Intergovernmental Oceanographic Commission
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IOC-SCOR Workshop on Global Ocean Ecosystem Dynamics

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TABLE OF CONTENTS

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FOREWORD

Concerns for global climate change emphasize the need to understand how changes in the global environment will affect the abundance, diversity, and production of animal populations comprising ocean ecosystems. The only existing marine-biologically oriented international global-change program is the Joint Global Ocean Flux Study (JGOFS). JGOFS, an International Geosphere/Biosphere Programme (IGBP) program is primarily concerned with average changes in the flux of biogenic elements (particularly carbon) and the role of ocean primary production in the exchange of carbon dioxide between the ocean and atmosphere especially in the context of global warming. In particular JGOFS addresses the role of ocean physics in determining the magnitude of new production. No component of the IGBP Study of Global Change is focused upon the mechanisms by which climate change will impact the dynamics of marine animal populations, some of which are important food resources.

Among marine animal populations, zooplankton play a pivotal role in shaping ecosystem structure and the cycling of biogenic elements. Zooplankton grazing determines the size, species composition and fate of phytoplankton stocks and the nature of dissolved and particulate detritus that fuel microbial regeneration. Zooplankton secondary production represents the only route along which the products of phytoplankton photosynthesis flow to the animals that constitute the marine living resources.

Surprisingly, very little about production cycles of marine zooplankton populations is known (particularly in comparison with phytoplankton production cycles). Where algal growth rates exceed grazing rates, blooms develop and where the reverse situation applies, phytoplankton stocks remain small in spite of ample nutrient resources. On an evolutionary time-scale, the advent of physical conditions favorable to algal growth has not resulted in a commensurate response by herbivores. Thus, organic material in excess of the demands of marine zooplankton are occasionally produced by phytoplankton. This phenomenon has great bearing on the uptake of CO2 in surface layers, and its eventual removal via vertical particle flux. Zooplankton life cycles appear to be geared to specific Hydrographic patterns at space and time scales that differ from those of phytoplankton. The connections between the phytoplankton and zooplankton stocks are widely postulated. Yet from long term fishery catch statistics and other records, we know that decadal changes of orders of magnitude have occurred in the major fish stocks of the ocean which cannot be explained merely by fishing pressure. It has been hypothesized that large year classes are uncommon events driven by a combination of favorable interactions of ocean physics and chemistry on the early life history of species, which occasionally magnify the normal, very low survival rates that occur during the recruitment process and vastly increase adult biomass. Exploring these patterns is a major challenge for marine ecology that has acquired a sense of urgency in connection with global change.

The Workshop participants took the above observations as a starting point for their deliberations, conclusions and recommendations, which follow.

1. THE ESTABLISHMENT OF THE WORKSHOP

At the 23rd Session of the IOC Executive Council at UNESCO (Paris, March 1990), the President of SCOR, Professor Jarl-Ove Stromberg, taking account of a proposal from the Guiding Group of Experts of OSLR, stressed the importance of ecosystem dynamics, and invited the IOC to co-sponsor with SCOR a Workshop on Ocean Ecosystem Dynamics. IOC accepted the invitation and the meeting was organized by the Executive Director of SCOR, Elizabeth Tidmarsh, and Senior Assistant Secretary of IOC, Thomas Osborn. Professor Stromberg provided overall guidance and the meeting was chaired by Professor Brian Rothschild, who also acted as host to meeting held in Solomons MD, USA 29 April to 2 May 1991.

The need for the workshop became evident because several countries were in the process of establishing major scientific research programs focused on ecosystems dynamics e.g., BICED (Brazil), ECOMONOC (USSR), GLOBEC (USA), OPEN (Canada). In addition, the IOC determined that its programs on recruitment (SARP and PREP) and Harmful Algal Blooms would benefit from a more complete framework for their studies.

2. THE ROLE OF THE WORKSHOP

The role for the IOC-SCOR workshop was to consider the scientific status of ocean ecosystem dynamics research, and determine whether there is a need for international coordination. The central scientific question for biological and fisheries oceanographers and living resource managers over the coming years concerns climate and its interaction with the physics and chemistry of the oceans to affect and control variability of ocean ecosystems and their component animal populations.

Will a global warming trend over the next few decades and its consequent modification of ocean circulation result in non-reversible ecological changes? Will overall ocean animal biomass and secondary production be adversely impacted? Will major resource species be replaced by others unsuitable for harvesting? Will the structure of marine ecosystems be radically altered, or some, such as coral reefs, be eliminated? What effects would such changes in ocean ecology have, in turn, on the biogeochemical cycles to influence climate, through, for instance, the modification of the CO2 cycle in the oceans?

3. THE WORKSHOP DISCUSSIONS

The central theme which emerged from the workshop discussions is that zooplankton population dynamics is the unique nexus through which phytoplankton production, fish stock, and climatic variation are related. This theme is of paradigmatic importance, since it underpins our view of the dynamics of the entire marine ecosystem and forms the basis of the proposition that **zooplankton population dynamics and ocean physics are directly coupled to control not only the magnitude of secondary production and variability of marine living resources, but also the magnitude and fate of primary production.**

The tendency toward "top down" rather than "bottom up" ecosystem structure is much better accepted in terrestrial ecosystems. Biogeochemists have emphasized primary production and re-cycling as the dominant biological processes in the ocean. In this view, zooplankton population dynamics are merely a result of primary production variability controlled by ocean physics and chemistry. In fact, the reverse is probably more often true that phytoplankton production is controlled by zooplankton population dynamics (through grazing). This is not to say that photosynthesis is not the necessary process at the base of the food chain, but that its magnitude is controlled by, rather than controlling secondary production.

Thus, the conclusion of the workshop was that the role of zooplankton is far more important than generally assumed. Although a lack of sophisticated knowledge of zooplankton population dynamics prevents us from understanding the total contributions that they make to the overall variability of the ecosystem and biogeochemical dynamics, examples offered by workshop participants (see below) support the expectation that their contribution is fundamental and global.

3.1 EXAMPLE 1: THE ROLE OF ZOOPLANKTON IN CONTROL OF ALGAL BIOMASS

In extensive areas of the world ocean, algal biomass is low and macronutrients (as opposed to "trace" nutrients) are high. The only high latitude ocean ($> 40^\circ$ Latitude) experiencing seasonal nutrient exhaustion following a prominent spring bloom is the North Atlantic. A particularly striking example of the role of grazers (in this case, krill) is in the seasonally ice covered waters of the Antarctic. Recent studies have shown that krill overwinter under the ice cover and in spring they enter the meltwater zones where the algae grow and control production. Thus, heavy grazing by the large overwintering krill stock effectively suppresses build up of an excessive algal biomass. The Antarctic meltwater zones display markedly lower algal biomass in spring that those in the Arctic where the zooplankton grazing impact is not mobilized so quickly. In this example the effectiveness of grazing control is an evolved response to the physical environment. Macronutrients remain high in the Southern Ocean.

Pelagic ocean ecosystems are dominated by copepods which have evolved overwintering strategies to provide an early grazing impact in the following spring. In this way the physical environment determines the transfer of biomass from algae to the zooplankton. This depletes the nutrients and increases the chance of nutrient limitation of the algal division rate.

3.2 EXAMPLE 2: THE ROLE OF ZOOPLANKTON IN FISH STOCK VARIABILITY

Since the early seventies, much attention in biological oceanography has focussed on the microbial loop and the picoplankton, with a consequent loss of interest in the "traditional" food chain. Cushing recently proposed that there may be two main ecosystems in the sea - one normally associated with weakly stratified waters and the other where they are strongly stratified. These result in two forms of production cycle (a) spring outburst of temperate seas and upwelling areas of subtropical and tropical seas and (b) the summer production of temperate seas and in the oligotrophic ocean. The fisheries are found in the first form. In the microbial loop, where the thermocline is fully established, there are three levels of grazers, all of which feed on particles less than 5 µm in diameter. Most of the energy is used where it is formed in the upper water column and ends up as ammonia. The "traditional" food chain of diatoms, copepods and fish is associated with weakly stratified water columns. In terms of production the microbial loop out-produces by far the "traditional" food chain. The material produced within the former, however, is microscopic or dissolved.

We know that detailed knowledge of adult fish stocks is, in general, a poor predictor of future adult biomass. A fish population, like all other populations, is sustained by the number of young which grow into the adult population (in fisheries terminology - the recruits). The dynamics of recruitment may well be fixed at a very early age when the young fish are simply one more vulnerable component of the vast array of zooplankton species attempting to eat and not be eaten. Although recruitment may be modified to some degree by the initial fecundity, the physical and biological variability of the ecosystem is strongly transmitted through larval growth and survival. Because the rates of growth and mortality are highest during larval life, the variability of recruitment may well be established then.

This places a somewhat different emphasis on the central question involving grazing versus nutrient limitations. The fact that this question is not understood may very well be the reason for our inability to link fishstock production and primary production.

Thus the Workshop participants focussed on the "traditional" food chain and the-overarching role of copepods in transferring primary production into the macroscopic animal populations that compose the ecosystems and living resources of the ocean. In order to understand the natural fluctuations in ecosystems and to predict the potential for variability with changing climate, it is recognized that we must first understand the processes that control material and energy flow through the "traditional" food chain.

3.3 EXAMPLE 3: THE ROLE OF ZOOPLANKTON IN CO2 DRAWDOWN

While our relative ignorance of zooplankton-phytoplankton dynamics lends point to the proposal for an international research initiative, it is global change which gives it immediacy. Governments and other organizations with a vital interest in the management and optimization of the oceans' living resources face the requirement to predict the future course of events and develop responses to them. In order to do this their scientists must develop the understanding to distinguish between natural and human-induced variability. The latter cannot be predicted without the ability to predict the former. As ecosystems change, they will, in turn, impact the rest of the biogeochemical and climate system. Quantification of the nature of such changes will be sought from ecologists by scientists interested in these feed-back phenomena. The ocean CO2 system, and hence the atmospheric CO2 system and global warming, for instance, will be affected by changes in secondary production.

In the Greenland Sea, CO_2 drawdown reaches a global maximum in the seasonal ice-migration zone from Cape Farewell to Spitsbergen, largely as a result of phytoplankton-zooplankton interactions in the special circumstances which arise from the almost instantaneous onset of "biological spring" as the ice cover rolls back. The factors which promote such a radical CO_2 drawdown are all peculiar to the marginal ice zone and, although model simulations vary on the amount of global warming to expect, they seem agreed that surface temperature increases at more northerly latitudes will be up to several times larger than global average. Thus, the planktonic interactions which promote one of the most important CO_2 sinks in the hemisphere are also among the most vulnerable to global warming, and could even result in the loss of this narrow marginal ice zone. It remains to be demonstrated by measurement what this change will mean to the global ocean sink of CO_2, but it already appears evident that it will act via a change in the effectiveness of grazing.

The Workshop concluded that these examples were typical of the scientific problems to be faced during the next decade. To move ahead it will be necessary to develop the theory, modeling, and sampling techniques that permit a more comprehensive view of ocean ecosystems in the context of the interaction between population dynamics and ocean physics.

4. THE WAY FORWARD

Currently planned and implemented Ocean Global Change programs (see Annex II) are oriented towards understanding the effects of large-scale ocean physics and carbon flux on climate modification. What is missing is an understanding of the role of short-term variability in the system. For instance, it was recently shown in the JGOFS North Atlantic Bloom Experiment that about two-thirds of the total annual primary production at a single station occurred within two weeks. It has been hypothesized that the timing of such sharp production events are closely correlated to success or failure of year classes of larvae of major fish stocks, and in turn their extreme adult biomass fluctuations on decadal time scales. We need to know much more about the natural causes of biological variability in the ocean in order to understand the overlying long-term changes being caused by human-induced global climate changes.

What is also missing is an understanding of the contribution of the population dynamics of the zooplankton to overall system variability. We know, for instance, that virtually every major predator, including those constituting the living resources of the oceans, depend on copepods and other zooplankton for their food at some stage (if not all) of their life cycle. Every copepod species has a complex life cycle and grows through several orders of magnitude in biomass during its lifetime, which may take days to years. To date, we have no well-accepted methodologies for estimating the production of copepods in the field, nor even the ability to routinely estimate population biomass in anything near real time.

The way forward requires a complex of activities. First we need to better understand how population variability is propagated and suppressed. This cannot be approached without an understanding of the dynamics of the various populations that comprise the ecosystem. In turn these cannot be understood without a knowledge of the physical driving variables. By developing an understanding of the dynamics of the animal populations, particularly the critical connecting links through the zooplankton, we will be better able to predict, for instance, large year classes of fishes, the fate of coral reef ecosystems, changes in metabolic pathways resulting from anthropogenic inputs, and biological influence and/or feedbacks to climate.

The Workshop participants defined the Goal of an International Program on Global Ocean Ecosystems. This is: To understand the effects of physical processes on predator-prey interactions and population dynamics of zooplankton, and their relation to ocean ecosystems in the context of the global climate system and anthropogenic change. An international program for global ocean ecosystems research (GLOBEC) will: improve understanding of the relationship between primary production and variability of fish stocks and other living resources, as controlled through the mediation of the zooplankton; quantify the influence of zooplankton on biogeochemical cycles, through grazing control of the phytoplankton; lead to advanced utilization of acoustic, optical, and image-identification in sampling technology to measure the time-space distribution of plankton on biologically critical scales; lead ultimately to a capability to model and predict ocean ecosystem dynamics on regional and global scales.

It was also agreed that there are two fronts upon which it is vital to advance in order to develop a largescale international program to understand the effects of physical processes on predator-prey interactions and population dynamics of zooplankton, and their relation to the global climate system and anthropogenic change. These are in (1) sampling technology and long time series and (2) theoretical approaches and modelling. Advances on these fronts will form the necessary foundations and long-term context for new large-scale field oriented process studies designed to understand the great ocean ecosystems of the world.

5. WHY AN INTERNATIONAL PROGRAM?

The participants in the workshop recognized that a proposal for a new international effort in oceanography must be seen in the context of existing global change research programs already under way and which are straining the resources available to the oceanographic community. Any new initiative must, therefore, respond to a widely accepted scientific need and must complement, rather than compete, with existing activities. The participants believe that the time is right for such an initiative. The International Program for GLOBEC will represent a timely and well-founded response to this need.

It is timely to address questions of the physical-biological interactions in marine ecosystems. Programs already under way, such as TOGA, WOCE and JGOFS, are addressing the physical and biogeochemical responses of the ocean to global climatic change. JGOFS, which focuses on the oceanic carbon cycle and primary productivity, requires improved understanding of the coupling between phytoplankton and zooplankton, population dynamics and biological variability. A global ocean ecosystems dynamics program will provide just such a complementary effort.

The results of GLOBEC will be of interest to a large number of countries, particularly those with a heavy dependence on living marine resources. Improved predictive capabilities resulting from GLOBEC will assist in the provision of scientifically sound basis for policy and management decisions. The scientific goals of GLOBEC outlined above demand an internationally coordinated effort for the following reasons:

An international program will provide a commonly accepted intellectual framework for dealing with issues of global concern. This framework will permit a common base upon which to build and extend national programs. Additionally, it should provide impetus to create new national efforts where none presently exist. Implicit in the formation of an international program is the understanding that the problem under study is either too large or too complex for any one national effort. Cooperation and integration of many disparate groups ensures greater geographical coverage, more resources (both human and material) and greater potential for the successful development of technological innovation required to successfully achieve the stated goals. It also provides a means of developing agreement on necessary constants such as a set of universal measurements, associated protocols and policies on data submission and sharing.

Given the diversity of physical and biological environments, the comparative analysis of varied ecosystems is an integral component of a global program. Individual national studies, within an international framework can provide both parallel and serial efforts, hopefully leading to greater clarity in the search for general principles.

6. OTHER CONSIDERATIONS

6.1 SAMPLING TECHNOLOGY

Science progresses through the unending cycle of observation and theoretical development. A major impediment to maintaining the cyclic progression towards more refined, informative, and predictive theory is the fact that present observational or sampling devices generally depend upon 19th century technology (towed nets and microscopic identification). This is extremely labor intensive and consequently few long time series exist. Data sets such as the Continuous Plankton Recorder, Station P. and CALCOFI are notable exceptions. For phytoplankton biomass the situation is currently much further advanced, where modern satellite and in-situ optical techniques offer potentially continuous sampling and real-time analysis.

Improvements and new developments in zooplankton sampling systems are only slowly emerging, but promise to provide new data on population levels and their distributions. For example, a multi-frequency acoustic profiler system (MAPS) in conjunction with net samples for ground truth, produced a transect across the Irish Sea that relates the backscattered acoustic signal to the relative concentrations of different zooplankton. The advantage of such a system is the potential for real-time analysis. Such measurements give a deeper appreciation of the spatial variability and a better measure of the spatia' coherence between species.

There are optical systems capable of identifying fish larvae, zooplankton, and even some phytoplankton. These developments enable studies of patchiness and the coincidence of predator and prey with detailed knowledge of the relative concentrations as a function of time. In addition, information on feeding and predation rates is crucial to modelling population growth and mortality. Recent advances in biochemical and molecular biology show great promise for transfer to biological oceanography. For example, the RNA/DNA ratio indicates the nutritional condition of fish larvae. Techniques have been developed to assess food sources from chemical tracers in stomach contents. Automation of these techniques to speed processing and reduce the labor involved is necessary.

In order to make progress in developing new technology the Workshop participants agreed that specifications needed to be drawn up. The first criterion regards size range. After much discussion it was agreed that as a first approximation, the size range of 5 μm to 5 cm should be set as a goal. The rationale was that the lower end of the range encompassed most of the autotrophic and heterotrophic biomass which would be at the base of the "traditional" food chain (see above) and not that of the re-cycling microbial food chain. The upper end of the range encompassed all but the largest adults of what are usually defined as the zooplankton or micronekton. Within this size range most grazing and most acts of predation would occur.

It was recognized that no single technological device was likely to be capable of dealing with the entire range but that possibly a combination of acoustic and optical technologies might provide the solution. The appropriate mix of technologies would of course be defined by the problem at hand. A draft report of the Technology Working Group of U.S. GLOBEC was brought to the attention of the participants and its conclusions studied. In developing new technological approaches to sampling, it is important to keep in mind not only the short-term fine scale measurements needed for process-oriented field experiments, but also the requirements for large-scale long time series or monitoring programs.

Historically a portion of this information has been provided by the Continuous Plankton Recorder (CPR) over a portion of the North Atlantic. For a program on predator/prey interaction, centered on zooplankton, the CPR Program can provide relevant information:

(i) pan-oceanic coverage,
(ii) temporal (1 month) and spatial (10 mile) resolution,
(iii) historic context (30 to 60 years), and
(iv) robust technology.

The CPR, however, falls short of meeting some needs of a modern program envisaged by the workshop participants in that it:

(i) does not sample the smallest size fraction (5 micron nauplii, 20 micron dinoflagellates) that are central,
(ii) does not sample the larger size fraction associated with predators such as ctenophores, salps, etc.,
(iii) samples at a fixed depth of 10 m and the relevance of changes at that depth to the total euphotic layer is unknown,
(iv) is time consuming in analytical effort, and
(v) lacks concomitant environmental data.

Preservation of the continuity and integrity of the present data set, as well as the development of substantially increased capabilities are crucial. A new and expanded program must be developed and calibrated in conjunction with the present survey in order to respond to societal needs.

Some of these developments are already possible. Some are not. Of the "possible" one significant improvement readily available:

i) a wider geographic coverage by the existing system. A more global coverage by large regional monitoring efforts is possible now.

Other possible improvements are:

ii) Undulating oceanographic recorders are now relatively available with a suite of useful sensors in place - optics, bioluminescence, nitrate (under development), and
iii) other environmental parameters relevant to stratification (T,S, etc.), and Some proxy measure for dinoflagellates are already available (e.g. bioluminescence) and the CPR already quantitatively captures the larger dinoflagellates whose response to environmental change may be representative of smaller forms.

However, new technological developments are undoubtedly necessary. It is possible to see "Autosub" and other developments becoming the CPR Program of the future.

The workshop endorsed the belief that present transition period for the CPR program needs to be supported while a new system with enhanced capabilities is developed to provide a global ocean observing system for plankton for the next fifty years. Ultimately, it should be secured within existing intergovernmental frameworks for administering large marine programs.

6.2 MODELLING AND THEORY

The question of problem identification is intimately related to theoretical development. The theory will need to be focussed upon the propagation of population variability. A first step in understanding population variability involves understanding the interrelationship between the dynamics of the populations that comprise the ecosystem and the physical forcing factors.

To move ahead it is important to place in perspective the kinds of models or explanations that have structured our information base. In this regard, a distinction was made between kinematic and first-principle models. Kinematic models are oriented toward accounting for observations of the natural world, while firstprinciple models use first principles to "predict" real-world system dynamics. Many of the models used in biological oceanography are based upon kinematics rather than on first principles and dynamics.

It is not easy to develop system dynamics models particularly of highly aggregated components and those with complex life history stages. Nevertheless it is doubtful that models that do not take explicit account of physics interacting with detailed population dynamics can result in major advances in understanding variability. For example, it was shown that there is critical variability in copepods whose life history stages consist of six naupliar five copepodite, and an adult stage, each involved with a different mix of predator and prey. Variability and understanding is masked by treating all members of the population(s) as a single variable.

In addition, the variability in copepod populations is intimately bound with their feeding behaviors and the interactions of physics on the fine scale. Most copepods feed on algal cells which detect and select in the immediate few millimeters of water that surrounds them. They are armed with chemo- and mechano-receptors in order to detect the range and direction of the cells. These cells are picked out of the water with a complex behavioral mechanism. The processes of detection and capture depend entirely upon the local physics. The physics of grazing is a difficult but essential problem that requires much more sophisticated investigation.

7. THE NEXT STEP - WORKSHOP RECOMMENDATIONS

The Workshop participants agreed to the following recommendations. This Workshop recommends:

A. to its sponsoring organizations that they agree to jointly organize an international Global Change Program on Global Ocean Ecosystems Dynamics Research and Monitoring (GLOBEC) which will provide a coordinating framework in which an international science plan can be developed, which takes into consideration ongoing national planning activities. The science plan should form the basis for the implementation of a global-scale research and monitoring program to accomplish the objectives enumerated below;

B. that SCOR and IOC should invite other interested international agencies to participate, particularly those regional bodies (e.g. ICES, PICKS) with known programs or interests in the ocean ecosystems dynamics and global change;

C. that SCOR should propose to its parent body (ICSU) that a programme in Global Ocean Ecosystems Dynamics become established as a Core Project of the International Geosphere/Biosphere Programme to complete its suite of Global Change studies;

D. that IOC should adopt this joint program as its proposed new initiative Ecosystems Dynamics and Living Resources component of Ocean Sciences and Living Resources (OSLR);

E. that, in the meantime, until SCOR and IOC governing bodies can convene to discuss these proposals, the workshop participants should continue their activities on behalf of SCOR and IOC over the next year, under the continuing chairmanship of Professor Rothschild, as an interim ad hoc international planning committee;

F. that this ad hoc international planning committee should consider a series of potential activities in connection with a global ecosystems dynamics program and report on an order of priorities to SCOR and IOC. The potential list of activities are:
   - (i) develop the strategy to focus on zooplankton population dynamics in a trophodynamic and physical setting;
   - (ii) develop models that integrate fundamental biological and physical processes;
   - (iii) facilitate the proper specification of physical models from the GCM scale to the regional scale, so that the models can be linked;
   - (iv) develop an overall strategy for defining research projects, selecting study sites, trophic levels, species, etc;
   - (v) identify "core" elements of the international program, to be included in each regional study;
   - (vi) consider a strategy for long-term monitoring of appropriate scales to observe global change and test predictions from regional models;
   - (vii) evaluate technology needs;

(viii) consider the generic problems of sampling and experimental design;
(ix) facilitate communication and review progress;

G. in order to accomplish these aims the ad hoc international planning committee should convene as required (incorporating additional members from other countries not represented as they can be identified), and also form working groups in the areas of (a)theory and modelling, and (b)technology and long term monitoring. Some of the initial terms of reference for these working groups appear as Annex I.

ANNEX I

TERMS OF REFERENCE OF WORKING GROUPS

1. TECHNOLOGY AND LONG-TERM MONITORING

The Working Group on Technology and Long-term Monitoring should take as its initial Terms of Reference the following.

Progress in understanding predator-prey interactions requires new capabilities to sample and observe organisms in relation to their environment. Sampling/observing systems must be designed to meet needs of specific programs or projects, at both national and international levels. Sampling/observing systems need to:

- Count organisms and determine their size frequencies;
- Determine rates of growth, mortality and reproduction;
- Observe organisms (optically, acoustically), their interactions and relationships in the context of their environment;
- Sample and capture organisms;
- Discriminate taxonomic groups, possibly using their biochemical characteristics; and\
- Determine age and physiological condition of organisms.

Systems will be required to deal with individual organisms and with populations of organisms over a wide size range (5 microns to 5 cm). Many observations will be made over long times (weeks) and space scales (kilometers). Some measurements must be made with high resolution in time and space. Sampling/observing Systems will require:

- New sensor development (or improvement)
- Integration of new and existing sensors
- Integration of sampling/observing systems with data/information-handling systems
- An international structure to develop acoustical and optical instrumentation International intercomparisons

The Continuous Plankton Recorder (CPR) should be updated. It has been "saved" for three years, but a new international funding mechanism must be developed and work must begin on a modern replacement and augmentation of the system.

2. THEORY AND MODELLING

The Working Group on Theory and Modelling should take as its initial terms of reference the following:

- Models, especially those that focus on zooplankton as the vital transmission link should be developed. A physical model should be linked to the photosynthesis algorithms further to a physics-zooplankton model to describe the algal mortality due to grazing. This combination would be followed by a higher predator model to describe the changes in the populations of phytoplankton and zooplankton properly.
- Modelling, data assimilation and data interpretation will require significant effort. Both ecosystem models (energy, carbon, nitrogen,etc) but also the more novel approach to a grazing model using behavior etc sa well as the population dynamics secondary ion. A joint workshop on modelling and instrumentation could focus on the problems of making models appropriate for the measurements and vice-versa.
- Many developing countries are interested in local ecosystem modelling to increase technical capabilities, assist fisheries management, and to guide aquaculture. From an IOC perspective these are important aspects.
- Call for international support in developing, testing, and using ecosystem models for local fisheries management.
- Develop physical models at scales relevant to zooplankton dynamics. These will range from basin to microscale. The development of these models will entail examination of existing models to determine how they might be useful and a systematic determination of those areas that might be most fruitful for future work.
- Develop zooplankton population dynamics model(s) for use by the scientific community." This would involve reconciliation of existing models and identify needs for the future. Such models could be developed in their own right while serving as a basis for conducting research by non-specialists in population dynamics.
- Develop models of zooplankton population dynamics and their interactions with their food and predators, as influenced by physical oceanographic processes. To do this the group should report within one year on appropriate models and techniques that may be used;
- In the report, propose a plan of action to develop models over a realistic period, and select case studies to validate models;
- Cooperatively develop the models at over the range of physical and biological scales, from the micro-scale physics of grazing to the meso-scale; and
- Suggest experiments and field studies to validate models - Consider data/needs and technology needed for the validation.

ANNEX II

A REVIEW OF CURRENT STATUS OF OCEAN-RELATED GLOBAL CHANGE PROGRAMS

The science communities representing the disciplines of atmospheric and ocean climate and circulation, and ocean biogeochemistry have been planning, and in some cases embarking on field observational programs on the global physical and chemical interconnections which drive ecosystem and population change. Much of the information biological oceanographers and resource managers will need will be generated over the next 10 or more years, and a substantial part of the basis of the necessary models will also be in place. Equally importantly, the computing resources needed to integrate biological parameters into models of circulation and biogeochemistry will become readily available through technology advances.

Other disciplines have not been slow to recognize the enormity of the research challenges facing them. One of the first planning efforts, born out of the very strong El Nino of 1982-83, was the TOGA (Tropical Ocean - Global Atmosphere) Program. This program, an international effort to identify the role of the coupling of tropical ocean and atmospheric dynamics on the interannual variability of global climate and weather, is already half-way through its ten-year implementation phase. Scientists expect that, by the year 2,000, it will be possible to predict the occurrence and strength of El Nino phenomena accurately enough to provide forecasts of the ensuing regional ocean physical dynamics, and in turn the distribution and biomass of populations as far north as Alaska in the Pacific and on the coral reefs in the Atlantic.

WOCE, the World Ocean Circulation Experiment, in planning for a decade has, as its goal, to obtain a "snapshot" of the world ocean circulation now, which would provide a baseline with which to compare future changes. In doing so, the massive amounts of oceanographic and satellite-based data will be used to greatly improve the precision of regional and general circulation models.

The prospect of the ocean being called upon to receive greatly increased loads of CO2 and other gases prompted the initiation of the JGOFS (Joint Global Ocean Flux Studies) Program. The mechanisms and rates of movement of carbon dioxide from the atmosphere into the ocean, its long-term deposition in the ocean sediments or return to the atmosphere are largely unknown, yet vital to computations of potential global warming. These processes are intimately bound with the activities of the ocean biota. Because the JGOFS program is primarily interested in mass balances and fluxes of biogenic gases, it has chosen to focus on the variability and control of primary productivity - the input term -for atmospheric CO2 and the vertical transport and transformation of subsequently produced biological particulate detrital material.

Within the IGBP framework for A Study of Global Change - Initial Core Projects (IGBP Report no. 12; 1990) two other potentially relevant programs are described. Under the heading Ocean Biogeochemical Processes is GOEZS -Global Ocean Euphotic Zone Study - as a potential Core Project. It is being designed as a "next generation" project to follow and built upon WOCE and JGOFS jointly, and to focus on physical mixing processes in relation to upper ocean primary productivity. The second program is LOICZ - Land-Ocean Interactions in the Coastal Zone - and is designated a proposed Core Project. Although specifically concerned with land/sea interactions within the coastal zone, is more specifically related to ecosystems dynamics and the potential for alterations through climate change and the effect on human populations.

Taken as a whole, the resources which are being set aside for these programs by governments are an indication of the immense amount of research of potential relevance to ocean ecosystems dynamics which will be forthcoming. In the U.S. alone the projected outlays amount to over $50M in FY 1991, rising to over double that within five years. International governmental and non-governmental organizations like the Intergovernmental Oceanographic Commission (IOC), the World Meteorological Organization (WMO), the International Geosphere/Biosphere Program (IGBP) of the International Council of Scientific Unions (ICSU), and its scientific committees such as that for ocean sciences (SCOR), have helped to forge successful planning and implementation activities for these programs. To date, there does not exist any comparable international organization for research on the impact of global change on ocean ecosystems.

It is time to organize a concerted international program to make use of the massive influx of data and models on how the ocean works which will be forthcoming from programs like WOCE, TOGA and JGOFS. We must apply it to understanding how ocean ecosystems work, and how they will change.

ANNEX III

THE ICES COD AND CLIMATE CHANGE PROGRAM

The initiative to an international study on how climate variability and climate change influence the Atlantic Cod stocks was taken during the ICES statutory meeting in the Hague in October, 1989. The result was that ICES Study Group on Cod Stocks Fluctuations was established. A part of this group met in Bergen in January 1990 and outlined the problem. The Study Group presented their report "Cod and Climate Change - A Framework to the Study of Global Ecosystem Dynamics" at the ICES Statutory Meeting in Copenhagen in October 1990. The Study Group outlined that the problem should be met by organizing a hierarchy of models where large scale circulation models, describing the large scale climate, give the boundary conditions for regional physical models, and biological and physical process models are linked to regional physical models. The Study Group was asked to proceed in 1991 to work out an implementation plan for the Cod and Climate Change Program.

The goal of the Program is to investigate how climate fluctuations and climate change influence reproduction, growth and mortality of cod directly and through its predators and prey. In particular, during the planktonic stages of cod, when the year class of strength is determined, the interaction with zooplankton (and in particular the copepods) is important. Copepods comprise the main prey organisms for larvae and early juveniles. Little is known about the predators of the early stages of cod, but it is strong reasons to believe that the main predators on cod larvae is also found among zooplankton species. In spite of that, the biology of cod is more investigated than any other fish species. The processes that determined the year class strength is not substantially more understood than for other species. Therefore, the future focus of recruitment studies should be moved in the direction of zooplankton population dynamics.

We have evidence of that climate parameters have a substantial influence on recruitment within major cod stocks. The climate parameters partly influence recruitment directly, as for example through temperature dependent growth rate of larvae. However, probably at least equally important is how climate influences production and advection of zooplankton.

ANNEX IV

NATIONAL PROGRAMS

1. BRAZIL

ECOSYSTEM DYNAMICS INITIATIVE IN BRAZIL (BICED) In order to understand the structure and dynamics of tropical coastal ecosystem, an integrated oceanographic investigation was started in 1985 by the University of Sao Paulo at a coastal region near Ubastuba (24°S). During last four years, intensive sampling has been carried out in this region by groups of researchers from different specialties. One of the objectives was to investigate an interaction among physical, chemical and biological components and to study energy flow in the coastal ecosystem. Many new findings on dynamics of ecosystem have been obtained. The project will be concluded at the end of 1990.

2. CANADA

OCEAN PRODUCTION ENHANCEMENT NETWORK (OPEN) is a network of university, industry and government scientists whose objective is to provide the information base necessary to enhance the competitive position of Canada's fishery industries. OPEN will bring together the country's best fisheries biologists and oceanographers in a unique integrated research program. The initial focus of the program will be on two species which are of great commercial value: the sea scallop (Placopecten magellanicus) and Atlantic cod (Gadus morhua). Using these species as models, scientists will investigate the processes which control the survival, growth and reproduction and distribution of fish and shellfish. OPEN is organized around the concept of fisheries as ecological production systems. The research program will bring together biological and physical oceanographers as well as physiologists and geneticists in a uniquely integrated program that will focus on the interactions between organisms and their physical environment. The program consists of thirty eight projects which are linked to six major research themes.

3. CHILE

In Chile, the National Committee of IGBP organized a workshop (January 1990) to assess the potential impact of climate change on terrestrial and marine ecosystems. With emphasis on the prediction of changes in the distribution and availability of agricultural and hydrological resources. A second workshop convened by E.Frientes and H.Mooney (December 1990), sponsored by the AAAS, the U.S. NAS and the Chilean Academy of Sciences, in conjunction with the National Committee of IGBP, concentrated in the comparative analysis of terrestrial and marine ecosystems between North and South America, with the purpose of identifying processes that by being particularly sensitive to global change, could benefit of bi-hemispheric joint studies. As a result of these activities, a project got started with the purpose of starting a small network of stations in charge of generating coastal time-series of temperature and chlorophyll along the west coast of South America, in order to perform an integrated analysis with the 19 coastal stations monitored by Scripps Institution of Oceanography in California.

4. FRANCE

Aside from France-JGOFS program under which some process studies are designed to study flux of matter in the sea, other programs ARE area and species oriented. The objective of the PNDR program is to understand the biological and physical mechanisms controlling the fluctuations in abundance of stocks and the population dynamics of some target species. Target species are either exploited by man (Flat fish, scallops, cockle) or not (polychete worms, sea urchin, copepods).Whole life cycles are taken into consideration in the hydrodynamical environment of specific areas. A second program is considering blooms of harmful phytoplankton species. The principal species studied are dinoflagellates. Spatial distributions, physiology, cultivation techniques, toxin development are the main objectives. This program involves about 10 laboratories (IFREMER and universities). It is funded by different governmental agencies and IFREMER.

5. GERMANY

Most of the ongoing ecological esearch programs are being conducted within the JGOFS framework and are focused on biological processes governing vertical flux. The study sites are the central N. Atlantic, the Arctic (including Greenland, Norwegian and Barents areas) and the Weddell Sea in the Southern Ocean. In all these studies, much effort is concentrated on the role of zooplankton (protozoa and metazoa) in vertical flux. These biological programs are closely linked with studies conducted by other disciplines, in particular paleoclimatology (sedimentary geology) and oceanography. WOCE and JGOFS studies in the Weddell Sea are being carried out in close collaboration. In addition, international programs studying biological processes at the ice edge (EPOS = European "Polarization" Study) have been particularly successful in the Weddell Sea and are being continued in the Arctic. Monitoring and process oriented studies are also conducted in coastal waters of the North and Baltic Seas aimed at ascertaining the impact of eutrophication in these waters. The investigation of recruitment of commercial fish stock is being conducted on sprat in the North Sea and such studies have been conducted in collaboration with South American countries along the caster shelf of South America.

6. JAPAN

Fisheries oceanographers in Japan have long been interested in the long-term variations of fish stocks and fishing conditions. Hence, eggs and larvae surveys of main pelagic fishes nave been monitored for more than 40 years. However, as ecodynamics of the recruitment have not been well investigated, the Fisheries Agency determined to conduct BIOCOSMOS Project of ten years to make clear the mechanisms which control the variability of the Pacific Sardine (Sardinops melanosticta). Besides these Sardines research projects, Japan/Canada Cooperative study on marine science, is conducted by Hokkaido National Fisheries Research Institute, to one of those focus is variations in marine environment and secondary production dynamics in the Oyashio and the Labrador Current based on WOCE and JGOFS funds. Future Plans include research projects on the population dynamics of pelagic and demersal fishes is under planning by the fisheries oceanographers and biologists in the University of Tokyo and Hokkaido University, etc., where international collaborations are expected under international GLOBEC Project. Comparative fisheries ecosystems studies including secondary production between the high, mid and low latitude areas and comparison between the ecosystem in the eastern and western boundary regions of the Pacific will also be very useful in discriminating the complicated systems including their long term variations.

7. NORWAY

PRO MARE (Program on Arctic Marine Ecology up to 1990) and MARE NOR (Program on Coastal Ecology of northern Norway, 1990 onwards). PRO MARE focused on the ecodynamics of how the melt water close to the retreating ice border in the Barents Sea gives rise to the production of phytoplankton, how it is grazed down by zooplankton and how capelin feed on the zooplankton. It consisted of field investigations in open waters and under the ice, and a numerical model of the dynamics of ice melting, phytoplankton production and zooplankton grazing was made. MARE NOR is a 3-year program based on the experience of PRO MARE. Other related activities include reproduction strategy in Arcto-Norwegian Cod, influence of age, size and condition of female spawners on the quality of eggs and larvae, and influence of turbulence and light on the encounter rate between cod larvae and their prey.

8. SOUTH AFRICA

South African Marine Research Ecosystems Programmes commenced in 1975 with the kelp bed project (1975-1982) which resulted in building an energy budget for a kelp bed in the Benguela current, followed by dynamic simulation models of carbon and nitrogen flows and the influence of upwelling/downwelling on the functioning of the food web. The Benguela Ecology Programme (1982-1991) aims at providing fundamental scientific understanding of physical and biological processes leading to fish production, with the emphasis on pelagic fish such as anchovy. Hake and rock lobster are also included. The ten year programme will culminate in an international symposium in Capetown in September 1991. The Benguela Ecology Programme is to be succeeded by a Marine Boundary Processes programme (1991-1996) which will also be a collaborative effort between the Sea Fisheries Research Institute and universities, national and private funding bodies. Effort will be concentrated on the physical and biological processes that occur at and across boundaries such as the shelf-edge front, thermocline, sediment- water, air-sea, and land-sea interfaces, with the emphasis on how these processes lead to fish production.

9. SWEDEN

Although Sweden does not have a GLOBEC-type programme as yet, it plans to take part in the Nordic WOCE exercise work of Iceland. Some components of JGOFS are being planned as parts of an Arctic cruise in 1991, on board the Swedish ice-breaker, the "Oden." Another part is planned in cooperation with Chilean scientists to cover an eastern boundary current situation between Easter Island and the Chilean coast. Ongoing Programmes include, i.e. SKAGEX, a study of ocean dynamics in the Skagerrak-Kattegatt area, which is an ICES undertaking with 10 participating nations. Another programme deals with the Bothnian Bay (of the Baltic Sea) comprising an extensive Swedish-Finnish cooperative investigations on physics, chemistry, and biology of this brackish water body. The programme starts in 1991 and will continue through 1992. Extensive monitoring of coastal waters has been carried out both in the Baltic and on the Swedish west coast over a long period (close to 20 years).

10. U.S.A.

U.S. GLOBEC (GLOBal ocean Ecosystems dynamics) is a research initiative is organized by the oceanographic and fisheries communities to address the question of how changes in global environment are expected to affect the abundances and production of animals in the sea. The approach is to develop a fundamental understanding of the mechanisms that determine both the abundance of key marine animal populations and their variances in space and time. The physical environment is a major contributor to patterns of abundance and production of marine animals, in large part because the planktonic life stages typical of most marine animals are intrinsically at the mercy of the fluid motions of the medium in which they live. Consequently, a logical approach to predicting the potential impact of a globally changing environment is to understand how the physical environment, both directly and indirectly, contributes to animal abundance and its variability in marine ecosystems. The Core Science Theme of GLOBEC is The Coupling of Physical and Biological Systems.

11. USSR

PROGRAMME ON INTEGRATED STUDIES AND MONITORING OF MARINE ECOSYSTEMS EXPOSED TO ANTHROPOGENIC IMPACT AND GLOBAL CLIMATIC CHANGE (ECOMONOC) The main goal of the Programme ECOMONOC is the long-term studies of marine ecosystem dynamics in various geographical zones of the World Ocean and assessment of man- induced changes in marine ecosystems exposed to global climatic change. The tasks of the Programme include: (1) Investigations of biogeochemical pollutant cycles and contaminant distribution mapping; (2) Assessment of the ecological consequences of the World Ocean Pollution in various geographical zones; (3) Assessment of the assimilative capacity in the key regions of the World Ocean; (4) Investigation of carbon biogeochemical cycle elements in the ecosystems of the World Ocean and determination of its role in global climatic processes.

ANNEX V

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