale
GLOBEC can meet its objective to understand the impact of climate variability through ecosystem comparison only, if well-trained scientists from the widest network of countries have good opportunities to become involved in cooperative research.

Specific objectives
• Organize training courses
• Enhance short-term exchange of scientists between developing and developed countries.

Implementation
A number of organizations for international cooperation such as SCOR, IOC-UNESCO, Global Change System for Analysis Research and Training (START), SADC or the Inter-American Institute (IAI) as well as national agencies for technical cooperation have a strong interest in fostering capacity building for global change research in developing countries. Consequently, they may be prepared to assist in organising courses and to contribute to funding them. Regional courses would be particularly appropriate for joint development by GLOBEC and START.

Such courses can offer training in appropriate methodologies for GLOBEC measurements, but will be worthless if the “students” return to laboratories and institutions which do not possess the instruments or facilities required to make these measurements. GLOBEC will give careful consideration to matching the training it offers to efforts improve the capabilities of the participating institutions. At sea training opportunities will also be provided on GLOBEC research cruises whenever possible.

The experience of other programmes, and especially JGOFS, is instructive. Regional training courses in the interpretation of remotely-sensed ocean colour data have been matched to local scientific interests and to the acquisition of funds for relatively inexpensive SeaWIFS data receiving stations to be located at institutes in the region. The design of training courses in modelling techniques should not exceed the potential of local researchers to apply these techniques, or should be linked to the acquisition of new computing capabilities. When the research vessels of developed nations are operating in the waters of a developing country, high priority should be given to providing berths for local scientists who are unlikely to have access to well-equipped ships.

Output
• Improvement of research capabilities of scientists from developing countries
• Increased geographic coverage, especially for regional programmes such as SPACC.
Task 8.2  Development of Scientific Infrastructure and Enhancement of Capacity Building in Developing Countries

Rationale
There is a need for improvement of scientific and technical capabilities and of research infrastructure in developing countries to enhance sustainable development.

Specific objectives
• Enhance mutual assistance between researchers from developing and developed countries in GLOBEC projects
• Full participation of developing countries in SPACC, and other developing regional programmes.

Implementation
A whole suite of procedures will be incorporated into GLOBEC to meet these specific objectives. SPACC will organize field campaigns involving scientists and technicians from both developing and developed countries. A by-product of these international campaigns is “training on the job”. Long-term exchange of researchers between developing and developed counties will be promoted. A particularly useful tool for enhancing institutional or regional capacity is twinning between research institutions from developing and developed counties. Communication between scientists from developing countries will be supported especially to initiate south/south cooperation. SPACC is particularly suited for such an undertaking as SPACC researchers in South America and Northern and Southern Africa share similar research problems as they work in ecosystems dominated by the same fish communities and sharing the same physical forcing processes.

Task 8.3  Interdisciplinary Training of Students and Especially Post-Doctoral Fellows in Both Observational and Modelling Methods

Rationale
A major GLOBEC thrust needs to be in the area of training of students and post-doctoral fellows in techniques relevant to the challenging research tasks posed by GLOBEC. In particular, researchers of GLOBEC problems will be most effective if they are well grounded in both observational and modelling areas, a relatively rare combination today. Special means, such as short courses, exchange programmes, etc., need to be developed to satisfy this need. In accord with this recommendation, international networking among GLOBEC students and researchers is now feasible and highly desirable as a tool for education as well as research. Through these means, exchange of state-of-the-art methodologies, data, and models can be facilitated. Further, intercomparisons of regional studies can be accomplished. To under-
score the importance of this GLOBEC activity, other evolving and future pro-
grammes (e.g., GOOS-LMR) will likely base some of their observational methodolo-
gies and standards as well as modelling components upon the framework of the
GLOBEC programme.

Few students are provided with truly interdisciplinary training. Most academic
structures necessitate making a choice between pursuing training in biology or
physics, modelling or observational studies. Thus, relatively limited numbers of
young oceanographers are capable of contributing to the execution of the Tasks out-
lined under Activity 3 unless given special educational opportunities. Also, the
broader oceanographic community is sometimes unaware of what has been learned
via modelling and what can be accomplished with this approach.

Specific objectives
• To train students and post-doctoral fellows in observational and modelling ar-
eas relevant to GLOBEC
• Convene workshops/training activities that will allow exposure of the larger
oceanographic community to the use of interdisciplinary models.

Implementation
Summer internships and postdoctoral fellowships should be provided for use at in-
stitutions which are active in collaborations involving interdisciplinary observa-
tional and modelling studies in collaboration with the Regional programmes. In ad-
dition, short courses, summer courses and workshops on interdisciplinary modell-
ing, will be organized and sponsored.

Outputs
• GLOBEC reports on the impact of training programmes, and the dissemination
of trained personnel into the field programmes.
GLOBEC REGIONAL PROGRAMMES

GLOBEC is currently implementing four major regional research programmes (Figure 26). These are briefly described below; more detailed planning documents are available for each of them.

The first two field studies – SO-GLOBEC and SPACC – are the responsibility of two GLOBEC working groups and, therefore, fall directly under the oversight of the GLOBEC SSC. In the case of the former, the extent of the Southern Ocean region, the number of countries involved and the enormous logistical difficulties encountered in any major oceanographic effort there, make full international coordination essential. The SPACC programme involves a very large number of countries in studies in many different regions of the world ocean.

Secondly, there are two large-scale studies, each of which is confined to a single ocean basin, which are being coordinated by regional oceanographic organizations in very close cooperation with GLOBEC. While individuals involved in each of these studies provide scientific input to the international GLOBEC SSC, the lead responsibility for these programmes is taken by the regional organization as its contribution to the GLOBEC programme. These programmes are the CCC programme in the North Atlantic Ocean which is cosponsored by GLOBEC and the ICES, and the programme on CCC of PICES and GLOBEC.

Figure 27 illustrates the interactions between the four Research Foci, their Activities, and the current GLOBEC Regional Programmes, showing how particular programmes will emphasize and contribute to particular Foci and Activities.
Figure 26

Map showing the schematic distribution of the four current major GLOBEC Regional Programmes.
Figure 27

Illustration of the interactions between the four Research Foci, their Activities, and the current GLO BEC Regional Programmes. Particular programmes will emphasize and contribute of particular Foci and Activities.

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<tr>
<th>FOCUS 1</th>
<th>Activity 1.1</th>
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**KEY**

- A major component of the Regional programme
- A major activity; some contribution
- No likely, or planned activity
GLOBEC Southern Ocean Programme
(SO-GLOBEC)

Background
The Antarctic marine food web is characterized by the importance of a single key species, Antarctic krill (*Euphausia superba*), and by dependence of many of the components of this food web on sea ice during some or all of their life history. These unique characteristics make the Antarctic marine ecosystem vulnerable to changes in environmental conditions or to resource exploitation. However, predictions of how this system will respond to environmental variability and climate change first require understanding of the cycles of natural population variability, especially in those that occur in response to physical variability. More detailed discussions of the biological and environmental couplings of the Antarctic marine ecosystem are given in US GLOBEC Report No. 5 and International GLOBEC Report No. 5.

Implementation plans
The first SO-GLOBEC Implementation Plan (GLOBEC Report No. 7) outlined a programme consisting of field studies in three primary regions, modelling efforts to develop coupled circulation-sea ice-biological models, and data management that included historical data sets. However, recently the role of sea ice and winter processes in determining krill recruitment and subsequent survival and/or breeding success of krill-dependent top predator species has been increasingly recognized (Figure 28). While the inclusion of winter processes has been part of SO-GLOBEC planning since the outset, the recent studies have indicated that coverage of this part of the year is critical to understanding the physical-biological coupling of the Antarctic ecosystem. Incorporation of current ideas and hypotheses about the Antarctic marine ecosystem required revision of the existing SO-GLOBEC Implementation Plan. This was done through a SO-GLOBEC Planning Group, which was appointed by the GLOBEC SSC in 1996.

As presented in GLOBEC Report No. 7A, the SO-GLOBEC programme will focus on Antarctic krill as the target species; however, this focus includes krill habitat, prey, predators and competitors. The SO-GLOBEC programme will be a year-round study, with emphasis on winter processes. The key science questions for SO-GLOBEC given in GLOBEC Report No. 7 were modified to reflect this narrowing in focus and are presented in International GLOBEC Report No. 7A, which provides an addendum to the original Implementation Plan.

Field activities related to SO-GLOBEC will begin in field season 1999/2000 and will consist of focused studies in limited regions that will provide information related to SO-GLOBEC science questions. Potential studies within this time frame are a March-May 1999 German cruise and three Australian cruises in 1999 (July-August, September-October, December) that will focus on demographic features of krill population. The Australian cruises will provide a limited time series that will document winter to summer changes in part of the Antarctic marine ecosystem. The British Antarctic Survey core programme at South Georgia in 1999/2000 will be focused on various aspects of krill-predator interactions. The results of these field efforts will be incorporated into planning for the larger SO-GLOBEC field effort.
Figure 28

The Antarctic krill, *Euphausia superba*. Concept of the relationships between krill recruitment and sea ice parameters, timing of krill spawning and salp abundance (modified from Siegel and Loeb 1995)
The primary field activities for SO-GLOBEC (Figure 29) will be concentrated in the Antarctic Peninsula area and the 70° E region, will have six months of continuous coverage, and will encompass the summer and winter seasons. The SO-GLOBEC field year will be 2000/2001. It has been determined that sufficient ship resources will be available within this time frame to provide year-round coverage in the Antarctic Peninsula region and seasonal coverage, especially in the winter, in the 70° E region. The next effort for SO-GLOBEC will consist of focused regional planning meetings that will design the field study efforts. These meetings continued during latter part of 1998 and early 1999. Also, SO-GLOBEC will exchange coordination plans and ideas with the Commission for Conservation of Antarctic Marine Living Resources (CCAMLR) for krill field research activities for the austral summer seasons 2000/2001 or 2001/2002.

The SO-GLOBEC Planning Group identified a critical need for standardization of techniques, especially winter krill measurements, and that these should occur across regions. Also, there is a need to have a set of core measurements for the next two-year period prior to the larger SO-GLOBEC field effort. There is now an effort underway through the SO-GLOBEC Planning Group to provide standards for core measurements and methods so that data from different regions and times can be directly compared. This will relate closely to the Framework Activity 5.0.

Given the multi-nation effort required for a year-round SO-GLOBEC field programme, the need for a central coordination/planning office was identified. Discussions have been held with the individuals/nations that have expressed an interest in hosting this office. It is anticipated that the SO-GLOBEC coordination office will be established. This office will be separate but coordinated with the IPO. This will allow coordination with other International GLOBEC and IGBP activities.

Working groups on data management and modelling have been established. A data policy for SO-GLOBEC was published as an appendix to International GLOBEC Report 7A.

The SO-GLOBEC field effort will provide an opportunity to obtain distribution and abundance estimates of marine mammals in the Antarctic Peninsula and 70 E regions that are concurrent with other environmental and biological data sets. Thus, the SO-GLOBEC programme is currently undertaking discussions with the International Whaling Commission (IWC), concerning IWC participation in SO-GLOBEC field activities. Participation by IWC would benefit the science objectives of SO-GLOBEC and coordination with SO-GLOBEC by IWC would further the IWC interests in determining potential effects of climate change on cetaceans and the foraging ecology of baleen whales.

SO-GLOBEC has been recognized as a contributing programme to the Scientific Committee on Antarctic Research (SCAR) programme of research on Global Change in the Antarctic (GLOCHANT). Discussions are currently ongoing with SCAR and GLOCHANT to co-convene workshops in the areas of Sea Ice Ecology and Overwintering Strategies of Marine Antarctic Invertebrates.

Information and updates on the SO-GLOBEC programme can be obtained by accessing:
http://www1.npm.ac.uk/globec/Major2~1.htm or
http://www.usglobec.berkeley.edu/usglobec/globec.homepage.html
Figure 29

Map of the proposed SO-GLOBEC field activities, showing planned ship tracks and working areas (stippled).
Small Pelagic Fishes and Climate Change (SPACC)

The objective of SPACC is to identify how physical forces are linked with the growth of pelagic fish populations, which is believed to be mediated through the dynamics of zooplankton populations (Figure 30). The long-range goal of SPACC is to forecast how changes in ocean climate will alter the productivity of small pelagic fish populations. To address this goal, SPACC will use comparative retrospective and process studies. The scientific questions addressed by SPACC are presented in the 1994 Science Plan (GLOBEC Report No. 8). The SPACC Implementation Plan has been published as GLOBEC Report No. 11.

Small pelagic fishes constitute about 30 percent of the world fish catch. They are an ideal group for comparative ecosystem studies because of their global distribution; their great swings in abundance; possible teleconnections between different ecosystems; their short, plankton-based food chains; and the rich retrospective data resources.

SPACC is unique among the current GLOBEC Regional Programmes because of its global coverage, the participation of many developing as well as developed countries, and its emphasis on capacity building, education, and training.

Organization of SPACC
SPACC is organized through the activities of ten working groups and a SSC. The working groups comprise a modelling component that links all parts of the program; four groups that use retrospective studies to understand how past long-term climate changes have affected the dynamics of the stocks; three process study groups that carry out field studies to link population dynamics to physical forcing; a group that examines how changes in ocean climate affect the availability of fish to the fishery; and a proposed economic group to assess how climate variability affects the economics of small pelagic fisheries (Figure 31).

Approaches of the Working Groups
Modelling
Models are needed that will integrate the various SPACC components into a common framework, test hypotheses, link different kinds and scales of information, and summarize results in terms of future predictions. SPACC modellers (Working Group 1) recommend the development of transport and early life history models, retrospective models, population models (including spatially explicit models), models of environmental influences on growth and mortality, models of fisheries, and mass-balance ecosystem models. The first priority should be given to models that are instrumental to the initial development of SPACC. These include:

- Population models that link or translate catch and other fishery data to estimates of fish production
- Models for use with the comparative process studies. These models should be generally applicable to both developing and developed countries, and should enhance the interpretation of measured process variables
Recruitment of anchovy, *Engraulis encrasicolus*, in the Bay of Biscay (thousands of individuals caught by cohort and boat by year) and upwelling (m$^3$.s$^{-1}$.km$^{-1}$) from March to July for the years 1967-1996 (upper panel). Fitted regression and confidence intervals (95% and 99%) for the regression line of recruitment and upwelling for the same data-set (lower panel). Modified after Borja et al. (1998).
Figure 31

Organization of SPACC working groups (SPACC Implementation Plan).

GLOBEC SPACC

Advise
Resource Managers
Industry
Public

Economic Consequences Working Groups

Retrospective Studies Working Groups
Modelling Working Group
Process Studies Working Group

Decadal Changes of Ecosystems
Comparative Population Dynamics
Palaeoecology
Genetics

Daily Growth and Zooplankton
Spawning and Nursery Habitat Quality and Dynamics
Spawning Habitat Dimensions and Location

New Topic
Fish energetics models that can be used to assess the growth potential of the habitat. These models can be used in conjunction with remotely sensed chlorophyll data or underwater acoustic survey data to estimate fish production.

To advance these objectives, workshops composed of modellers and representatives of other working groups are needed. Such workshops would address specific questions, identify the kinds of models required, and link the modelling requirements to ongoing field studies and available historical data. Participants from other working groups will summarize the existing knowledge on various components of the ecosystem for each participating region, as well as the kind and form of data generated by ongoing studies. Key individuals for further training in modelling approaches will be identified.

Retrospective studies
Working groups 2–5 will use retrospective data to understand how the productivity of small pelagic fish populations is related to long-term changes in ocean climate. Working Group 2 (Decadal Changes of Ecosystems) uses long time series of data and modelling to determine how variation in the coupled ocean-atmosphere climate system affects the ecosystems in which small pelagic fish are important. Working Group 2 has a global and atmospheric perspective because climatic teleconnections are believed to be involved. Working Group 3 (Comparative Population Dynamics) is a complementary but more narrowly focused group that will estimate fish production, the central dependent variable of the SPACC programme. This group will use fish biomass per unit of stock to compute and compare quantitative estimates of small pelagic fish production and, most important, production of biomass or recruits per unit area of spawning and feeding habitats. This work will provide a quantitative basis for comparing fish production between and within all systems in standard production units.

Working Group 4 (Palaeoecology) and Working Group 5 (Genetics), in contrast to the preceding retrospective groups, will generate primary data for examining how fish populations respond to ocean climate over time spans of hundreds to thousands of years. The palaeoecological group (Group 4) is driven by the fundamental discovery that the abundance of small pelagic fishes and the anoxic sediments in many of their habitats make it possible to use the presence of fish scales in sediments to reconstruct time series of abundance over thousands of years (see Figures 8 and 9). This group proposes explorations to discover new sites for building scale (fish abundance) chronologies; developing palaeoecology indices for phytoplankton, zooplankton, sea temperature, and circulation; and developing calibrations that integrate this information with that collected over historic time. The genetic group (Working Group 5) will identify and interpret major population events such as population crashes, extinctions, recolonization, and migrations, all of which influence genetic diversity.

Process studies
Three working groups will use field studies to investigate the physical and biological processes affecting population growth. Working Group 6 (Daily Growth and Zooplankton) will compare daily somatic growth of young fishes, plankton produc-
tion, and physical forcing to investigate how climate variability may affect the productivity of small pelagic fish populations. In these studies, comparisons between systems will help separate stock-dependent effects on fish productivity from physical forcing mediated through zooplankton. The group also proposes to identify a set of practical measurements that could be used as an early warning of imminent change in the ecosystem. Although somatic growth throughout the first six months of life is the subject of this group, for practical reasons, the principal method will be back-calculated larval and juvenile growth from the surviving juveniles.

Working Group 7 (Spawning and Nursery Habitat Quality and Dynamics) will assess how variability in the dominant physical process and key mesoscale features in each system will affect population growth. Comparisons between system groups will identify how small pelagic fishes adapt their reproductive strategies to the various kinds of physical forcing and mesoscale features of their habitat, and how such systems constrain fish productivity. This group will focus on life stages most practical to sample on a fixed, fine-scale plankton sampling grid: egg and larval stages during roughly the first 20–30 days of life.

Working Group 8 (Spawning Habitat Dimensions and Location) has the most narrow scope. It is designed to evaluate the hypothesis that changes in productivity are caused by changes in the temporal and spatial dimensions of the spawning habitat, as well as its location. A new method for mapping eggs will be combined with satellite imagery and other ocean data to develop a model for estimating the distribution of spawning prior to the season. This model could be used each year to anticipate interannual changes in distribution such as those caused by El Niño. Comparisons between ecosystems will be used to separate physical forcing from stock-dependent effects on habitat selection and to examine the extent to which productivity is limited by space and time variation in spawning habitat.

These three process working groups are complementary. The site-intensive mesoscale studies of the effects of physical forcing in the spawning habitat (Group 7) will profit greatly from the accurate mapping and modelling of spawning habitat dimensions proposed by Group 8. In addition, accurate maps of spawning habitat derived from remote sensing and egg pumping are the best means for identifying the mesoscale features most important to study. The six-month trajectories of daily somatic growth provided by Group 6 will link the population dynamics of larvae studied by Group 7 to the juvenile growth dynamics and the annual generation of recruits. The ideal programme would contain all three elements.

Implementation Strategy
The overall implementation strategy of SPACC is to provide a comprehensive approach to addressing the scientific goals of SPACC and GLOBEC, to build capacity, and to encourage broad participation. The ten working groups treat the science comprehensively by including prehistoric time scales of hundreds to thousands of years, long-term historical records, and current biological and physical processes. New technologies also cover a broad range: modelling, molecular genetics, high-resolution reconstructions of palaeoecological time series, satellite oceanography, and new ocean monitoring techniques. The working groups complement one another by following different paths to answer the same fundamental questions about how ocean climate affects the productivity of stocks.
Recognizing that every interested country could not participate in all of these approaches, the working groups were designed as stand-alone entities to yield advanced knowledge on linkages between climate and dynamics of fishes, introduce new techniques, and build scientific capacity. Process Working Groups 6 and 8, for example, have adopted minimal implementation programmes to maximize participation. The core programmes were designed to use existing regional surveys. Thus, while a broad SPACC programme incorporating the activities of all working groups is the ideal, participation at even the minimum level in any one working group will provide lasting benefits to participating countries, regions, or institutions. In reality, we expect that most countries will have enough interested scientists and institutions to participate in a number of the working groups.

In addition to meeting the long-range goals of SPACC, understanding and predicting decadal-scale changes in the productivity of marine fish stocks, the strategy of implementation was designed to ensure that near-term, practical benefits would accrue to participating countries. Such practical benefits may include short-term predictions about how an El Niño event will affect fisheries, as well as introducing new techniques and training (modelling, egg mapping, daily-increment aging, molecular genetics, and satellite oceanography).

Issues
The implementation strategy was crafted carefully to minimize costs and maximize the widest scientific participation. In many countries the scientific agenda of SPACC cannot be implemented fully until appropriate ocean observing systems have been developed, along with numerical models and modelling expertise. These are difficult issues because they may require significant new resources and commitment. The working groups strongly emphasize the use of satellite data, combined with existing ocean data, yet few countries routinely use satellite data in fisheries. In many countries fishery-related products are inaccessible. Training in the analysis of images is also needed, and there is a shortage of modelling expertise in most SPACC regions. Some countries within SPACC have not yet acquired the necessary skills to develop even the simplest numerical model, which will be required to meet the programme needs. The SPACC programme requires an educational programme for graduate training in developing advanced and large-scale models, as well as short training courses in using existing simple models to adapt to SPACC requirements. In addition, it is important that the large-scale atmospheric linked models that can be developed only in large computing centers be made available to SPACC researchers in all regions.

The Implementation Plan for SPACC has been published as GLOBEC Report No. 11 and the Report of the First SPACC Modelling Workshop as GLOBEC Report No. 12). The current GLOBEC SPACC network is shown in Figure 32, which indicates countries or regions with field programmes on small pelagic fishes who have participated in SPACC meetings and workshops to date.
Figure 32

The GLOBEC SPACC network. Stars indicate countries or regions with field programmes on small pelagic fishes who have participated in SPACC meetings and workshops to date.
Background

The International Council for the Exploration of the Sea (ICES) and GLOBEC have joined together to develop an innovative programme to advance the understanding and prediction of variability in fish stock recruitment, both in the short term (annual forecasts) and in the long term (“climate effects”). Cod (Gadus morhua) has been chosen to function as the candidate species for this exercise because its biology is well-known and supported by ample data bases, it has a pan-Atlantic distribution, and its abundance and distribution have been shown to be sensitive to specific past examples of environmental variability (Figure 33). These considerations provide CCC with the possibility of developing new capabilities in predicting fish recruitment from a better understanding of the interaction of physical processes and population dynamics.

The central question being investigated by the CCC programme is the effect of climate variability on cod stock fluctuations. It is simply stated, but involves many different scientific disciplines and scales of investigation. These range from the effects of small-scale turbulence on encounter rates between fish larvae and their prey, to large-scale effects of interdecadal changes in wind fields on circulation and transport of heat and young fish. In spite of the complexity of the processes by which variable physical forcing may affect cod stocks, the effects of climatic variability can be detected for several stocks. For example, periods of low temperature are observed to result in stock declines at the northern limits of cod distribution (Barents Sea, Greenland); particular hydrographic and wind conditions result in unusual transport of eggs and larvae (Iceland-Greenland) or flush out deoxygenated basins where cod spawn (Baltic). These examples combine empiricism, a growing understanding of ocean/climate variability and detailed knowledge of processes during the life history of cod (especially the early life history). They give grounds for believing that the question posed is not intractable and that it may be possible to predict at least the broad direction of changes in cod abundance under different physical regimes.

With the establishment of the new ICES framework in November 1997, the ICES Science Committees were requested to develop a scientific strategy and plan of action in order to improve the way in which the Committees function. The CCCWG falls under the Oceanography Committee whose area of responsibility is the physical, chemical and pelagic biological oceanography, especially processes relevant to living marine resources and environmental quality. They include such issues as impacts of climate variability and the physical, chemical and biological fluxes in coastal areas, shelf seas and the open ocean. The ICES Consultative Committee requested the Science Committees to develop a 5-year plan, clearly identifying long-term goals. The Oceanography Committee subsequently asked its associated working groups to develop their own 5-year plan. Specifically to: (i) identify critical knowledge gaps and scientific priorities; (ii) identify priorities to address issues that require the attention of other scientific committees; (iii) take into account the long term needs of the advisory function of ICES; (iv) be sensitive to the emergence of new marine science issues; and (v) develop an interdisciplinary programme of work to address the science of marine ecosystems.
Figure 33

Relationship between cod and temperature off Greenland (K. Brander).
Implementation
The CCCWG identified seven major research components within a five-year plan based upon perceived scientific needs and likelihood of success. The word environment in the following text includes the biological (e.g. plankton, food and predators), as well as the physical and chemical characteristics of the water.

1. Fisheries Management
Objective: To incorporate environmental information in a quantitative manner into fisheries management strategies and planning.

Justification: Traditional stock assessments which implicitly assume that environmental and ecological conditions are unchanging, are by themselves not sufficient to ensure sustainable fisheries. Incorporation of environmental and ecological variability offers the potential of providing additional explanatory power of changes in fish stocks. Fisheries management was considered by the Working Group to include annual stock assessment, risk analyses and long-term management plans.

Specific Activities: Building upon the discussion and recommendations of the Workshop on Applications of Environmental Data in Stock Assessments held in Bergen, Norway during March 1998, a follow-up workshop that focuses upon a specific case study is proposed. Using the West Greenland/Iceland Cod example, models of the circulation will be used to develop transport indices for incorporation into fisheries management models. This workshop is planned during the year 2000 or 2001. A workshop on cod growth (see discussion below) will also address some aspects of the inclusion of environmental information into fisheries management.

2. Retrospective Analyses
Objective: To examine past events or periods as a means of better understanding the links between changes in the environment and fisheries.

Justification: Insights into the response of fish stocks to environmental variability have the greatest chance of success when examining periods of minimal fishing pressure, large climate variability and/or large changes in fish stock characteristics such as growth, recruitment, abundance etc. Acknowledging the usefulness of past retrospective workshops (i.e. Backward Facing I, II and III), the CCCWG decided to continue these types of activities.

Specific Activities: A workshop on the Gadoid Outbreak in the North Sea (Backward Facing IV) is proposed for March 1999. This will explore the increase in abundance of gadoid fishes in the North Sea during the 1960s and 1970s and, in particular, the possible role of environmental changes as a causal mechanism. Investigations undertaken as a follow-on to Backward Facing III will also be presented.
3. Zooplankton-Cod Linkages

Objective: To understand the relative importance of zooplankton in determining the variability in cod abundance and production.

Justification: Many regional and national GLOBEC programmes are focusing upon zooplankton dynamics. Efforts are required to establish quantitative links between zooplankton and fish in order to make full use from the fisheries perspective of the information gathered within these GLOBEC programmes. Equally important are establishment of the diet of cod larvae, including the main zooplankton species eaten and the relationship between larval condition and survival with possible physical-induced changes in diet.

Specific Activities: The CCCWG will strongly encourage examination of zooplankton-cod linkages during the Trans-Atlantic Studies of *Calanus finmarchicus* Symposium scheduled for Tromso, Norway, in August 1999. In addition a Theme Session at the ICES Annual Science Conference in September 2000 on the linkages between zooplankton and cod will be proposed.

4. Comparative Analyses

Objective: To undertake comparative studies of life history strategies and interannual variability in growth, distribution, and abundance between cod stocks around the North Atlantic.

Justification: Research in recent years has expanded our understanding of the dynamics of individual cod stocks and some of the causes of interannual variability. Comparative studies between stocks, such as those on growth and recently on recruitment, have provided knowledge that was unattainable from stock-specific investigations. More such studies offer good potential of providing additional significant insights. Areas where such studies were considered beneficial include further examination of growth and recruitment and investigations into distribution and migration. Application of similar analytical methods for different stocks will be encouraged.

Specific Activities: A Workshop on the Dynamics of Growth in Cod is proposed for autumn 1999 or winter 2000. The aim of the workshop will be to develop a single growth model for cod that will allow interpretation of information from all parts of the geographic range of cod. Incorporation of this information into fisheries management practices will be attempted.

5. Climate and Atmosphere-Ocean Interactions

Objective: To understand and predict climate variability and its associated ecosystem response.
Justification: Fisheries managers are demanding increased knowledge of climate-induced ecosystem changes and asking for predictions of future climate conditions. Although difficult and initially predictive success is unlikely, improvements in prediction over the long-term are expected and worth the effort. Both short and long-term (decadal) predictions are of interest to fisheries management. Several large international programmes such as CLIVAR are being developed to gain understanding of the climate of the North Atlantic and the role of the NAO. The CCCWG will communicate its needs and establish links to the CLIVAR community and to other such climate programmes.

Specific Activities: A Workshop on Long-term Climate Change and Prediction is planned for the year 2000, the purpose of which is to explore long-term and short-term predictions in ocean climate, the possible existence of “regime shifts” of climate and the relationship between climate change, and associated ecosystem responses. The mechanisms linking the large-scale atmospheric circulation such as the NAO to ecosystem changes will be sought as a follow-on from the Workshop on Decadal-Scale Ocean Climate Fluctuations of the North Atlantic.

6. Data Availability and Management

Objective: To ensure that environmental and fisheries data are easily and widely available.

Justification: Data are critical for research and as such it is important that they be easily accessible to a wide scientific audience. This will encourage and ease activities such as comparative analyses.

Specific Activities: Working relationships with other groups will be established to ensure data accessibility and, where possible, standardize formats. Primary data sources and information required for the proposed workshops will be made available, as much as possible, on the web. The ICES website will be kept up to date.

7. Synthesis

Objective: To provide a synthesis of the research information obtained on cod stocks.

Justification: Much material has been published on many of the cod stocks around the North Atlantic. The CCCWG recognizes the requirement to synthesize this information into a general framework of cod dynamics.

Specific Activities: While an overall synthesis is the long-term aim, the initial work will proceed in a modular manner. Thus, ongoing synthesis of the workshops and theme sessions is identified as a critical aspect.
Potential Joint Work with other Working Groups and Committees

As part of the 5-Year Plan, potential joint work with other ICES Working Groups and Committees and international programmes was identified as follows. This list does not exclude possible links to other groups and committees.

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<th>Associated Group</th>
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<td>• Zooplankton-Cod Interactions</td>
<td>• TASC, Zooplankton Ecology WG</td>
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<tr>
<td>• Climate and Atmosphere-Ocean Interactions</td>
<td>• Oceanic Hydrography WG, Shelf Seas Oceanography WG, CLIVAR</td>
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<tr>
<td>• Data Availability and Management</td>
<td>• Marine Data Management</td>
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The North Pacific Marine Sciences Organisation (PICES) and GLOBEC agreed in 1993 to organize an international science programme on Climate Change and Carrying Capacity (CCCC) in the temperate and subarctic regions of the North Pacific Ocean. A PICES-GLOBEC Workshop in 1994 developed a Science Plan for CCCC and an Implementation Plan was approved at the PICES Annual Meeting in October 1995. Throughout the CCCC planning process, there have been close links with international GLOBEC activities. The CCCC’s Programme goal is to integrate and stimulate national activities on the effects of climate variations on the marine ecosystems of the subarctic North Pacific through the oversight of its coordinated implementation plan. The CCCC programme is directed to studying the effects of climate variations on the marine ecosystems of the oceanic and coastal regions of the subarctic Pacific, and in particular on the food webs and their spatial, seasonal, and temporal variability, and on the physical and biological processes that affect the productivity of key fish species and the carrying capacity of high trophic level carnivores.

Terms of Reference

1. Develop plans for the design and implementation of a programme to study the effects of climate variations on the marine ecosystems of the oceanic and coastal regions of the subarctic Pacific.

2. Integrate country activities into a coordinated implementation plan and provide oversight of the implementation phase.

3. Determine how the work of PICES SCs and WGs can most effectively support the CCCC Programme, and recommend the establishment of subsidiary groups to provide expert advice as necessary.

4. Identify existing foreseen national and international research programmes with which the CCCC Programme could be coordinated, and determine how this can most effectively be achieved.

5. Provide scientific direction for liaison with other regional and global organizations in pursuit of the goals of the CCCC.

The major geographical components of the programme are shown in Figure 34.
Figure 34

PICES-GLOBEC Climate Change and Carrying Capacity Programme components (PICES-GLOBEC).

- Western Bering Sea/Kamchatka
  - Eastern Bering Sea
- Okhotsk Sea
- Western subarctic gyre
- Eastern subarctic gyre
- Japan Sea/East Sea
  - Oyashio/Kuroshio
- Bohai, Yellow Sea
  - East China Sea
- Southeast, Central Alaska
- California Current System, Oregon to Vancouver Island
- California Current System, south
Background

Remarkable changes have been observed in the North Pacific and adjacent seas in recent decades. Concurrent changes in atmospheric pressure and ocean temperatures indicate that in 1976 and 1977 the North Pacific shifted from one climate state, or regime, to another that persisted through the 1980s (Figure 35). Analysis of records of North Pacific sea surface temperature and atmospheric conditions show a pattern of regime shifts lasting several years to decades. Specifically, since 1976 the Aleutian low has intensified during the winter and has shifted further east. Associated changes took place in wind stress curl, the corresponding Sverdrup transport, a warming over Alaska and cooling in the central and western North Pacific. The strengths of flows in the Alaska and California currents may fluctuate out of phase with one another. Modelling studies suggest that effects should be most strongly developed, and initially observed, at high latitudes.

Although the important linkages are poorly understood, there is growing evidence that biological productivity in the North Pacific responds to these decadal-scale shifts in atmospheric and oceanic conditions, by alternating between periods of high and low productivity. In coastal areas, both the far eastern and California stocks of Pacific sardine peaked in abundance in the 1930s, declined in the 1950s and 1960s, then began to increase synchronously in the 1970s. Large scale changes in pelagic fish production in the western Pacific suggest that coastal production is linked to variations in ocean climate (see Figure 6). Palaeosedimentary records indicate that such interdecadal fluctuations have been characteristic of the California Current system for the last 2000 years (see Figure 8).

Summer biomass of zooplankton increased two-fold between the 1960s and the mid-1970s, as did the biomass of some higher trophic level carnivores in the eastern subarctic Pacific. There were also significant fluctuations in zooplankton biomass in the Oyashio and Kuroshio current systems off the coast of Japan. While salmon catches in the North Pacific declined steadily from historic highs in the late 1930s to a low in the mid-1970s, this was followed by a striking increase in which the combined national salmon catches in the North Pacific nearly regained the earlier historic highs.

In addition to the decadal-scale regime shifts, longer-term global climate change may result in substantial changes in the biological carrying capacity of the North Pacific. For example, coincident with the recent increases in salmon catches, the average size of adult salmon has significantly decreased in some areas of the North Pacific (Figure 36). There is also evidence that growth and mortality of some salmon stocks may vary with production: in some cases the growth rates appear to be inversely related to stock size. Some portion of these patterns of variation may be due to the combined current abundance of salmon and other high trophic level carnivores approaching the present carrying capacity of the subarctic North Pacific.

The term “carrying capacity” is used in the CCCC Science Plan to mean the means by which the dominance and productivity of zooplankton and higher trophic level carnivore species respond to changes in ocean climate. The CCCC programme will develop a new theoretical and mathematical framework which extends the classical, single species concept of carrying capacity into the multi-species ecosystem domain that the CCCC programme addresses.
Figure 35

Distribution of zooplankton biomass in the Gulf of Alaska from 1956-1962 (upper panel) and 1980-1989 (lower panel) (from Brodeur and Ware 1992).
Figure 36

Changes in salmon weight at age; changes in weight at age of salmon indicate changes in ocean productivity in the North Pacific (GLOBEC-Canada).
The general scope of the CCCC Programme has a strong emphasis on coupling between atmospheric and oceanographic processes, their impact on the production of major living marine resources and how they respond to climate change on time scales of decades to centuries. It will include the following elements:

1. The use of mechanistic processes to improve understanding and develop early recognition and prediction capabilities for regime changes.
2. The development and use of models to guide research activities, integrate results and improve capabilities for forecasting ecosystem responses to climate change.
3. The development of broader insights through the use of regional comparative studies.
4. Links to other activities within the international GLOBEC project and to other existing and planned international programmes.

The Central Scientific Issues to be Addressed in CCCC

Physical forcing: What are the characteristics of climate variability, 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 the higher trophic levels 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?

Programme Organization

As with other components of GLOBEC, research activities within CCCC fall into major categories: retrospective analyses, development of numerical models, ecosystem process studies, the development of observation systems and data management. The Programme is organized into Task Teams to accomplish its goals.

It was recognized that the comparative approach would be an important ingredient to the study of the central scientific issues. Particularly, comparative studies of the ecosystems along the continental margins of the subarctic Pacific and east/west comparisons of the subarctic gyres. The first two Task teams of the programme were formed to provide that key ingredient: REX, to consider regional experiments to compare findings of coastal GLOBEC and GLOBEC-like programmes, and BASS, to consider development of comparative research studies in the open ocean subarctic.
gyres. Subsequently, two more Task teams were established; MODEL, to consider modelling requirements; and most recently, at PICES VI, MONITOR to review monitoring requirements of the programme. The Implementation Panel of the programme (which consists of two co-chairs, the four Task teams, and an executive committee) oversees and performs the work of the programme.

**Task Teams**

MODEL Task Team has reviewed the roles and limitations of modelling for the CCCC Programme, proposed the level of modelling required, and provided a plan for how to promote these modelling activities (PICES Press, vol. 4 No 2; PICES Scientific Report No. 7, 1997). The Task team recognized that many modelling activities are already taking place regarding North Pacific physics and biology. But what seems to be lacking is awareness and communication among these activities, and the possible linkages among physical and biological modellers and awareness and communication with field programmes. Therefore, the primary role of MODEL has been identified as:

- Facilitate communication among modelling studies, and with field programmes
- Identify and stimulate areas of modelling that are significant to the CCCC’s Programme but which are not presently addressed
- Assist field programmes of CCCC (e.g. REX, BASS) with model-related needs.

REX Task Team recently reviewed the status of national research programmes in order to identify areas for cooperative research experiments in support of the CCCC’s Programme. Recommendations that the team adopted for 1998 included:

- PICES member nations should compile a catalogue of historical samples and data sets which are not yet analyzed or readily available
- Issues of standardization of sampling and analysis methods for comparative studies should be addressed
- A two-day symposium and workshop on climate effects on small pelagic species should be convened prior to the PICES VII annual meeting in Fairbanks, Alaska
- A scientific session that highlights research findings of GLOBEC and GLOBEC-like programmes in the North Pacific should be convened as part of the PICES VII annual meeting.

BASS Task Team began work in 1997 to identify comparative research projects in the North Pacific subarctic gyres. In order to develop plans for intensifying research in the subarctic gyres of the northern North Pacific, BASS reviewed present scientific knowledge of these features, with particular attention being given to comparisons of the eastern and western sides of the ocean basin. Recommendations on possible comparative experiments from this review are presently being examined and BASS will decide how they can be implemented in the near future. A discussion paper will be prepared and will be the basis for the development of a long-term work plan.
**MONITOR Task Team.** The formation of a new Task team, MONITOR, was approved at PICES VI in Pusan, Korea. The terms of reference for the new Task team are:

1. Review existing activities of PICES member nations and suggest improvements in the monitoring of the Subarctic Pacific to further the goals of the CCCC Programme.
2. Consult with REX, BASS and MODEL Task Teams and TCODE on the scientific basis for designing the PICES monitoring system. Questions of standardization and intercalibration of measurements, particularly in the area of biological collections, should be addressed.
3. Assist in the development of a coordinated monitoring programme to detect and describe events, such as El Niño, that strongly affect the Subarctic.
4. Report to CCCC IP/EC on the monitoring in the Subarctic to be implemented in the international GOOS or other related activities.
INTEGRATING ACTIVITY

ACTIVITY 9.0 Towards a GLOBEC Synthesis: Ecosystem Comparisons

Introduction
The synthesis of the results of GLOBEC research needs to start at the beginning of the programme, not at the end. Many GLOBEC programmes are now on-going (some for several years), and there is considerable information available for some regions from other programmes. A synthesis of this information needs to begin now, in order to track progress, compare experiences among projects, and recognize and act upon surprise events as they occur rather than decades later (for example, shifts between “regimes” or “ecosystem states”). Synthesis provides a constant opportunity to evaluate increasing understanding of the structure and functioning of global ocean ecosystems, as derived from the national and regional programmes, and tracks improvements in predictive capabilities. The synthesis phase uses these studies to build a broad assessment of the responses of marine ecosystems to global changes, including extension to areas that are poorly studied. It also attempts to identify early indicators of large and qualitative system changes that may result from global changes.

Overall objectives
The overall objectives of this synthesis Activity are the:

- Development of marine ecosystem typologies and classification of ecosystems into these typologies
- Identification of key ocean systems not presently being studied by GLOBEC activities, and encouragement of programmes in these regions
- Synthesis of the responses by characteristic “ecosystem-types” to large-scale global changes.
The GLOBEC approach

Marine ecosystems are integrated complexes of physical, biogeochemical, and biological interactions. At the very basic levels of ecosystem processes, such as predator-prey interactions, there is likely to be a high degree of similarity among ecosystems with respect to the dynamics of these interactions (e.g. the effects of turbulence). However, more complex processes, such as trophic linkages which embody species diversity, energy flow, turnover rates, etc., are likely to be quite diverse and to have much lower similarity among ecosystems (Figure 37). Ecosystems such as tropical Atlantic coral reefs and temperate Atlantic continental shelves may rapidly decrease in similarity as the complexity of the processes increases (e.g. the dashed curve in Figure 37) whereas ecosystems such as temperate Atlantic and temperate Pacific continental shelves may maintain a high degree of similarity as the complexity of the processes increases (e.g. the dotted curve in Figure 37). Identification of the dominant change in slope of such relationships may identify critical processes at which the similarity among ecosystems begins to diverge.

The current Regional programmes of GLOBEC were selected to represent major marine ecosystems. However, a formal categorization of marine ecosystem types has been developed only for the lower trophic levels, and that only very recently (Longhurst 1998). In addition, there may be other important marine ecosystems which are not presently being investigated by the regional, multi-national, or national programmes. For example, it might be argued that the oligotrophic ocean (e.g. South Pacific and Indian Ocean tuna environments), coral reefs, or monsoon-dominated systems should also be areas in need of GLOBEC research. This integrating Activity will provide comparisons among marine ecosystems through development of characteristic system typologies. Its goal is to synthesize and generalize knowledge and information among (what may be considered as similar) marine ecosystems around the globe, and also to identify substantive differences. This will determine the extent to which generalized responses to perturbations can be predicted for various marine ecosystems, rather than having to describe responses in each ecosystem separately. It will also permit extension of predicted responses to similar but less-well studied ecosystems, reflecting the very real constraints on limited personnel, funding, and time which prevent detailed study of all important systems.

Synthesis activities will also involve comparisons of processes within and among marine ecosystems, and comparisons of ecosystem responses to large-scale forcings (both natural, such as climate variability, and anthropogenic, such as fishing). Understanding and prediction of the different responses by these “ecosystem-types” to such large-scale forcing is a core objective of GLOBEC which involves local, regional, and global concerns. Models, and formal methods for comparative analyses (meta-analyses), are the central approaches by which the syntheses will be conducted. A key outcome is expected to be identification of “early-warning” indicators of large-scale ecosystem changes, and to what extent they may be similar among a variety of ecosystem types. Identification of potential indicators early in the GLOBEC programme would provide for their monitoring and assessment throughout the duration of GLOBEC field and modelling activities. Further key outputs of these syntheses should include evaluation of what the effects of changes in marine ecosystems may be to global biogeochemical processes (e.g. Focus 4) and to human social systems (e.g. interactions with the GECHS project, see 7.5.1, above).
Figure 37

Relationships between the complexity of ecosystems processes, and the similarity among ecosystems. For example, the dynamics of predator-prey interactions are expected to be similar among most ecosystems, whereas the details of trophic linkages (including species composition, energy flows, turnover rates, etc.) are likely to differ greatly among ecosystems as different as tropical coral reefs and temperate shelf systems. The dashed line represents systems which diverge very quickly with increasing complexity of the ecosystem process being considered; the dotted line represents systems which maintain high similarity as complexity of the process being considered increases. The location of the major change in slope represents a characteristic complexity at which similarity among ecosystems diverges.
Task 9.1 Development of Marine Ecosystem Typologies and Classification of Ecosystems

Rationale
Concern about the impacts of climate variability and anthropogenic forcing of marine ecosystems is global. However, resources are insufficient to study each local system in order to understand the local responses to global changes. Development of marine ecosystem typologies and classification of ecosystems is one approach to extrapolate the predicted responses to global changes to less-well studied or unstudied systems. It is also an attempt to synthesize results from local and regional GLOBEC programmes to larger spatial and temporal scales.

Objective
- The objective of this Task is the development of marine ecosystem typologies, and classification of marine ecosystems into these typologies.

Implementation
Development of system typologies, and ecosystem comparisons, should consider a variety of approaches. Simplest may be the “whole ecosystem level”, such as the Bering-Barents-Okhotsk Seas; upwelling Eastern Boundary Current systems; Kuroshio/Oyashio and Gulf of St. Lawrence/Labrador Sea; etc. Longhurst (1998) provides a classification of pelagic marine environments based primarily on physical processes and the responses of planktonic algae. The Large Marine Ecosystem concept provides additional starting points for the initial definition and comparison of systems at this level. However, within the whole ecosystem level, or perhaps as an alternate approach, the focus also could be placed on comparing similar physical processes and or species in different systems, e.g., the effects of sea ice in the Southern Ocean and Bering Sea; upwelling vs downwelling processes; shelf-deep ocean exchange processes; or Calanoid copepod or gadoid comparisons, for example between the North Pacific and North Atlantic ecosystems. A key point here will be the evaluation of links between energy characteristics of physical processes (i.e. available potential energy and kinetic energy) and the structural-functional characteristics of the ecosystem.

Several methodological problems occur immediately in such an exercise to compare and type marine ecosystems. Meta-analytical methods are a logical framework for this approach, however, to date these methods are better developed for experimental rather than the observational approaches which generally must be used in the marine sciences. A standard suite of processes or parameters to measure, using a common set of methodologies or at least acceptable conversions among measures, will also greatly facilitate ecosystem comparisons (see the Measurement and Modeling Framework Activity; also the PICES CCCC programme has recommended a common set of processes to measure in studies around the North Pacific). Other concerns include the definition of response variables, within and between study variance, and choice of replicates and contrasts. One approach, moving from simple and perhaps more readily available ecosystem information to more complex analyses and finally to interactive ecosystem simulation models, is presented in Table 1.
<table>
<thead>
<tr>
<th>Observational basis</th>
<th>Concepts and techniques</th>
<th>Potential insights</th>
</tr>
</thead>
<tbody>
<tr>
<td>abundances and body mass (biomass spectra)</td>
<td>biological species, allometric relationships, time-series analyses, biomass size distribution, trophic continuum concept</td>
<td>species list, quantitative importance of species with respect to biomass (and process rates), size conversion efficiency, variations in time and space</td>
</tr>
<tr>
<td>abiotic parameters</td>
<td>regression analyses</td>
<td>potential abiotic impacts</td>
</tr>
<tr>
<td>trophic interactions (binary web)</td>
<td>aggregation of species into trophic guilds, food web analyses</td>
<td>food web structure, connectance, linkage density, potential direct interactions</td>
</tr>
<tr>
<td>process rates (<em>e.g.</em> production, respiration), diet compositions, trophic webs</td>
<td>population dynamics, flow analyses, network analyses, trophic level concepts</td>
<td>mass-balance flow diagrams, trophic transfer efficiencies, trophic structure and function (direct and indirect effects)</td>
</tr>
<tr>
<td>regulation of flows</td>
<td>dynamic simulation models</td>
<td>direct and indirect effects and dynamic interactions</td>
</tr>
<tr>
<td>adaptability, adaptive interaction web</td>
<td>fully reactive and predictive simulation models with a flexible community structure</td>
<td>prediction of community structure and function for different environmental scenarios</td>
</tr>
</tbody>
</table>
The IPO, in consultation with the SSC, will be tasked with drafting an initial definition of an ecosystem typology, drawing upon existing information from ongoing GLOBEC, Large Marine Ecosystem, and other studies. Workshops will then be held on groupings of potentially similar ecosystems attended by experts in those systems in order to compare, contrast, and refine typology definitions to identify levels of similarity among the systems. This certainly should include extrapolation to less-well studied ecosystems. Results of these workshops are to be published in the scientific literature.

**Outputs**

- Initial definitions of marine ecosystem typologies, and classification of ecosystems into these typologies
- Workshops on sets of potentially similar ecosystems, to compare, contrast, and refine classifications, and to extrapolate to poorly-studied systems where warranted
- Publication of workshop proceedings.

**Task 9.2 Identification and Prediction of Responses of Marine Ecosystem Types to Global Changes**

**Rationale**
The goal of the GLOBEC synthesis is to determine the responses of marine ecosystems to global changes. Having identified characteristic marine ecosystem types and classified ecosystems, understanding their responses to global changes is the next step. The advantage of using ecosystem types for this Task is that similar ecosystems should respond in broadly similar ways; identification of divergences from predicted responses will be even more informative. Identification of “early warning” indicators of large scale system changes within and across ecosystem types will greatly help prediction and possible mitigation of the effects of global changes.

**Objectives**

- To identify and characterize components of the major marine ecosystems which are likely to be affected at an early stage by global changes (i.e. early-warning indicators)
- To understand the responses to global change of each component of the ecosystem, focusing on both zooplankton and fish
- To use ecosystem models to identify and compare predicted and observed responses of marine ecosystem types to global changes.

**Implementation**
Success in achieving this Task will depend critically on retrospective analyses of systems (i.e. comparisons of how similar and different system-types responded to past global changes) and modelling of system processes (e.g. modelling system responses to hypothetical global changes). The collection of ecosystems within a typology will
serve as replicates to compare responses. The retrospective and modelling analyses will also identify parameters and system variables that may serve as early warning indicators of qualitative changes in system states. From this point of view it may be worthwhile to link ecosystem characteristics to a system of ocean-atmosphere parameters. These could include: sea surface temperature, sea level pressure, and latitudinal and longitudinal positions of the atmospheric Centres of Action (COAs) (i.e. Icelandic Low, Azores High, Aleutian Low, etc.). For instance, the North Atlantic Oscillation has been shown to be related to zooplankton abundance in the North East Atlantic. However, the NAO represents the oscillation of mass between two semi-permanent atmospheric pressure systems, the Azores High in the subtropical Atlantic and the Icelandic Low in the subpolar Atlantic region. A relationship between zooplankton and the individual COA is more likely to be useful because it localizes the region of climatic influence on the main ecosystem. Each COA affects the atmospheric and oceanic circulation in its own sphere of influence. In order to make quantitative comparisons between the COAs in observed and simulated fields, it is useful to define objective indices for the intensity, latitude and longitude of a COA at a given time. Variations in the intensity of COAs should be reflected in mesoscale changes of physical and biological characteristics. Comparisons between the intensity of COAs and mesoscale variability of physical and biological characteristics of ecosystems, through different regions, should improve understanding of the interactions among scales. These analyses will follow from identification and comparisons of ecosystem typologies, and may be a component of the workshops discussed in Task 9.1, depending on the state of retrospective and modelling studies for these areas.
Figure 38

Schematic representation of the Integrating Activity, Towards a GLOBEC synthesis: ecosystem comparisons

INTEGRATING ACTIVITY

Towards a GLOBEC synthesis: ecosystem comparisons

- Marine ecosystem typologies and classification of ecosystems
- Responses of marine ecosystem types to global changes
OPERATIONAL CONSIDERATIONS

This Implementation Plan provides a framework for the international programme which encourages the fullest participation of national (and, in some cases, regional) scientific efforts but does not impose a rigid template. The GLOBEC Goal, its subsidiary Objectives and the strategic research Foci are intentionally stated in general terms. However, they do provide the underpinning for all GLOBEC research activities, whether these are at the individual, local, national, regional or international level. They will also provide the standard against which proposed contributions to the international GLOBEC effort will be judged. The question which should be posed in response to new activities seeking to be affiliated with the international GLOBEC programme is, “how does this particular activity help to meet our international objectives?” It is the responsibility of the GLOBEC SSC to ensure that GLOBEC research is focussed.

The approach of IGBP to the categorization of research is relevant in this context, as is a statement of the benefits and obligations of participation in GLOBEC. Table 2 gives a current summary of the activities of national and multi-national GLOBEC programmes, and Table 3 provides contact information for these programmes.
Categorization of Research

IGBP has developed a three category system for defining IGBP research (IGBP 1994):

- Core Research, which directly addresses the Science Plan goals of IGBP Projects, being part of their formal structure and coordinated by the relevant SSC
- Regional/National Research which is closely linked to the Science Plan objectives (but may have other overall aims), and is coordinated at a national or regional level
- Relevant Research which makes an indirect contribution to the project, without formal affiliation.

These criteria for the categorization of research are not based on scientific merit per se, but relate to research objectives, implementation procedures, and the practicalities of dividing coordination responsibilities between the different levels of Core Project structure. The benefits and obligations of participation in GLOBEC are outlined below. It is anticipated that this set of GLOBEC criteria will evolve as the project develops; as the nature of national contributions becomes clearer; and as feedback is received from the National Committees.
Benefits and Obligations of Participation in the International GLOBEC Project of the IGBP: Implications of Participation in GLOBEC

GLOBEC provides the opportunity for participation in an important multidisciplinary programme of oceanic research. GLOBEC recognizes that different levels of participation are possible, e.g. regional, national or individual. Given the potential diversity of involvement and the global character of the scientific agenda of GLOBEC, there must be appropriate integration and expansion of the results of all participants. Appropriate representation must therefore be provided to all contributors. These notes provide some guidance on the benefits and responsibilities associated with involvement in GLOBEC; they are not intended as a formal set of regulations.

Benefits

• Provides the opportunity for participation in the development, planning and implementation of a collaborative international science programme
• Adds to the scientific value of planned work by providing complementary information; for example, by widening the range of studies and extending their spatial and temporal coverage
• Promotes rapid communication of ideas and results, through meetings and publications
• Develops and tests standard methods and protocols for measuring variables, thereby facilitating quality control and meaningful data sharing
• Makes available data sets collected in component studies and develops a common data management strategy
• Enables close working links with other relevant international programmes and studies
• Facilitates process understanding of regional studies through comparisons with other ecosystems.

Responsibilities

• Acceptance of general principles and goals outlined in the GLOBEC Science Plan
• Carry out a programme in general accordance with relevant aspects of the GLOBEC Implementation Plan
• Participation in the activities of the GLOBEC SSC, by assisting in the planning and development of the programme as a whole
• Make data collected within the programme available to the wider GLOBEC community, in accordance with GLOBEC protocols for international data exchange
• Assist in programme coordination in the provision of central services; for example, data management
Time-line
The IGBP normally expect their Core Projects to be operational for ten years from the publication of the Implementation Plan. This would give GLOBEC a time-span from 1999 to 2008. However, it is in the nature of the development of such a major research undertaking that considerable research activity and momentum is already underway. Many GLOBEC National Programmes have been active and productive for a number of years prior to the development of the Implementation Plan for the international programme (see Tables 3 and 4, below). Other initiatives are just in the planning stage.

Projecting over a ten year period when research funding is uncertain, and is controlled through national and regional bodies, is difficult. However, to achieve its goals GLOBEC requires a clear overall time-line. This is illustrated diagrammatically for the major research components in Figure 39, showing those Activities which are expected to be active during the early mid, and final phases of the programme. In specifying this overall time-line it is important to recognize the interrelated nature of many of the Activities and Tasks. An example of this is illustrated in Figure 40, which shows how the work on individual based models is highly interactive with, and dependent on, process studies on zooplankton life histories, the successful completion of these two Tasks will then in turn lay the foundations for the development of regional and basin-scale coupled physical biological models.

The early sequence of implementation events, planned or completed to date, is summarized in Table 2.
Figure 39

Indicative time-line of anticipated phasing of Activities during early, mid, and final phases of the implementation of GLOBEC.

<table>
<thead>
<tr>
<th>FOCUS 1 Activity 1.1</th>
<th>Preservation of existing long time series studies and data</th>
<th>EARLY</th>
<th>MID</th>
<th>FINAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity 1.2</td>
<td>Analyses of existing retrospective data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity 1.3</td>
<td>Creation of new, retrospective, data sets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity 1.4</td>
<td>Development of new data sets for future comparisons</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>FOCUS 2 Activity 2.1</th>
<th>Research on life histories and trophodynamics and their modelling in ecosystems</th>
<th>EARLY</th>
<th>MID</th>
<th>FINAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity 2.2</td>
<td>Identification and understanding of multiscale physical-biological interactions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity 2.3</td>
<td>Response of marine ecosystems to fishing and species introductions</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>FOCUS 3 Activity 3.1</th>
<th>Design and testing of relevant sampling and observational system capabilities</th>
<th>EARLY</th>
<th>MID</th>
<th>FINAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity 3.2</td>
<td>Develop relevant modelling capabilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity 3.3</td>
<td>Develop coupled modelling-observational capabilities and applications</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>FOCUS 4 Activity 3.1</th>
<th>The climate interaction on multiple scales and its consequences for basic biological processes through the food web</th>
<th>EARLY</th>
<th>MID</th>
<th>FINAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity 3.2</td>
<td>The earth system impacts resulting from changes in marine ecosystems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity 3.3</td>
<td>Social impacts of changes in marine ecosystems</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 40

Schematic of the interactive and supportive nature of Activities and Tasks during the implementation of GLOBEC.

FOCUS 3
Task 3.2.1
Individual based models

FOCUS 2
Task 2.1.1
Zooplankton life history

Task 3.2.2
Develop regional and basin-scale coupled physical biological models
Table 2

Early sequence of events in the development of a time-line for GLOBEC.

<table>
<thead>
<tr>
<th>Year</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991-1995</td>
<td>• Preliminary science planning phase under SCOR and IOC and ICES sponsorship</td>
</tr>
<tr>
<td>1993</td>
<td>• GLOBEC Science Workshops</td>
</tr>
<tr>
<td>1995</td>
<td>• Acceptance of GLOBEC as an IGBP Core Project</td>
</tr>
<tr>
<td>1996</td>
<td>• First SSC meeting, John’s Hopkins University, Baltimore, USA, 11-13, November</td>
</tr>
<tr>
<td></td>
<td>• ICES/GLOBEC coordination office established in Copenhagen</td>
</tr>
<tr>
<td>1997</td>
<td>• GLOBEC Science Plan published</td>
</tr>
<tr>
<td></td>
<td>• Second SSC meeting, Plymouth Marine Laboratory, UK, 24-26, June</td>
</tr>
<tr>
<td></td>
<td>• Interim IPO established in Plymouth, UK</td>
</tr>
<tr>
<td>1998</td>
<td>• SPACC Implementation Plan published</td>
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<tr>
<td></td>
<td>• Revised SO-GLOBEC Implementation Plan published</td>
</tr>
<tr>
<td></td>
<td>• EUROGLOBEC Science Plan published</td>
</tr>
<tr>
<td></td>
<td>• First Open Science Meeting. Paris, 17-20, March</td>
</tr>
<tr>
<td></td>
<td>• Third SSC meeting, Paris, 16 and 21, March</td>
</tr>
<tr>
<td></td>
<td>• Interactions with GECHS begun</td>
</tr>
<tr>
<td>1999</td>
<td>• GLOBEC Implementation Plan published</td>
</tr>
<tr>
<td></td>
<td>• IPO established</td>
</tr>
<tr>
<td></td>
<td>• Executive Officer appointed</td>
</tr>
<tr>
<td></td>
<td>• Deputy Executive Officer (Data) appointed</td>
</tr>
<tr>
<td></td>
<td>• SO-GLOBEC coordination office established</td>
</tr>
<tr>
<td></td>
<td>• Start to implement data management strategy (Framework Activity)</td>
</tr>
<tr>
<td></td>
<td>• Initiate links with CLIVAR, and build links to other Global Change programmes and bodies</td>
</tr>
<tr>
<td></td>
<td>• Fourth SSC meeting, Shonan Village, Japan, 6 and 13 May</td>
</tr>
<tr>
<td></td>
<td>• Build inter-IGBP Core Project links during the IGBP Congress (principally with JGOFS, LOICZ and PAGES)</td>
</tr>
<tr>
<td></td>
<td>• Establishment of new combined Sampling and Modelling Working Group</td>
</tr>
<tr>
<td></td>
<td>• Establish Focus 1 Working Group (Retrospective Analyses and Time-Series)</td>
</tr>
<tr>
<td>1999/2000</td>
<td>• SO-GLOBEC field programme</td>
</tr>
<tr>
<td>1999 – (2008)</td>
<td>• SPACC moves to full implementation, and seeks funds for Capacity Building</td>
</tr>
<tr>
<td></td>
<td>• Establish Focus 2 Working Group (Process Studies)</td>
</tr>
<tr>
<td></td>
<td>• Activate Working Group for Focus 4</td>
</tr>
<tr>
<td>2001</td>
<td>• Second Open Science Meeting (IGBP Open Science Meeting)</td>
</tr>
</tbody>
</table>
## Table 3

Contact information for the current national and multi-national GLOBEC programmes

<table>
<thead>
<tr>
<th>Country</th>
<th>Acronym</th>
<th>Contact</th>
<th>Website</th>
</tr>
</thead>
</table>
| BRAZIL    | DEPROAS           | Dr. Yasunobu Matsuura  
Institito Oceanográfico  
Universidade de São Paulo  
Butantã, São Paulo  
05508-900, SP, Brazil  
Tel:  
Fax: (55) 11 210 3092  
E-mail: ymatsuur@usp.br |                                                            |
| CHILE     | FONDAP-HUMBOLDT   | Dr Ruben Escribano  
University of Antofagasta  
PO Box 170, Antofagasta  
Chile  
Tel: (55) 247542  
Fax: (55) 247542  
E-mail: escriban@reuna. |                                                            |
| CANADA    | GLOBEC Canada     | Dr. Brad deYoung  
Department of Physics and Physical Oceanography  
Memorial University, St. John’s, Newfoundland  
A1B 3X7  
Canada  
Tel: (1-709) 737 8839  
Fax: (1-709) 737 8739  
E-mail: bdeyoung@crosby.physics.mun.ca | http://www.globec.canada.mun.ca/globec/index.html |
| USA       | US GLOBEC         | Michael J. Fogarty  
Chesapeake Biological Laboratory, University of Maryland Center, P.O. Box 38, Solomons, MD 20688  
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Tel: (1-410) 326 7289  
Fax: (1-410) 326 7318  
E-mail: fogarty@cbl.cees.edu | http://www.usglobec.berkeley.edu/usglobec/globec.homepage.html |
<table>
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<th>Country</th>
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<th>Contact</th>
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<tbody>
<tr>
<td>BENEFIT</td>
<td>BENEFIT</td>
<td>Benguela Environment Fisheries Interaction and Training</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. Dr M O'Toole</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ministry of Fisheries and Marine Resources, Private Bag</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>x13355, Windhoek, Namibia</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tel: (264-61) 205 3084</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fax: (264-61) 220 558</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>E-mail: <a href="mailto:mick.otoole@iafrica.com.na">mick.otoole@iafrica.com.na</a></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Dr C. Hocutt</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BENEFIT Secretariat</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P.O. Box 912, Swakopmund, Namibia</td>
<td></td>
</tr>
<tr>
<td>S. AFRICA</td>
<td>BEP IV, SFRI</td>
<td>activities of Benguela Ecology Programme IV</td>
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<tr>
<td></td>
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<td>VIBES</td>
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<tr>
<td></td>
<td></td>
<td>SA-Franco programme</td>
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<tr>
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<td></td>
<td>BENEFIT, ENVIFISH</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Angola, Namibia and South Africa regional programmes</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>1. Prof Frank A Shillington</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Dept Oceanography, UCT, Rondebosch 7701, South Africa</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Tel: (27-21) 650 3979</td>
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<tr>
<td></td>
<td></td>
<td>Fax:(27-21) 650 3278</td>
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<td>E-mail: <a href="mailto:shill@physci.uct.ac.za">shill@physci.uct.ac.za</a></td>
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<td></td>
<td></td>
<td>2. Dr Hans Verhey</td>
<td></td>
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<td></td>
<td>SFRI, Private Bag X1, Roggebaai, 8012, South Africa</td>
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<tr>
<td></td>
<td></td>
<td>Tel: (27-21) 402 3346</td>
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<td>GLOBEC France</td>
<td>Dr François Carlotti</td>
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<td></td>
<td>Universite P. et M. Curie, URA 2077, Station Zoologique, BP 28,</td>
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<td>06234, Villefranche sur Mer, France</td>
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<td></td>
<td></td>
<td>Tel: (33) 4 93 76 38 39</td>
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<td>Fax:(33) 4 93 76 38 34</td>
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<td>E-mail: <a href="mailto:carlotti@ccrv.obs-vlfr.fr">carlotti@ccrv.obs-vlfr.fr</a></td>
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<td>Dr Jürgen Alheit</td>
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<td>D-18119, Germany</td>
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<td></td>
<td></td>
<td>Tel: (+49) 381 5197 208</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Fax: (+49) 381 5197 440</td>
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<td></td>
<td>E-mail: <a href="mailto:juergen.alheit@io-warnemuende.de">juergen.alheit@io-warnemuende.de</a></td>
<td></td>
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<tr>
<td>Country Acronym</td>
<td>Contact</td>
<td>Website</td>
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<tr>
<td>BLACK SEA</td>
<td>Temel Oguz Middle East Technical University, Institute of Marine Sciences, P.O.Box 28, Erdemli 33731, Icel,Turkey Tel: (90-324) 521 2406 Fax: (90-324) 521 2327 E-mail: <a href="mailto:oguz@taurus.ims.metu.edu.tr">oguz@taurus.ims.metu.edu.tr</a></td>
<td><a href="http://www.metu.edu.tr/home/wwwdbe/staff/oguz/main.html">http://www.metu.edu.tr/home/wwwdbe/staff/oguz/main.html</a></td>
<td></td>
</tr>
<tr>
<td>CHINA</td>
<td>1. Prof. Jilan Su Second Institute of Oceanography, Hangzhou 310012, P.R.China Tel: (86-571) 8840332 Fax: (86-571) 8071539 E-mail: <a href="mailto:sujil@ns2.zgb.com.cn">sujil@ns2.zgb.com.cn</a> 2. Prof. Qisheng Tang Yellow Sea Fisheries research Institute, 106 Nanjing Road Qingdao 266071, P.R. China Tel: (86-532) 582 2941 Fax: (86-532) 581 1514 E-mail: <a href="mailto:ysfri@sdqd.qdinfo.gov">ysfri@sdqd.qdinfo.gov</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JAPAN</td>
<td>Dr Takashige Sugimoto Ocean Research Institute, University of Tokyo, 1-15-1 Minamidai, Nakano-ku, Tokyo 164-8639, JAPAN Tel: (81-3) 5351 6511 Fax: (81-3) 5351 6506 E-mail: <a href="mailto:sugimoto@ori.u-tokyo.ac.jp">sugimoto@ori.u-tokyo.ac.jp</a></td>
<td><a href="http://tokyo.ac.jp/~guests/globec..homepage.html">http://tokyo.ac.jp/~guests/globec..homepage.html</a></td>
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<tr>
<td>Country/programme</td>
<td>Brazil</td>
<td>Chile</td>
<td>Canada</td>
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<tr>
<td><strong>System Types Studied</strong></td>
<td>Southeastern coast of Brazil between São Tomé Cape (22°S) and São Sebastião Island 25°S. Coastal upwelling and its relation to dynamics of the Brazil Current.</td>
<td>The Eastern Boundary Humboldt Current</td>
<td>Scotian Shelf, Labrador Sea (modelling), Vancouver Island Shelf, Northeast Pacific</td>
</tr>
</tbody>
</table>
| **Target Organisms** | Sardinella brasiliensis  
Paracalanus spp.  
Sciaenid fish assemblage  
Benthic fauna | Calanus chilensis  
Engraulis ringens | Gadus morhua, Calanus finmarchicus, Chum salmon, coho salmon, chinook salmon, sockeye salmon, Neocalanus plumchrus, and others |
| **Physical Processes Examined** | Coastal upwelling  
Penetration of the South Atlantic Central Water (SACW) in the coastal region  
Water column stratification  
Meandering movement of the Brazil Current | Remote forcing  
Coastal trapped waves  
Coastal Upwelling  
Oxygen minimal layer distribution | Coupling of topography and stratification Bank dynamics  
Open ocean modelling  
Coastal ocean wind dynamics  
Cross-frontal mixing  
Turbulence |
**Key Hypotheses and Issues**

- Input of nutrients in coastal region by intrusion of the SACW
- Concentration process of prey organisms by water column stability between cool SACW and warm Tropical Water
- Interannual and seasonal variation of intrusion of the SACW
- Coastal zone physical processes and carbon fluxes in the Humboldt Current System (HCS) are strongly modulated by both local and remote physical forcing
- The occurrence of an intense oxygen minimum layer determines the presence of special adaptations/ responses in the pelagic and benthic communities and/or populations (e.g. community structure, life cycles, metabolic strategies, and species distributions) and strongly influence biogeochemical cycling over the HCS
- Importance of seasonality and timing match between critical physical and biological events
- Amount and timing of freshwater inputs and effects on physical mixing and transport patterns
- Importance of advective coupling between continental shelf banks and basins
- and between the open ocean and continental margins
- Interactions between zooplankton and fish populations
<table>
<thead>
<tr>
<th>Country/Programme</th>
<th>System Types Studied</th>
<th>Target Organisms</th>
<th>Physical Processes Examined</th>
<th>Key Hypotheses and Issues</th>
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<tr>
<td>NW Atlantic: Georges Bank</td>
<td>NE Pacific Coastal Gulf of Alaska, buoyancy-driven flow</td>
<td>Gadus morhua, Melanogrammus aeglefinus, Calanus finmarchicus, Pseudocalanus sp</td>
<td>Stratification, Retention/Loss, Cross-Frontal-Exchange</td>
<td>Retention and in situ growth are more important than lateral exchange processes.</td>
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<tr>
<td>Eastern Boundary Current</td>
<td>Onchorhyncus tshawytscha, Euphausia pacifica, Thyasorella spinifera, Calanus spp.</td>
<td></td>
<td></td>
<td>Stratification results in prey aggregation and increased predator survival.</td>
</tr>
<tr>
<td>NE Pacific: Georges Bank</td>
<td>Onchorhyncus gorbuscha, Esula pacifica, T. spinifera, Neocalanus spp.</td>
<td></td>
<td></td>
<td>Variation in mixing and stratification affects phytoplankton production and food web dynamics.</td>
</tr>
<tr>
<td>NE Pacific: California Current</td>
<td></td>
<td></td>
<td></td>
<td>Large episodic water mass exchanges contribute to population variability.</td>
</tr>
</tbody>
</table>

Local wind forcing and basin-scale currents affect spatial and temporal variability. Mesoscale features impact zooplankton biomass, production, and retention and loss of zooplankton. Variation in the intensity of cross shelf transport and the levels of primary and secondary production control juvenile salmon growth. High and variable predation mortality on juvenile salmon is responsible for population variation. Local wind forcing and basin-scale currents affect spatial and temporal variability. Mesoscale features impact zooplankton biomass, production, and retention and loss of zooplankton. Variation in the intensity of cross shelf transport and the levels of primary and secondary production control juvenile salmon growth.
<table>
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<th>Country/programme</th>
<th>Benefit</th>
<th>South Africa</th>
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<tbody>
<tr>
<td><strong>System Types Studied</strong></td>
<td>Benguela Current Eastern Boundary Upwelling System</td>
<td>Southern Benguela/Benguela System</td>
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<tr>
<td><strong>Target Organisms</strong></td>
<td>Sardinops ocellata, Trachurus capensis, Engraulis capensis, Merluccius capensis, Merluccius productus, Nyctophanes capensis, Euphausia hansenii, Centropages brachiatius, Calanoides carinatus</td>
<td>Calanus agulhensis; Calanoides caranatus small pelagic fish</td>
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<tr>
<td><strong>Physical Processes Examined</strong></td>
<td>Upwelling, Cross frontal exchanges Stratification and intensity of frontal systems Anoxia and sulphur cycle in coastal waters</td>
<td>Upwelling</td>
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<tr>
<td><strong>Key Hypotheses and Issues</strong></td>
<td>• No direct goals: GLOBEC research associated with SFRI line function of resource management</td>
<td>• No direct goals: GLOBEC research associated with SFRI line function of resource management</td>
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<tr>
<td>Country/ programme</td>
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<tr>
<td><strong>System type studied</strong></td>
<td>Bay of Biscay</td>
<td>Bay of Seine English Channel</td>
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<tr>
<td><strong>Target organisms</strong></td>
<td>Anchovy</td>
<td>Benthic species with pelagic larvae</td>
</tr>
<tr>
<td><em>Copepods</em></td>
<td><em>Calanus helgolandicus</em> <em>Centropages typicus</em> <em>Oithona sp.</em> Gelatinous carnivores</td>
<td></td>
</tr>
<tr>
<td><strong>Physical processes examined</strong></td>
<td>Processes in coastal - oceanic interaction</td>
<td>Mesoscale and microscale controlling settling of larvae</td>
</tr>
<tr>
<td><strong>Key hypotheses and issues</strong></td>
<td>• Meteorological forcing on water circulation, as well as adult anchovies distribution control larvae distribution and recruitment success. • Meteorology is the dominant factor in recruitment fluctuation • Role of pelagic gelatinous carnivores dynamics</td>
<td>• Current patterns in Eastern Channel affects recruitment in different populations of the same species. Species specific effects dependent on larval development characteristics.</td>
</tr>
<tr>
<td>Country/programme</td>
<td>Germany</td>
<td>TASC</td>
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<tr>
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<tr>
<td><strong>System type studied</strong></td>
<td>Baltic Sea</td>
<td>North Sea</td>
</tr>
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</table>
| **Target organisms** | *Gadus morhua*  
Sprattus sprattus  
*Clupea harengus*  
Copepod species to be determined  
Aurelia aurita  
*Mysis* | Ammodytes  
Sprattus sprattus  
Clupea harengus  
Copepod species to be determined  
Aurelia aurita  
*other jellies* |
<p>| <strong>Physical processes examined</strong> | To be determined | To be determined |
| <strong>Key hypotheses and issues</strong> | To be determined | To be determined |</p>
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<th>Country/programme</th>
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<th>Japan</th>
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<tr>
<td><strong>System type studied</strong></td>
<td>Semi enclosed, marginal sea with buoyancy and wind driven circulation dominated by mesoscale dynamics and intense meandering boundary current structure</td>
<td>Semi-close Sea</td>
<td>Kuroshio, Oyashio, and their transition region</td>
</tr>
<tr>
<td><strong>Target organisms</strong></td>
<td><em>Engraulis encrasicolus</em>, <em>Sprattus sprattus</em>, <em>Calanus exinus</em>, <em>Mnemiopsis leidyi</em>, <em>Pleurobrachia pileus</em></td>
<td><em>Bohai Penaeid shrimp</em> (<em>Penaeus chinensis</em>)</td>
<td><em>Saury, Sardine, Anchovy, Walleye pollack, Copepod, Euphausia, Lantern fish, diatoms</em></td>
</tr>
<tr>
<td><strong>Physical processes examined</strong></td>
<td>Stratification, cross-frontal exchanges, eddy mean flow interactions, shelf deep basin interactions in the western Black Sea, the role of sub-basin and mesoscale features on the biogeochemistry, upwelling.</td>
<td>Stratification</td>
<td>Variation in ocean currents and winter monsoon Stratification Cross frontal exchange/coastal retention Effect of frontal eddies and warm streamers</td>
</tr>
</tbody>
</table>
| **Key hypotheses and issues** | - Food competition and fishery result in collapse of commercial fishery of anchovy  
- Biomass of exotic invader *Mnemiopsis* is first exploded and thereafter decreased-classical scheme of invader behaviour  
- Impact on zooplankton biomass and species composition  
- Decrease in physiological condition (lipid and its components) due to food competition | - Stratification and trophodynamics exchanges contribute to the ominent species shift and copulation variability | - Interannual variations of the coastal Oyashio effect on walleye pollack population, through transport and aggregation of pollack eggs and larvae as well as their food organisms: timing and aggregation hypothesis.  
- Interdecadal variations of winter monsoon (and the Kuroshio meander) and southward intrusion of the Oyashio, associated with climatic regime shift, effect recruitment of sardine through food availability during the stage of larvae and juvenile, respectively.  
- Strategy change of sardine and anchovy in spawning season and area, associated with their stock size and carrying capacity, effects on recruitment rate. |
REFERENCES


APPENDICES

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Terms of Reference for the Scientific Steering Committee of the Global Ocean Ecosystem Dynamics Project of the IGBP

- To oversee the development and implementation of the Global Ocean Ecosystem Dynamics programme in accordance with the published Science Plan;
- To develop a detailed Implementation Plan for GLOBEC for presentation to the sponsors and the larger scientific community;
- To recommend to the sponsoring organizations the necessary actions to be taken in accordance with the GLOBEC Science and Implementation Plans and to coordinate and manage the resulting activities;
- To collaborate, as appropriate, with other related global change programmes and planning activities, such as JGOFS, LOICZ, WCRP, the IOC programme on Ocean Science and Living Resources (OSLR), and the emerging Global Ocean Observing System;
- To establish appropriate data management policies to ensure sharing and preservation of the GLOBEC data set taking into account the related policies of the sponsors; and
- To report regularly to SCOR, IGBP and IOC and to other bodies such as WCRP, ICES and PICES, on the state of planning and accomplishments of GLOBEC.

The GLOBEC SSC, its Officers, subsidiary groups and Core Project Office shall operate in accordance with the guidelines established by SCOR and the SC-IGBP.

Operating Procedures for the SSC

The Global Ocean Ecosystem Dynamics Programme (GLOBEC) is a Core Project of the International Geosphere-Biosphere Programme of ICSU. The Scientific Steering Committee of GLOBEC (henceforth referred to as SSC) is sponsored by the Scientific Committee on Oceanic Research (SCOR), the Intergovernmental Oceanographic Commission (IOC) and the Scientific Committee of the IGBP (SC-IGBP). The three organizations are jointly responsible for the appointment of the Chairperson, Vice-Chair and members. The sponsors of important regional components of GLOBEC (e.g. ICES and PICES) will be consulted about the nominations of members of the SSC.

The primary functions of the GLOBEC SSC are:

- To provide scientific guidance to and oversee the development, planning and implementation of the Core Project;
- To encourage publication of results with an appropriate form of acknowledgement of SCOR, IOC, IGBP and ICSU support;
- To encourage the promotion and wide awareness of GLOBEC amongst the science community;
- To demonstrate progress and achievements of the project through the definition and monitoring of milestones and results;
• To provide on request, scientific advice and assistance to the GLOBEC and IGBP national Committees and START Regional Committees, in the planning of national and regional research which is designed to contribute to the overall goals of the GLOBEC Core Project.

• To encourage national governments, regional and international funding agencies to support the implementation of Core Research and the achievement of Core Project goals through the provision of adequate support to the necessary national, regional and international research;

• To encourage collaboration between GLOBEC and other IGBP Core Projects and International Programmes and Agencies concerned with the scientific study and assessment of global change; and

• To recommend to SCOR, IOC and the SC-IGBP:
  - Members for appointment by SCOR, IOC and the SC-IGBP to the committee;
  - A Chairperson for appointment by SCOR, IOC and the SC-IGBP;
  - A Vice-Chair for appointment by SCOR, IOC and the SC-IGBP; and,
  - Such amendments to these terms of reference as may prove necessary from time to time.

In undertaking these responsibilities the SSC shall collectively:

• Meet at least once a year, to review progress in the development and implementation of the GLOBEC and to advise the Chair and Core Project Executive Officer on the scientific developments which should be initiated or undertaken between meetings;

• Prepare plans and guidelines for the conduct of meetings, workshops, and conferences designed to assist the SSC in executing its functions;

• Prepare and revise, as necessary, criteria for the identification of national and regional research which contributes to the goals of GLOBEC as: Core Research; Regional/National Research; or Relevant Research;

• Develop guidelines for the preparation, publication and distribution of substantive and technical reports resulting from Core Research; from the work of the GLOBEC Core Project Office; and, from related activities of GLOBEC individually and collectively;

• Develop and devise a methodology for monitoring and assessing progress;

• Advise the Core Project Executive Officer on the necessary actions required of the Core Project Office in support of the work of the SSC and,

• Consider such other matters as individual members or the Core Project Executive Officer bring to the attention of the SSC or are referred to it for consideration by SCOR, IOC or the SC-IGBP.

Members of the SSC serve in their individual capacities and are expected to:

• Attend in full, the meetings of the SSC;

• Be willing to expend considerable effort outside of SSC meetings;
• Provide the best possible scientific information and advice concerning their field of specialization as it relates to the goals and Operational Plan for the Core Project;
• Provide scientific advice to the Chairperson and Core Project Executive Officer on the development and implementation of the GLOBEC programme;
• Represent the scientific interests of the Core Project at relevant scientific meetings;
• Provide a written report to the CPO within one month of attendance at a meeting at the expense of the CPO;
• Provide a two-way channel of communication between the SSC and the national and where possible, regional and international research community;
• Organize, convene, conduct meetings and provide reports for such Core Project Workshops as shall be agreed by the SSC;
• Keep the Core Project Office and Chairperson of the SSC fully informed of all actions directly or indirectly related to the Core Project; and
• Assist in securing financial and other support for the execution of Core Research, adopted and approved by the Committee.

The Chairperson of the SSC is expected to:
• Chair the meetings of the Committee;
• Conduct the meetings in accordance with “good practice” guidelines to be established by the IGBP;
• Undertake advocacy on behalf of the project and enlist wide international participation in the project;
• Work closely with the Core Project Executive Officer in implementing agreed activities between meetings of the Committee;
• Report periodically to SCOR, IOC and the SC-IGBP on progress implementing the project and seek the assistance of SCOR, IOC and the SC-IGBP in addressing difficulties encountered in the implementation.

The Vice-Chair of the SSC is expected to:
• Chair the meetings of the committee in the absence of the Chairperson;
• Undertake advocacy on behalf of the project and enlist wide international participation in the project; and
• Assist the Chair and the Core Project Executive Officer in implementing agreed activities between meetings of the Committee.
List of GLOBEC Reports

GLOBEC Reports are available from:
GLOBEC International Project Office, Plymouth Marine Laboratory, Prospect Place, West Hoe, Plymouth PL1 3DH, United Kingdom.
Tel: (01752) 633100; Fax: (01752) 633101; Email: anwat@pml.ac.uk.

To be placed on the GLOBEC mailing list contact the above address or Email: anwat@pml.ac.uk.

GLOBEC IPO web-site: http://www1.npm.ac.uk/globec/

GLOBEC Special Contributions No. 1
Predicting and Monitoring of the Physical-Biological-Chemical Ocean.

GLOBEC Report No. 1 Towards the Development of the GLOBEC Core Programme.


GLOBEC Report No. 3 Sampling and Observational Systems.

GLOBEC Report No. 4 Cod and Climate Change.

GLOBEC Report No. 5 Southern Ocean.

GLOBEC Report No. 6 Numerical Modelling.

GLOBEC Report No. 7 Southern Ocean Implementation Plan.

GLOBEC Report No. 7A Report of the meeting of the Southern Ocean Planning Group

GLOBEC Report No. 8 Small Pelagic Fishes and Climate Change Programme.

GLOBEC Report No. 9 GLOBEC Science Plan

GLOBEC Report No 11 SPACC Implementation Plan

GLOBEC Related Web-Sites

GLOBEC IPO web-site
http://www1.npm.ac.uk/globec/

JGOFS International Core Programme Office
http://ads.smr.uib.no/jgofs/org.htm#CORE PROJECT TT

JGOFS Data Management Task Team
http://ads.smr.uib.no/jgofs/pgtt.htm# DATA MANAGEMENT TT

IGBP report#23-Joint Global Ocean Flux Study-Implementation Plan
(a.k.a..report#9) JGOFS

US JGOFS Implementation Plan
http://www1.whoi.edu/strategy6.html

US GLOBEC reports:
http://ww.usglobec.berkeley.edu/usglobec/Reports/reports.home.html

Description of the US GLOBEC/ Georges Bank DMO:
http://globec.whoi.edu/globec-dir//dmo.html

Data Management and Synthesis (Northwest Atlantic Implementation Plan):
http://www.usglobec.berkeley.edu/usglobec/Reports/nwaip/nwaip.chapter6.html

US GLOBEC Data Policy (Report #10)
http://www.usglobec.berkeley.edu/usglobec/Reports/datapol/datapol.contents.htm

US GLOBEC Home Page:
http://www.usglobec.berkeley.edu/usglobec/

GLOBEC Canada Home Page
http://www.globec-canada.mun.ca/globec/index.html

US GLOBEC Georges Bank Programme
http://globec.whoi.edu/globec.html

Japan GLOBEC Home Page
http://www2.ORI.u-tokyo.ac.jp/~glbc/index.html

TASC Home Page
http://calanus.nfh.uit.no/TASC.HTML

International Council for the Exploration of the Sea (ICES)
http://www.ices.dk/
Joint Global Ocean Flux Study (JGOFS)  
http://ads.smr.uib.no/jgofs/jgofs.htm

North Pacific Marine Science Organisation (PICES)  
http://pices.ios.bc.ca/

International Geosphere-Biosphere Programme (IGBP)  
http://www.igbp.kva.se/index.html

Scientific Committee on Oceanic Research (SCOR)  
http://www.jhu.edu:80/~scor/

Intergovernmental Oceanographic Commission (IOC)  
http://www.unesco.org/ioc/iochome.htm

Land-Ocean Interactions in the Coastal Zone (LOICZ)  
http://www.nioz.nl/loicz/

Past Global Changes (PAGES)  
http://www.pages.unibe.ch/
LIST OF IGBP PUBLICATIONS

IGBP Report Series. List with Short Summary

IGBP Reports are available free of charge from:
IGBP Secretariat, Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden. Tel: 46-8 16 64 48; Fax: 46-8 16 64 05; E-mail: sec@igbp.kva.se

Report Nos. 1-11 and reports marked * are no longer available.
Report Nos. 12-19 are available in limited numbers.

No. 20*
This report outlines a proposal to produce a global data set at a spatial resolution of 1 km derived from the Advanced Very High Resolution Radiometer primarily for land applications. It defines the characteristics of the data set to meet a number of requirements of IGBP’s science plan and outlines how it could be created. It presents the scientific requirements for a 1 km data set, the types and uses of AVHRR data, characteristics of a global 1 km data set, procedures, availability of current AVHRR 1 km data, and the management needs.

No. 21*
The objectives of GCTE are: to predict the effects of changes in climate, atmospheric composition, and land use on terrestrial ecosystems, including agricultural and production forest systems, and to determine how these effects lead to feedbacks to the atmosphere and the physical climate system. The research plan is divided into four foci: ecosystem physiology, change in ecosystem structure, global change impact on agriculture and forestry, and global change and ecological complexity. Research strategies are presented.
No. 22
The report presents general recommendations on global change research in the region, thematic studies relating to IGBP Core Project science programmes, global change research in studies of eight countries in the area, and conclusions from working groups on the participation of the region in research under the five established IGBP Core Projects and the related HDGEC programme.

No. 23
The Report describes how the aims of JGOFS are being, and will be, achieved through global synthesis, large scale surveys, process studies, time series studies, investigations of the sedimentary record and continental margin boundary fluxes, and the JGOFS data management system.

No. 24
The report presents the main findings of the joint Working Group of the IGBP and the International Social Science Council on Land-Use/Land-Cover Change; it describes the research questions defined by the group and identifies the next steps needed to address the human causes of global land-cover change and to understand its overall importance. It calls for the development of a system to classify land-cover changes according to the socioeconomic driving forces. The knowledge gained will be used to develop a global land-use and land-cover change model that can be linked to other global environmental models.

No. 25
*Land-Ocean Interactions in the Coastal Zone (LOICZ) Science Plan.* Edited by P.M. Holligan and H. de Boois, with the assistance of members of the LOICZ Core Project Planning Committee (1993). IGBP Secretariat, Stockholm, 50 pp.
The report describes the new IGBP Core Project, giving the scientific background and objectives, and the four research foci. These are: the effects of global change (land and freshwater use, climate) on fluxes of materials in the coastal zone; coastal biogeomorphology and sea-level rise; carbon fluxes and trace gas emissions on the coastal zone; economic and social impacts of global change on coastal systems. The LOICZ project framework includes data synthesis and modelling, and implementation plans cover research priorities and the establishment of a Core Project office in the Netherlands.
No. 26*
The Fontainebleau Workshop, July 1992, defined a strategy to initiate a global terrestrial monitoring system for the IGBP project on Global Change and Terrestrial Ecosystems, the French Observatory for the Sahara and the Sahel, and the UNESCO Man and the Biosphere programme, in combination with other existing and planned monitoring programmes. The report reviews existing organizations and networks, and drafts an operational plan.

No. 27*
A presentation of the mandate, scope, principal subjects and structure of the BAHC research plan is followed by a full description of the four BAHC Foci: 1) Development, testing and validation of 1-dimensional soil-vegetation-atmosphere transfer (SVAT) models; 2) Regional-scale studies of land-surface properties and fluxes; 3) Diversity of biosphere-hydrosphere interactions; 4) The Weather Generator Project.

No. 28*
This Report provides an overview of the global change research to be carried out under the aegis of the International Geosphere-Biosphere Programme over the next five years. It represents a follow-up to IGBP Report No. 12 (1990) that described the basic structure of the global change research programme, the scientific rationale for its component Core Projects and proposals for their development. The IGBP Core Projects and Framework Activities present their aims and work programme in an up-to-date synthesis of their science, operational and implementation plans.

No. 29
A summary is given of the conference arranged by the Global Change System for Analysis, Research and Training (START) on behalf of the IGBP, the Human Dimensions of Global Environmental Change Programme (HDP), and the Joint Research Centre of the Commission of the European Communities (CEC) that describe the global change scientific research situation in Africa today.

No. 30
This report sets out the goals and directions for GAIM and IGBP-DIS over the next five years, expanding on the recent overview of their activities within IGBP Report 28 (1994). It describes the work within IGBP-DIS directed at the assembly of global
databases of land surface characteristics, and within GAIM, directed at modelling the global carbon cycle and climate-vegetation interaction.

No. 31
The workshop focused on interactions between African savannas and the global atmosphere, specifically addressing land-atmosphere interactions, with emphasis on sources and sinks of trace gases and aerosol particles. The report discusses the ecology of African savannas, the research issues related to carbon sequestration, ongoing and proposed activities, and gives a research agenda.

No. 32
The goals of IGAC are to: develop a fundamental understanding of the processes that determine atmospheric composition; understand the interactions between atmospheric chemical composition and biospheric and climatic processes, and predict the impact of natural and anthropogenic forcings on the chemical composition of the atmosphere. The Operational Plan outlines the organization of the project. The plan describes the seven Foci, their related Activities and Tasks, including for each the scientific rationale, the goals, strategies.

No. 33
LOICZ is that component of the IGBP which focuses on the area of the Earth’s surface where land, ocean and atmosphere meet and interact. The implementation plan describes the research, its activities and tasks, and the management and implementation requirements to achieve LOICZ’s science goals. These are, to determine at regional and global scales: the nature of these dynamic interactions, how changes in various compartments of the Earth system are affecting coastal zones and altering their role in global cycles, to assess how future changes in these areas will affect their use by people, and to provide a sound scientific basis for future integrated management of coastal areas on a sustainable basis.

No. 34
The Science Task Team discussed and developed recommendations for multi-Core Project collaboration within the IGBP under three headings: process studies in terrestrial environments, integrated modelling efforts, and partnership with developing country scientists. Three interrelated themes considered under process studies are: transects and large-scale land surface experiments, fire, and wetlands. Methods for implementation and projects are identified.
The Science/Research Plan presents land-use and land-cover change and ties it to the overarching themes of global change. It briefly outlines what is currently known and what knowledge will be necessary to address the problem in the context of the broad agendas of IGBP and HDP. The three foci address by the plan are: (i) land-use dynamics, land-cover dynamics - comparative case study analysis, (ii) land-cover dynamics - direct observation and diagnostic models, and (iii) regional and global models - framework for integrative assessments.

The IGBP Terrestrial Transects are a set of integrated global change studies consisting of distributed observational studies and manipulative experiments coupled with modelling and synthesis activities. The transects are organized geographically, along existing gradients of underlying global change parameters, such as temperature, precipitation, and land use. The initial transects are located in four key regions, where the proposed transects contribute to the global change studies planned in each region.

This report was prepared by scientists representing BAHC, IGAC, and GCTE. It is a prospectus for an integrated hydrological, atmospheric chemical, biogeochemical and ecological global change study in the tundra/boreal region of Northern Eurasia. The unifying theme of the IGBP Northern Eurasia Study is the terrestrial carbon cycle and its controlling factors. Its most important overall objective is to determine how these will alter under the rapidly changing environmental conditions.

This report summarizes the findings and recommendations of an International Geosphere-Biosphere Programme (IGBP) Workshop which aimed to develop an approach to modelling landscape-scale disturbances in the context of global vegetation change.
No. 39
This report is the major product of a three-day workshop entitled: “Modelling the Delivery of Terrestrial Materials to Freshwater and Coastal Ecosystems” held in Durham, NH, USA from 5-7 December 1994.

No. 40
Based on a draft plan written by the SCOR/IOC SSC for GLOBEC in 1994. That plan was itself based on a number of scientific reports generated by GLOBEC working groups and on discussions at the GLOBEC Strategic Planning Conference (Paris, July 1994). This document was presented to the Executive Committee of the Scientific Committee on Ocean Research (SC-SCOR) for approval (Cape Town, November 14-16 1995), and was approved by the SC-IGBP at their meeting in Beijing in October 1995. The members of the SCOR/IGBP CPPC were: B.J. Rothschild (Chair), R. Muench (Chief Editor), J. Field, B. Moore, J. Steele, J.-O. Strömberg, and T. Sugimoto.

No. 41
This report describes a science and implementation plan for the Miombo Network Initiative, developed at an IGBP intercore-project workshop in Malawi in December 1995 and further refined during the LUCC Open Science Meeting in January, 1996.

No. 42
This report is the basis for the proposed Kalahari Transect proposed as one of the IGBPs Mega Transects.

No. 43
This report is the result of a workshop on IGBP mountain research issues held in Kathmandu, Nepal, from 30 March to 2 April 1996.
This report describes the Implementation of START (Global Change System for Analysis, Research and Training). START involves the establishment of a system of regional networks with particular emphasis on the developing regions. The primary mission of these networks is: (i) to conduct research on regional aspects of global change; (ii) to assess the impacts of the regional findings; and (iii) to provide regionally important integrated and evaluated information to policy-makers and governments. START’s overall objective is to build, through regional research activities, a world-wide indigenous capacity to tackle the scientific and policy aspects of environmental changes and sustainable development.

This report summarizes progress made thus far by the Past Global Changes (PAGES) programme element of the IGBP. The document also outlines the implementation plans for most of the Foci, Activities and Tasks currently within the PAGES remit. The plan first introduces the scope and rationale of PAGES science and explains how PAGES is organized structurally and scientifically to achieve its goals.

The IGBP Core Projects BAHC, LUCC and IGAC, in conjunction with Framework Activities GAIM and IGBP-DIS held a joint workshop to identify data and research needs for characterizing wetlands in terms of their role in biogeochemical and hydrologic cycles.

Book of Abstracts
This book of abstracts is a result of materials presented at the scientific symposium held in conjunction with the Fourth Scientific Advisory Council for the IGBP (SAC) held in Beijing, 23-25 October 1995.

IGBP Booklet*

Global Change: Reducing Uncertainties
IGBP Directory

IGBP Newsletter

IGBP Science No. 1
This executive summary presents the major findings of the synthesis of the first six years of the Global Change and Terrestrial Ecosystem (GCTE) Core Project of the IGBP. It begins by identifying the major components and drivers of global change. It then outlines the important ecosystem interactions with global change, focusing on the functioning of ecosystems and the structure and composition of vegetation. The executive summary then discusses the implications of these ecosystem interactions with global change in terms of impacts in three key areas: managed production systems, biodiversity and the terrestrial carbon cycle. The full synthesis results and conclusions, with a complete reference list, are presented as a volume in the IGBP Book Series No. 4, published by Cambridge University Press (Walker et al. (In Press)). Here key references only are included.

IGBP Book Series
IGBP Book Series Books are available by order from:
Customer Services Direct, Cambridge University Press
The Edinburgh Building, Cambridge CB2 1BR, UK
Tel: 44-(0)1223 325 588
Fax: 44-(0)1223 325 152
E-mail: directcustserve@cup.cam.ac.uk

The IGBP was established to describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human activities. The IGBP Book Series brings new work on topics within these themes to the attention of the wider scientific audience.
Series No. 1
This book describes approaches and methods for grouping species with similar characteristics into functional types in ways which maximize our potential to predict accurately the responses of real vegetation with real species diversity.
Details: 1997, 247 x 174 mm, 383 pp, 113 line diagrams, 5 half-tones, 5 colour plates, 25 tables
Price: 0 521 48231 3 Hardback £80.00
0 521 56643 6 Paperback £29.95

Series No. 2
Global Change and Terrestrial Ecosystems. Edited by Brian Walker and Will Steffen. Cambridge University Press, UK.
How will the world’s vegetation, from “natural” ecosystems to intensively managed agricultural systems, be affected by changes in land use, the composition of gases in the atmosphere, and climate? This major new book describes the current state of knowledge.
Details: 1996, 228 x 152 mm, 637 pp, 63 line diagrams, 11 colour plates, 51 tables
Price: 0 521 57094 8 Hardback £85.00
0 521 57810 8 Paperback £30.00

Series No. 3
There is a growing appreciation of the ways in which developing countries in the Asia region both contribute to global changes (by altering biogeochemical pathways and cycles) and are themselves affected by those changes. This volume uses the intellectual efforts and findings of the IGBP community to provide the first integrated analysis of the interactions between global change and Asia change, with particular attention given to the role of China. The book will be of interest to readers in a wide range of academic disciplines (natural sciences and socio-economic) and for those involved in national and international policy development relevant to global change.
Details: 1998, 247 x 174 mm, 364 pp, 90 line diagrams, 10 colour plates, 29 tables
Price: 0 521 62343 X Hardback £80.00
0 521 63888 7 Paperback £30.00
Series No. 4
This new synthesis summarizes the international research effort in the Global Change and Terrestrial Ecosystems (GCTE) Core Project of the International Geosphere-Biosphere Programme (IGBP). Five major thematic areas are covered: ecosystem physiology; ecosystem structure and composition; terrestrial production systems; global biogeochemistry; ecological complexity (biodiversity). A summary of the integrated and interactive efforts of global change on the terrestrial biosphere for four key regions of the world is presented, as well as a projection of future trends in the terrestrial component of the global carbon cycle. The book also includes a section of tools developed or modified for global change research.
Details: January 1999, 247 x 174 mm, 450 pp, 75 line diagrams, 8 colour plates, 20 tables
Price: 0 521 62429 0 Hardback c£65.00
0 521 62480 0 Paperback c£30.00

Series No. 5 [currently under production]
The Changing Ocean Carbon Cycle.
The world’s oceans act as a reservoir, with the capacity to absorb and retain carbon dioxide. The air-sea exchange of carbon is driven by physico-chemical forces, photosynthesis and respiration, and has an important influence on atmospheric composition. Variability in the ocean carbon cycle could therefore exert significant feedback effects during >conditions of climate change. The Joint Global Ocean Flux Study (JGOFS) is the first multidisciplinary programme to directly address the interactions between the biology, chemistry and physics of marine systems, with emphasis on the transport and transformations of carbon within the ocean and across its boundaries. This unique volume, written by an international panel of scientists, provides a synthesis of JGOFS science and its achievements to date. It will therefore appeal to all those seeking a recent overview of the role of ocean processes in Earth system science and their wider implications on climate change.
Details: [currently unavailable]
Price: [currently unavailable]
ACRONYMS & ABBREVIATIONS

ACC Anthropogenic Climate Change
ADCP Acoustic Doppler current profile
ARTS Annual Records of Tropical Systems
AU Autonomous underwater vehicle
BASS Basin Scale Studies
BAT Bermuda Atlantic Time-series
BENEFIT Benguela Environment Fisheries Interaction and Training
CalCOFI California Cooperative Fisheries Investigation
CCAMLR Commission for Conservation of Antarctic Marine Living Resources
CCC Cod and Climate Change
CCCC Climate Change and Carrying Capacity
CCCWG Cod and Climate Change Working Group
CLIVAR Climate Variability and Prediction Research Programme
COA Centres of Action
CPR Continuous Plankton Recorder
Crittercam Video system designed to observe zooplankton behaviours in situ
CTD Conductivity Temperature Depth
DecCen Decadal to Centennial Climate System
DIS(-IGBP) Data and Information System (IGBP)
DMWG Data Management Working Group
ECOSCOPE Video system designed to observe zooplankton behaviours and predator-prey interactions in situ
EEZ Exclusive Economic Zone
ENSO El Niño - Southern Oscillation
GAIM Global Analysis, Interpretation and Modelling
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<th>Acronym</th>
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<td>Global Climate Model</td>
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<td>GCM</td>
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