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GOOS Planning Workshop for Living Marine Resources

Prepared by the Scientific Committee on Oceanic Research of ICSU for J-GOOS

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EXECUTIVE SUMMARY

The Planning Workshop for the Living Marine Resources Module of the Global Ocean Observing System (LMR-GOOS) was convened at the University of Massachusetts Dartmouth, 1 to 5 March, 1996 in order to initiate the scientific planning for the LMR-GOOS module, building on the groundwork laid by the First Session of the *ad hoc* Panel for the Monitoring and Assessment of Living Marine Resources (Costa Rica, December 1993).

The workshop considered:

- the scope and objectives of the LMR module
- the user needs for LMR
- present and potential observational capabilities
- methods for modelling and data assimilation
- implementation of LMR
- capacity building

The conclusions and recommendations of the workshop on these issues are summarized in Sections 8 and 9. The workshop specifically recommends that J-GOOS establish a Panel for LMR-GOOS and proposes revised and updated Terms of Reference for the Panel (see Annex VIII).

This report is intended to be comprehensive and includes previously unpublished background documents on LMR-GOOS (Annexes VI and VII) and a bibliography. Annex X gives definitions of the acronyms and abbreviations used in the report.

1. INTRODUCTION

At the request of the IOC/WMO/ICSU Joint Scientific and Technical Committee for the Global Ocean Observing System (J-GOOS), the Scientific Committee on Oceanic Research (SCOR) convened a workshop on the scientific planning for the Living Marine Resources Module of GOOS (LMR-GOOS) which took place at the University of Massachusetts Dartmouth from March 1-5, 1996. This document results from the deliberations at the workshop and is to be transmitted to J-GOOS for its third session (April 1996) as the basis for more detailed LMR-GOOS planning. The workshop was Chaired by Professor John Shepherd (UK) and was attended by 17 participants (see Annex I). Dr. Nic Flemming (UK) and Ms. Elizabeth Gross (SCOR) served as Rapporteurs for the workshop. The Agenda for the workshop appears in Annex II.

2. SCOPE AND OBJECTIVES OF THE LMR-GOOS MODULE

The Living Marine Resources Module is one of 5 Planning Modules established within the Global Ocean Observing System. The others are:

- Climate Monitoring, Assessment and Prediction
- Monitoring of the Coastal Zone Environment and its Changes
- Assessment and Prediction of the Health of the Ocean
- Marine Meteorological and Oceanographic Operational Services.

Specifically, LMR-GOOS is intended to identify user requirements for oceanographic data on living marine resources, and to give advice on the design and implementation of the observing system. The implementation of GOOS will be integrated so that observations are obtained in the most efficient manner, pooling the requirements of different Modules, and sharing the costs of observing platforms and communications infrastructure.

The scope of the LMR Module is dictated by the need to obtain data and make predictions about living resources of the ocean and coastal seas which meet the economic, social, and environmental needs of society. This need is urgent given that global fish landings are calculated to be near the theoretical maximum that can be taken from the sea on a sustainable basis (Pauly and Christensen 1995), and the reasonable prospect that the biological carrying capacity of the world's oceans will decline as a result of anthropogenic stresses and related climate change. Thus, LMR-GOOS will provide a framework and specification for an adequate package of observations and research to understand and forecast major changes in the abundance and/or production of critical living marine resources over time scales of years to decades and beyond arising from changes in the carrying capacity and/or health of the ocean.

In general terms the objective of the LMR-GOOS Module is to design and implement a system of observation, data assimilation and modelling to monitor and predict the state of the marine ecosystem at regional and global scales, especially emphasizing those features of the living marine resources that are of economic, social and environmental importance. Specific aims include the observation, monitoring and prediction of:

i. ecological variables at trophic levels that underpin exploitable marine resources, particularly primary and secondary biological production;
ii. sustainability of critical marine habitats;
iii. regime shifts and changes in recruitment to fish populations;
iv. changes in marine biodiversity;
v. information relevant to the conservation of genetic resources; and
vi. impact from anthropogenic stress on the health of marine ecosystems including, but not limited to, the occurrence of toxic algal blooms.

In declaring these objectives, the workshop participants were aware that the last three will be shared with other GOOS modules, especially Coastal-GOOS and HOTO-GOOS, and that it would be inappropriate to develop these much further without adequate consultation among the planning groups. Accordingly, they have been identified here for completeness but largely set aside. Instead, the working group concentrated on those phenomena that were considered unique to the LMR module, especially that of oceanic production sustaining exploited living marine resources.

GOOS observations to meet LMR objectives will require monitoring of critical components of pelagic food webs from bacteria and phytoplankton to herbivores, carnivores and top predators. LMR must encompass a range of spatial scales from global down to ocean basin, regional, and local. The global approach is required because of the global scale of processes such as changes in ocean basin circulation, climatic teleconnections, and changes in through flow in critical straits, which may all impact on the biota. The regional and local focus is required because there are common processes in coastal waters and shelf seas which would benefit from consistent and standard monitoring so that changes can be observed and detected in a coherent manner. LMR observations must be collected over long temporal scales because the greatest system changes occur over decades and longer (Steele 1985); however, there will also be a need to monitor some changes more frequently (annually and sub-annually) in order to capture transient events responsible for substantive change in living marine resources (e.g. recruitment to fish stocks and regime shifts).

In designing a global observing strategy for LMR variables, the proposed Panel should note that at present the tropical regions are much less intensively observed and monitored than the mid-latitudes, especially the northern hemisphere. A globally balanced system will have to correct this.

2.1 Global Scope of LMR

Many aspects of the biology of the ocean and the interconnected shelf seas tend to be related on very large scales. There are atmospheric teleconnections that extend over basin and sub-basin scales in the ocean; surface and subsurface flow connects many parts of the ocean on various time scales, and some assemblages of algae and zooplankton have trans-basin distributions. The important point in advancing the LMR concept is that some local or regional variations might only be explained by examining events distant in time and space. The existence of LMR-GOOS provides the opportunity of taking account of large-scale spatial and temporal interconnections.

GOOS is a global system that is being designed to obtain data from all parts of the global ocean which have been identified as influencing the outcome of models and predictions. The observation scheme does not have to be uniformly intensive over the whole ocean, but all relevant variables must be measured in those areas which, if they were omitted, would reduce the accuracy of nowcasts and forecasts below acceptable limits.

Observations will be carried out from remote sensing satellites, aircraft, ships, moorings, drifting buoys, sub-surface drifters, AUVs, and seabed installations. Satellites and aircraft provide large scale connectivity for some variables with near synopticity. Ships, towed systems, undulating vehicles and AUVs provide further connectivity on a regional to local scale. Buoys, moorings, and drifters provide global synopticity and time series without connectivity. The technology required by LMR is discussed in Section 4.

The global scale of LMR is essential because many significant processes and events are decadal in time scale and ocean basin or larger in space scale. For example, variations in the Indonesian through-flow can affect the coast of East Africa several years later. Changes in biological regimes take place over years to decades, with space scales and teleconnections over thousands of kilometers. These events and changes can only be monitored and detected if the framework of LMR-GOOS is global. Nested models will then provide the predictions of fluxes and exchanges between regional and local shelf seas and the open ocean.

All local and regional models suffer from the uncertainty created at the open boundary. This problem will be progressively solved by having larger scale and coarse resolution models for predicting of state variables at the open boundary of smaller models. Logically the open boundary problem is only constrained completely by having global models at the largest scale.

As LMR-GOOS progresses it is certain that processes, trends, and changes will be detected, or suspected, on larger and larger time and space scales. The only way to monitor, quantify, analyze and model these changes will be by manipulating decadal or multi-decadal basin scale or global data sets. The only way to create such data sets is to start now on a consistent and logical global basis. If we plan to omit regions now (e.g. the poorly-observed tropical oceans) which are known to be scientifically relevant, it is certain that in 10 years' times essential data sets and models will be compromised, and solutions to key problems will be delayed for further decades. This is no crash program to produce a decade of data. The proposed LMR Panel should identify those variables that can be monitored globally as soon as possible, and provide this requirement to the Working Group drafting the GOOS Initial Priorities Report. It is recognized that LMR-GOOS will be implemented progressively, with some variables being monitored early on, and others developed later as instruments and data quality control become adequate for the task at hand.

2.2 Understanding Fish Recruitment and Regime Shifts

Fish populations are often characterized by decadal-scale long-term fluctuations (regime shifts) on which is superimposed the interannual variability caused by annual recruitment processes.

Fisheries research has traditionally focused on the interannual variability of recruitment and year-class strength of fish eggs, larvae and juveniles in response to physical and biological forcing. This approach has had limited success in explaining the observed year-to-year changes, and there has been less success towards the development of predictive tools (models). The main constraint seems to be the intra-annual (seasonal) and much shorter variability in the forcing functions, that affect the survival of fish larvae. Thus, to observe and ultimately to understand the fundamental year-to-year variability in the replenishment of fish stocks, it will be necessary to sample these high frequency phenomena, such as the duration and spatial extent of episodic events (upwelling, etc.) which may be vital to the survival of fish larvae. Shipboard methods cannot adequately measure the extent of variability of physical and biological processes either temporally or spatially and satellite and *in situ* remote sensing will be vital in this context.

There has been a recent change in the perceptions of fishery scientists concerning the basic nature of fish population variability. Regime shifts can rapidly reorganize ecological relationships in large ecosystems. They might be defined as drastic changes in ecosystem productivity of decadal-scale frequency and are characterized by changes in the dominance of certain fish species. Regime shifts are accompanied by substantial changes in the phyto- and zooplankton communities. It is not clear what causes regime shifts, however, they may be triggered by climatic or anthropogenic forcing. Changes in regimes might be detected at an early stage (for example, by observation of changes in zooplankton variables) long before they can be seen in changes of fish catches. Consequently, changes in zooplankton variables such as abundance or species composition might serve as an early indicator of regime shifts (Hunter and Alheit 1995).

Although difficulties remain in achieving understanding of the causal relationships of interannual fish recruitment, the "regime shift" problem seems to be much more tractable and predictions of medium-term trends in fish population fluctuations might soon be a reality once a regime change has been recognized.

2.3 Critical Marine Habitats

There are some marine habitats that can be defined clearly as having unique spatial boundaries and special assemblages of interacting species. These habitats tend to be identified in coastal and shelf seas, and are liable to be damaged by pollution, or destruction through land drainage, land reclamation, and the impact of increased sediment loads. The concept of "critical habitats" is rather subjective, but it is convenient to classify some habitats in this way. The critical habitats exhibit consistent characteristics which can be understood and managed in similar ways from region to region. Each site-specific phenomenon can then be studied with a combination of general methodology and locally unique data.

The Costa Rica meeting of the *ad hoc* LMR Panel (See Annex VI) listed several critical habitats, to which this Workshop has added more. The suggested list of primary concern is:

- Coral reefs.
- Mangrove forests
- Estuaries
- Upwelling systems
- Sea grass beds
- Coastal wetlands.
- Lagoons.

Critical marine habitats tend to be associated with high biodiversity, sharp biological and biogeochemical gradients, and high spatial and temporal variability. Modelling these habitats will be at the highest resolution within the LMR system of nested models, with a grid spacing less than 1km. These habitats are all coastal, thus the observational strategy and modeling for critical marine habitats needs to be developed in conjunction with other GOOS modules (especially the Coastal Module).

2.4 Large Marine Ecosystems Research and LMR

The workshop benefited from a presentation by Dr. Kenneth Sherman on the status of the Large Marine Ecosystem program which was implemented in support of the recommendations of the 1992 United Nations Conference on Environment and Development. The LMEs are regions of ocean or coastal waters covering large areas and characterized by distinct hydrography and types of ecosystems. Consequently, this is of great interest in terms of management of living marine resources.

Approximately 50 LMEs have been identified to date and they are described in IOC Information Document 942, published in 1993 (see Figure 1). An estimated 2 billion dollars has been allocated by donor nations to the World Bank's Global Environmental Facility (GEF) to support *inter alia* international projects focusing on the sustainability of marine resources within the extent of whole ecosystems.

Most of the identified LMEs include several coastal states. By sharing the same coastal zone or ecosystem, the need for coordination between jurisdictions in terms of monitoring and resource management is most important. Furthermore, there is an obvious need for coordination between the LMR of GOOS and the LME program in order to avoid overlap, achieve synergism, and to provide the basis of a unified interaction.

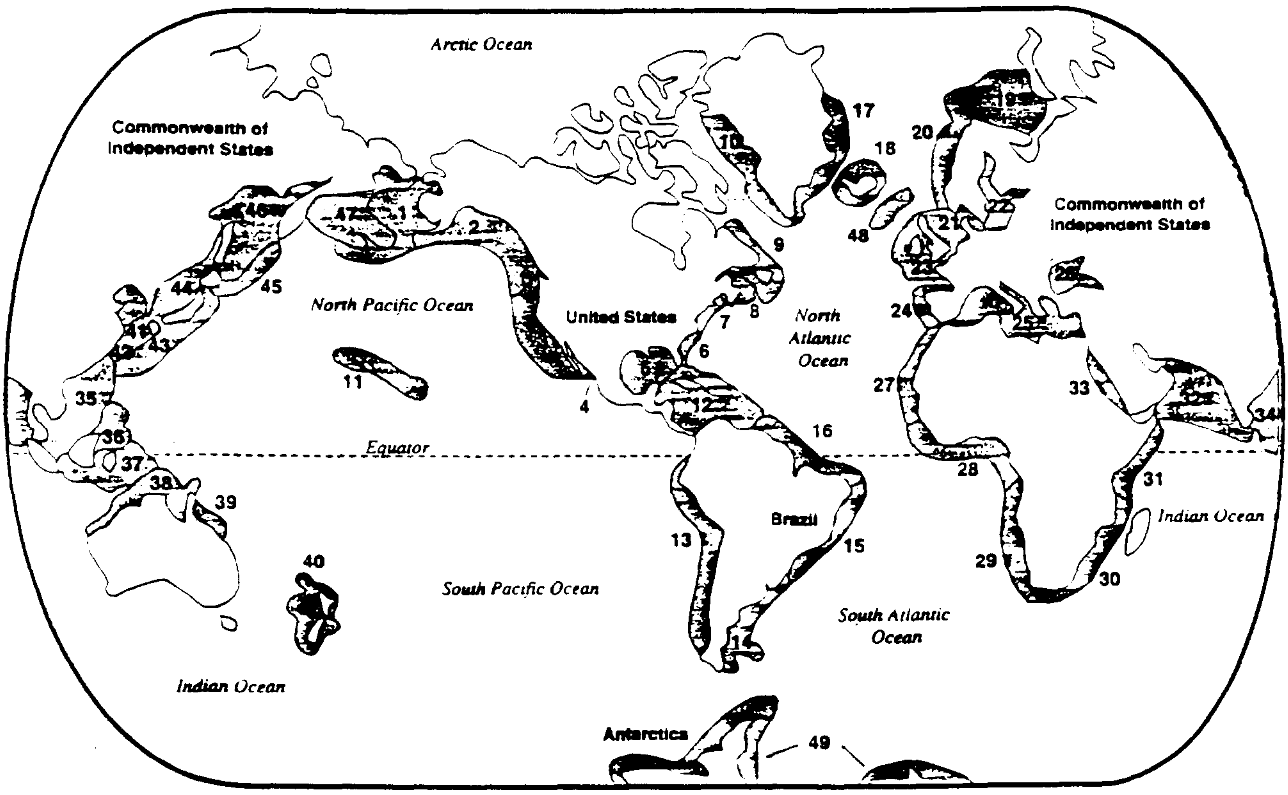
It is apparent that the locations defined for the LME program are very similar to these of interest to LMR, although the formal criteria used in their selection are different. Since it is probable that substantial observational programs will have been undertaken in a considerable number of LMEs by the time LMR becomes operational, the possibility of building on and maintaining observations in some of these areas should be considered. The LMR approach also provides a mechanism for judging the cost-effectiveness of some of the technologies recommended for large-scale monitoring.

2.5 Relation to Other GOOS Modules

The LMR-GOOS Module requires defined data sets and model outputs that will specify the physical dynamics of the ocean, biogeochemical variables, as well as biological responses. As a first approximation, this report assumes that a portion of the physical and chemical data and modeling required by LMR will be obtained through observing and modeling systems primarily specified by the Climate, HOTO, and Ocean Services Modules of GOOS. Additional variables, especially those describing coastal and shelf seas circulation, sedimentology and freshwater runoff, will be provided by the Coastal Module. It should be noted that the implementation of GOOS is unlikely to be divided into distinct programs corresponding to the modules which are essentially planning devices. Careful coordination between Module plans will be critical and to that end, the workshop suggested that the various planning Panels include corresponding or liaison members.

The output of physical and chemical modeling supported for the non-LMR purposes may suffice to provide inputs for fully coupled physical-chemical-biological models, but this point has not been proven, and needs analysis.

FIGURE 1 Boundaries of 49 Large Marine Ecosystems.



1. Eastern Bering Sea
2. Gulf of Alaska
3. California Current
4. Gulf of California
5. Gulf of Mexico
6. Southeast U.S. Continental Shelf
7. Northeast U.S. Continental Shelf
8. Scotian Shelf
9. Newfoundland Shelf
10. West Greenland Shelf
11. Insular Pacific - Hawaiian
12. Caribbean Sea
13. Humboldt Current
14. Patagonian Shelf
15. Brazil Current
16. Northeast Brazil Shelf
17. East Greenland Shelf
18. Iceland Shelf
19. Barents Sea
20. Norwegian Shelf
21. North Sea
22. Baltic Sea
23. Celtic-Biscay Shelf
24. Iberian Coastal
25. Mediterranean Sea
26. Black Sea
27. Canary Current
28. Guinea Current
29. Benguela Current
30. Agulhas Current
31. Somali Coastal Current
32. Arabian Sea
33. Red Sea
34. Bay of Bengal
35. South China Sea
36. Sulu-Celebes Seas
37. Indonesian Seas
38. Northern Australian Shelf
39. Great Barrier Reef
40. New Zealand Shelf
41. East China Sea
42. Yellow Sea
43. Kuroshio Current
44. Sea of Japan
45. Oyashio Current
46. Sea of Okhotsk
47. West Bering Sea
48. Faroe Plateau
49. Antarctic

It is possible that some biological models or predictions will require physical-chemical data or sampling patterns that are not provided by the specifications for the other GOOS Modules. In this case, LMR will add its physical-chemical requirements by reporting to J-GOOS for integration within the GOOS system design. In this report we are concentrating on the biological variables and parameters of the system, with the assumption that additional physical-chemical requirements will be included in the Final Report of the LMR Panel to J-GOOS.

There are a number of important topics which fall at the boundaries of the modules presently defined, and which J-GOOS will need to ensure are properly handled, either by deciding which module should take responsibility for them or by establishing joint inter-module working groups of two or three people from each module. In the case of LMR, these issues include *inter alia* the sustainability of critical marine habitats, changes in marine biodiversity, the conservation of genetic resources, the capacity of the ocean to uptake CO_2, ecosystem health and human health.

Overlapping interests have been identified as follows:

- With the Coastal Module:
- Sustainability of Critical Marine Habitats
- Biodiversity Issues, including Genetic Resources
- With the Health of the Oceans Module:
- Harmful Algal Blooms [n.b. - there is a relevant IOC program on this topic]
- Diseases in Relation to the Health of Humans and Marine Biota.
- With the Climate Module:
- Oceanic CO_2 Uptake via Primary Production

As noted elsewhere, there is also a close relationship with the Large Marine Ecosystem program, and formal linkage of some sort may be desirable

2.6 Relationships with Other Science Programs

A range of potential LMR data is already available from local, regional, and global science programs, and/or collected by regional and international organizations. These include GLOBEC, JGOFS, LOICZ, IOC, PICES, ICES, etc. Collectively, the data stream from these existing sources is important to LMR-GOOS, but there are still gaps leaving spatial and temporal discontinuities and inconsistencies which seriously undermine the objectives of LMR.

The existing scientific programmes will be essential to LMR in providing understanding of processes, and useful to LMR in providing partial data sets, some with historical continuity. sets, some with historical continuity. They will also provide information on the logistics of operating in different marine environments. For all these reasons, it will be essential to maximize coordination and communication these programs and LMR-GOOS, especially to achieve maximum scientific synergy and avoid duplication of effort. So far as possible, as each science programme approaches its final phase of observations, elements should be identified which can be continued as providing data to LMR.

The work envisaged as part of the LMR-GOOS concept is closely related to that planned by the SCOR/IOC/IGBP Core Project on Global Ocean Ecosystem Dynamics (GLOBEC). The relationship with GLOBEC will be very important, because the GLOBEC mission is to advance understanding of precisely those features of the marine ecosystem which LMR aims to monitor and predict. Indeed, it is probable that if GLOBEC did not already exist, LMR would have needed to create it. Informal linkage (common membership of planning groups, etc.) between GLOBEC and LMR already exists, but this should be formalized by cross-representation as key committees are formed in the future. In particular, it should be noted that the experience with logistics gained and the results and understanding obtained by GLOBEC will become a most important input to the evolving plans for LMR-GOOS in the next decade.

Science programmes tend to have the following limitations in comparison with operationally funded observations:

- dependence on limited science research funding.
- limited duration of experiments
- limited geographical extent leaving large areas of the global ocean unexamined.
- lack of inter-comparison of standard observing protocols

GOOS should be planned so as to take advantage of, build upon and contribute to the synergism which can exist between research and monitoring activities. Similarly, the research programs must recognize that they can both contribute to and benefit from an ocean observing system. For example, Keeling's Mauna Loa time series of CO_2 observations, begun in the 1950s, has provided the basis for extensive research efforts.

2.7 Relationships with Other Organizations:

The scope of LMR-GOOS extends to all living marine resources, and therefore includes, but is not limited, to marine fish. The state of many fish stocks is already monitored by national, regional and international organizations, and within the UN system this information is collated and disseminated by FAO. LMR-GOOS should seek to capture the maximum possible benefit from these existing sources and provide input about its own operational needs. It would neither be necessary nor desirable for LMR-GOOS to duplicate or seek to exert undue influence on such existing programs. The data they produce will however be an important component of the complete GOOS data set, and new data specifically produced by the LMR program is intended to be an important resource for such organizations to utilize. In practice, however, LMR will focus on providing information not collected by existing agencies, and for the foreseeable future will concentrate on providing large-scale information on the lower trophic levels, which is not available from other sources. It will therefore be necessary to create appropriate interfaces between LMR-GOOS, fisheries agencies and environmental organizations which may include cross-membership on appropriate panels and committees, but may also require the creation of joint bodies charged specifically with coordination. Clearly there is a need to establish close cooperation and relationship with FAO.

Other organizations with which formal relationships may be desirable include ASEAN, ICLARM, ICES, PICES, CCAMLR, regional tuna commissions etc. Finally, it will be desirable to ensure awareness of activities being managed by UNEP under the post-UNCED Global Plan of Action.

3. ASSESSMENT OF USER NEEDS

GOOS is needed to provide data and predictions to meet societal needs. For each component of the observing system, or for each variable that is included in the system, there must be evidence that the data are needed to generate products of proven value, and that they can be obtained at an acceptable cost. Accordingly, the workshop attempted to identify a preliminary list the classes of users and beneficiaries for each type of product, and to prioritize the implementation of LMR accordingly. The classes of users include:

- International, national, regional and local regulatory agencies responsible for managing the state of the marine environment, wildlife, fisheries, shell fisheries, and aquaculture.
- Public health organizations.
- Non-governmental environmental and wildlife organizations.
- Managers of marine parks and wildlife reserves.
- Sports fishing and tourist organizations.
- Agencies concerned with climate change and its impact on the environment.

The operational concept of the value or benefit of LMR-GOOS products is interpreted broadly as either a commercial sales value, or a "public good" benefit where market failure applies. In many cases the information and products supplied by LMR will have enormous value to regulatory authorities preserving fisheries, but it would be difficult or impossible to persuade the individual beneficiaries to pay for the system. The benefits of LMR will tend to fluctuate regionally and temporally as processes or events occur where information and forecasts allow beneficial decisions to be taken. These local values are generated because the system as a whole is operated on a steady basis and with large geographical extent. Analysis by the Organization for Economic Co-operation and Development (OECD), and other agencies, suggests that about 15-25% of total costs of an observing system can be obtained by direct sale of data products to users. The other services produce measurable benefits in the public good, but cannot be marketed for cash. Studies of costs and benefits are under way in a number of organizations (NOAA, Woods Hole, EuroGOOS, etc), and in general the benefit-to-cost ratio for GOOS type products is very favorable. In this report we have considered the classes of users, but not tried to evaluate the benefits.

The types of users can be reviewed in terms of the trophic level of data and data products which are most likely to be of value to them. Data types, models, and users should be studied more fully in order to identify the ranges of products needed by each group. The workshop identified potential users based on their needs for information on various trophic levels in the marine ecosystem.

Phytoplankton:

The workshop proceeded on the assumption that data on nutrients would already available to LMR-GOOS since they are in existing plans for other GOOS modules. Generate phytoplankton maps daily, weekly, monthly, annual and decadal average. The daily and weekly plots are of value in predicting harmful algal blooms.

- Fisheries managers require the data on all time scales. Monthly averages suffice to detect regime shifts.
- Public health organizations require bacterial and viral counts.
- Tourists and tourist organizations want to know the water quality near beaches.
- Nuclear waste and other contaminants enter the food chain at the phytoplankton level, and need to be monitored and forecast for waste management organizations.
- Shell fisheries require data on the phytoplankton food supply.
- Climate modelling requires data on CO_2 drawdown by phytoplankton.

Zooplankton:

- Fisheries require zooplankton data and forecasts on monthly and longer time scales. Weekly monitoring of fish larvae at critical periods provides information relevant to formation of cohorts.
- Krill harvesting in the Southern Ocean requires zooplankton modelling and forecasts.
- Outbursts of jellyfish and ctenophores have an impact on tourism and fisheries. In the Black Sea predation on plankton and fish larvae by introduced ctenophores has been very destructive to the local fisheries.
- Cholera epidemics in coastal areas can be linked to chitin and zooplankton blooms.
- Monitoring of the Southern Ocean has suggested that there is an alternation between assemblages dominated by krill and salps (i.e. regime shifts).

Fish and shellfish:

- Fisheries and wildlife agencies.
- Ports, trawler associations, local authorities.
- Developing countries (food forecasts and sustainability).
- Conservation organizations (biodiversity, genetics, etc.)
- Management and prevention of fish diseases and parasites.
- Sport fishing organizations, tourist organizations.
- Aquaculture operators (HABs).

Fish larval and juvenile stages:

Many of the same users of information on fish identified above would also require information on developmental stages of certain fish species. However, concern was expressed that there was need for information and models that could cope with the larval and juvenile stages of fish growth. It was agreed that this problem is presently intractable, and that present methods have failed to make much progress predicting recruitment and mortality of these stages. More research and data are needed to indicate how effective models and predictions might be in 10-20 years.

Marine Mammals, Birds, Top Predators:

The Workshop discussed events such as whale and dolphin beaching, albatross deaths from long-lining, and the effect on populations of seabirds and other predators when fish stocks collapse, whether as a result of natural regime shifts or because of overfishing.

- Regulatory bodies for the harvesting of whales, seals, etc.
- Fisheries organizations.
- Conservation organizations (public agencies and NGOs)

4. OBSERVATIONS: NEEDS, CAPABILITIES AND POTENTIAL

A substantial body of information now permits us to evaluate the state of observational capabilities pertinent to the development of the productivity components of the LMR module of GOOS. The following section draws on several recent reports (particularly GLOBEC Report Number 3 and U.S. JGOFS Planning Report no. 18) as well as the discussions that took place at the J-LMR-GOOS workshop. Several of the important documents are listed in the bibliography.

The sampling and observational challenges posed by LMR-GOOS arise from the multiplicity of potentially relevant physical and biological variables impacting on ocean productivity, many of which display scales of variability that span ten orders of magnitude. Practical limitations will impose constraints and require careful definition of key processes and selection of critical variables. Thoughtful selection of optimal sensors and systems will be necessitated by the requirement for large numbers of observations. Comprehensive summaries of relevant processes and variables are summarized in GLOBEC Report No. 3.

The global nature of GOOS dictates a comprehensive approach to sampling as well as modeling Many of the important measurements for the LMR module will be needed for other GOOS modules so that coordinated, complementary sampling will be an important implementation issue. Multiple use of existing and new platforms and data exchange among GOOS modules will be implicit, as will an interdisciplinary approach and a nested multi-platform strategy.

Critical components of LMR-GOOS models will need to include:

- Physics (including meteorology and optics)
- Phytoplankton production/biomass
- Zooplankton production and grazing
- Predation of zooplankton.
- Recruitment and tertiary production

Some of the primary core variables should include:

- Meteorological variables: barometric pressure, wind stress, air-sea fluxes of heat, fresh water flux (Evaporation - Precipitation), cloudiness, and surface spectral radiation
- Physical variables: currents, temperature, salinity, and density
- Optical variables: photosynthetically available radiation (PAR), spectral light at depth, and spectral light absorption and attenuation
- Biological variables: phytoplankton abundances (by size and taxonomic group), zooplankton and fish abundances (by size and species), production (primary, secondary, etc.), and mortality.

A comprehensive approach to sampling and modeling requires that methods which provide large-areal coverage, seasonal, year-long coverage or long-time series must form the core elements of the sampling strategy. Sampling strategies should incorporate nested sampling methods. Some of these must cover spatial scales of 100 to 1000 km quasi-synoptically.

The LMR-GOOS observational program will require a synergistic combination of platforms and sensor systems. These should include:

Platforms:

- Moorings, both permanent and expendable (instruments at fixed-depth and profiling);
- Drifters (instruments at fixed-depth and profiling);
- Research ships (for on-station profiling and towing);
- Ships-of-opportunity (for self-contained, autologging instrumentation packages on merchant vessels, ferryboats, and military vessels);
- Autonomous underwater vehicles (working from mother ships or shore bases and communicating to shore via satellite);
- Satellites and aircraft.

Sensor systems:

- Profiling and towed instrument packages (deployed from research ships and ships-of-opportunity);
- Expendable sensor systems (deployed from research ships and ships-of-opportunity);
- Moored and drifter-mounted sensor systems;
- Acoustic tomography (for 3-D temperature and current maps);
- Shore-based radar and acoustical systems which can be used to map coastal surface and subsurface features respectively (currents, acoustical back scatter from organisms, etc.).
- Satellite and airborne remote sensing systems (for biological properties based on ocean color, wind stress, physical structure, sea surface temperature, wave height, roughness, currents, etc.).

Telemetry of data in near real-time is now possible (e.g. Dickey et al., 1993) and is essential for prediction for all of the systems listed above, particularly in the context of utilization for data assimilation models described in the next section of this report.

Sampling strategies must include time series to provide continuity of data for adequate characterization of:

- Interannual variability and long-term trends;
- Seasonal cycles and seasonal variability;
- Sub-mesoscale and mesoscale eddies, jets, and fronts (days to months);
- Higher frequency cycles and phenomena (e.g., surface, internal and inertial waves, tides, diel cycles, etc.) and effects of episodic events.

Time series from moorings provide measurements from fixed depths or continuously with depth at a fixed geographic location over seasonal and annual time scales (some with sampling rates ~1/minute). Concurrent bio-optical, bio-acoustical, biochemical and physical measurements are now being done using a few moorings. These data are being used to estimate biomass, primary productivity and zooplankton size distributions. Drifters can give similar time series of data for a specific water mass followed in Lagrangian terms. Time series data have been collected using standard stations and sections obtained from research ships by a few research laboratories and national programs over several decades. For example, the Continuous Plankton Recorder (CPR) has been used for time series surveys in a few locations and has been made central to LME studies funded by the World Bank GEF. Future assessment of the cost-effectiveness of these deployments should form the basis of any recommendation to adopt this approach as part of the routine monitoring done for the LMR-GOOS. The power of this technique is that it resolves different components of zooplankton, but the "downside" is that this involves a high degree of human intervention and training. Future LMR-GOOS panels and workshops should seek to exploit emerging technologies to reduce the processing time (e.g. image analysis) required by systems such as the CPR and utilize *in situ* assessments based on biological and bioacoustical measurements. A careful analysis of all such surveys is required with particular attention directed towards upgrading of sampling systems using emerging technology .

Regional observations will require methods that give greater spatial coverage and necessitate the deployment of towed, semi-autonomous and autonomous systems, using both research vessels and especially ships-of-opportunity. Mesoscale resolution over regional scales is essential. AUVs will be important sampling platforms in the future as well. Towed (or AUV mounted) sensor systems give quasi-synoptic measurements which can be related to concurrent or quasi-contemporary satellite and acoustic tomographic observations. The use of modified CPRs and other towed sampling systems will be important, especially when used in conjunction with acoustic Doppler current profilers and commonly used (e.g., "fish finders") or future acoustical back scatter systems.

Satellite remote sensing of oceanic biology, physical structures like wind stress, sea surface temperature (SST), and currents and conventional *in situ* methodologies for biological oceanography can be deployed to yield powerful synergy. Together, they can provide integrated and relatively comprehensive sampling covering a considerable portion of the spectrum of time and space scales (i.e., from seconds to years and mm to 1000 km) with quasi-synoptic global coverage.

Airborne and satellite remote sensing technology and methodologies provide quasi-synoptic, large area observations unobtainable from ships or moorings, repeated regularly with long-term missions. The overview provided by these methods can provide the framework into which the nested *in situ* detailed sampling can be fit. Observations of ocean color from space can provide a measure (to roughly one optical depth) of the areas of enhanced biological production and plant biomass which can accumulate at shelf-sea fronts, topographic features (banks and ridges), shelf edges, and other upwelling zones, and at physical interfaces (current systems, eddies, squirts, jets, etc.) where zooplankton and fish populations are known to accumulate for feeding, spawning and early life development. Remotely sensed measurements of sea surface temperature provide an additional measure of these physical structures (where biological processes are enhanced) through AVHRR measurement (skin temperature only), but need careful interpretation (e.g., diel solar heating of the surface layer can reduce the utility of sea surface temperature imagery). Sea surface elevation can now be obtained from satellites and can be used to determine large scale as well as mesoscale near-surface current patterns which are important for advection of plankton and for estimating retention and dispersion of plankton regionally. Imagery of ocean color can provide both an estimation of the primary production and biomass at the base of the food chain and the location of areas where the higher trophic levels will thrive. By contrast, there are oceanic features, such as relatively long-lived anticyclonic eddies and convergences, which act as sinks for primary production, drawing down plants to the deep ocean. The study of "regime shifts" in fish populations, as discussed elsewhere in this report, is one area that seems likely to benefit from global analyses of satellite derived wind, color, temperature, and current maps.

In situ measurements of oceanographic properties, using medium to long-term moorings and drifters, daily sampling on station by research vessels and continuous measurements by instruments towed from research vessels or merchant ships in passage and in the future expendable mooring and AUVs, can provide higher precision, extra resolution in depth and time and a wide range of measurements of biological properties unobtainable by satellite or aircraft methods. These provide complementary links to the remote measurements and essential ground-truthing of the large-scale synoptic data sets.

A large number of physical, optical and acoustic sensors have been developed, or are in advanced prototype form, and many are ready for operational development. These can be deployed from moorings, drifters, profiling systems, underwater towed vehicles, and semi-autonomous and autonomous vehicles. They cover a broad spectrum of oceanographic variables which are of interest. These include:

- Physical: meteorological variables, currents, conductivity (salinity), temperature, and depth;
- Biological: phytoplankton pigments, dissolved oxygen, pH, and photosynthetic parameters and rates;
- Bio-optical: spectral beam attenuation and absorption, spectral radiance (including natural fluorescence), spectral irradiance, photosynthetically available radiation (PAR), stimulated fluorescence (broadband and spectral), and pump and probe fluorescence;
- Optical/video: biomass, organismal size distributions and identification;

- Acoustical: plankton and fish biomass and size distributions;
- Chemical: nutrients (both macro and micro)

Conventional deployments of most of these sensors from research ships, moorings and drifters have become or will become relatively routine within the research community, giving measurements of many of the parameters relevant to the LMR-GOOS module. These types of studies, which will provide albeit with limited spatial coverage, will be essential to the accuracy and consistency of the broader coverage.

The rapidly emerging assortment of interdisciplinary sampling sensors and systems provides timely opportunities. There is good reason to expect that technologies relevant to the LMR-GOOS module will continue to expand rapidly and that cost per sampling system will decrease. New instruments tend to require several years of use in the laboratory environment to ensure standardization of practice, elimination of systematic errors, and intercalibration. Following this phase, further engineering is needed to simplify operational characteristics and develop commercially marketable instruments which can be used in large numbers with relatively simple technical support. It will be critical to keep this point in mind in designing observational systems for the LMR module. The interpretation of signals generated by many of the new acoustical and optical systems remains as a serious research challenge. Emerging image analysis technology should be applied to the problem of identifying and determining the compositions of plankton. Thus, there will certainly be need for coordinated pilot studies under the auspices of organizations including the LMR-GOOS module, GLOBEC, and others.

The design and execution of the LMR-GOOS program will require cooperative efforts between modelers and observationalists as ship time, instrumentation, and computer resources will be at a premium. The merging of data sets collected and transmitted in near real-time from a host of platforms will be necessary for data assimilation modeling (GLOBEC Special Contribution Number 2; GLOBEC Report Number 6).

To summarize, the collective sampling and observational systems needed to accomplish the goals of the LMR-GOOS Module will require information concerning many interdisciplinary variables monitored over a broad range of time and space scales. It is evident that a hierarchy or nesting of sampling systems and experimental designs will be required. These must be used in conjunction with models to provide a continuum of information ranging from the basin-decadal scale through the mesoscale (10-200 km; weeks to months), and down to the local scale (<1 m to 10 km; seconds to several years). Great strides have been taken in the development of interdisciplinary sensors and systems with direct applicability to the LMR module. Nonetheless additional research needs to be devoted to relevant technologies involving bioacoustics, bio-optics, and image analysis. Most importantly, pilot studies incorporating both sampling and modeling efforts will be essential for achieving the goals of the LMR-GOOS.

5. MODELING AND ASSIMILATION

5.1 Ocean Prediction Systems

Ocean monitoring and prediction systems must be expected to substantially impact ocean science and technology in the near future. It is just now feasible to provide accurate and efficient nowcasts, forecasts, and data-driven simulations for management, operations, and research in the variable and intermittent marine environment.

Ocean monitoring and prediction systems are structured with three essential components:

- an observational network,
- a set of dynamical models, and
- a data assimilation scheme.

The models synthesize the status of understanding of fundamental ocean dynamics. By means of data assimilation, models: dynamically adjust the data with linkages between observed and non-observed state variables; dynamically interpolate in space and time; and provide a powerful method for forecasting into the future.

5.2 Coupled Interdisciplinary Ocean Dynamical Models

Modelling the coupled and interactive physical-biological-chemical ocean presents challenging and complex problems associated with fundamental research on biogeochemical cycles and ecosystem dynamics. Basic biological mechanisms are generally known but much remains to be learned about their manifestations in real ocean processes. Moreover, there are a variety of reasonable formulations of basic mechanisms, such as nutrient uptake, grazing, mortality, etc.; and more are highly nonlinear in structure. There is an almost unlimited number of potential state variables (species, life-stages, trophic levels, nutrients, trace chemicals, particle sizes, etc.). Thus, an important aspect of model formulation for particular investigations is the definition of key or critical variables, e.g. a generic aggregation of planktonic types and sizes. Another crucial problem is the quantification of the rates of biological processes, for example, mortality and grazing, in real ocean circumstances. Biological scales may be expected to reflect physical scales, but additional scales occur not only directly from biology, but from the competition between physics and biology. For example, some scales of biological patchiness probably arise from the competition between physical transports and biological behavior. Some important physical-biological interactions are well known, such as upwelling, large-scale advection and (partial) isolation of biological systems in ring eddies. However, as four-dimensional (x, y, z, t) coupled mesoscale (and sub-mesoscale) resolution modeling is in its infancy, many important physical-biological interactions remain to be discovered.

A useful overview of the status of ecosystem and biogeochemical modeling is provided by Rothschild (1988) and by Evans and Fasham (1993). The latter volume includes an extensive bibliography collected and annotated by Totterdell (1993). Of the 106 studies referenced by Totterdell, only 12 include horizontal processes (2 or 3 spatial dimensions). Additional, recent, three spatial dimensional studies include Fasham et al., (1993), Sarmiento et al., (1983), Nihoul et al., (1993), and McGillicuddy et al., (1995 a,b). The Totterdell bibliography is focused on biogeochemical processes and is therefore not comprehensive in regard to models which focus on more complex aspects of the food web, such as Hofmann (1988) and Moloney et al., (1991). Denman (1992) and Nihoul and Djenidi (1991) provide recent discussions of the scales of physical-biological interactions. Early studies involving the assimilation of biological and chemical data have been made by Fasham et al., (1993), Ishazaka (1990) and Lawson et al., (1995). The latter study is of special significance because it deals with the estimation of biological process rates via an adjoin assimilation method.
[The preceding section was extracted from Robinson, 1996.]

5.3 Ocean Forecasting

The ocean is now known to contain phenomena which occur over a considerable number of interacting space and time scales. The multi-scale synoptic circulation occurs on mesoscales; jet-scales; regional scales; sub-basin scales; and large scale. The mesoscale variability is itself episodic and intermittent. Mesoscales range from 0 (10-100km) and 0 (weeks-months), but sub-mesoscale event scales range from 0 (1-10 km) and 0 (days). Coastal scales are a multi-scale mix. Time scales range from short period (e.g. gravity waves) to decadal and longer variability and climate change scales. Forced responses (wind, tide, and boundary forced) and internal dynamical processes (mesoscale and event-scale processes analogous to the open ocean) occur in the presence of complex topography and geometry.

The multiplicity of scales requires nested high resolution observational domains; compatible nested high-resolution modeling domains; sub-gridscale parameterization of unresolved scales; parameterization of scales larger than the forecast domain as open boundary conditions.

The methodology for the development and verification of regional forecast systems can be usefully regarded as consisting of three phases: exploratory, dynamical, and predictive. In Phase I (Exploratory), dominant scales, processes, and interaction are identified. Dynamical models are set up and validated, i.e., chosen so as to be generally relevant for the regional dynamics. In Phase II (Dynamical), a definitive knowledge of circulation, structures, and interactions is obtained. Specific dynamical processes of synoptic evolution and for the occurrence of events are established. The regional forecast system is calibrated, including the tuning of model parameters. In Phase III (Predictive), forecast experiments with dense, high quality data sets need to be carried out. These experiments must accomplish the quantitative verification of the regional system's capability for real time forecasts. The final step is the design of an efficient regional forecast system with minimal resources for desired accuracy and applications (Robinson et al., 1996).

5.4 Data Assimilation

Data assimilation (GLOBEC Special Contribution No. 2; Bennet, 1992) provides field estimates based on the melding of data and dynamics which agree with the observations within observational errors and which are constrained by the dynamics within dynamical model error bounds. There are several goals and purposes of data assimilation (Robinson et al., (1996)):

- i. In atmospheric and oceanic systems, nonlinear scale interactions grow and transfer errors initially negligible into scales of interest which results in loss of synoptic predictability. Data assimilation is used to control such phase errors.
- ii. Assimilation of adequate data into somewhat dynamically deficient models can produce useful field estimates which resemble nature.
- iii. Parameters may be estimated, including internal parameters of the model (eddy diffusion, biological rates, etc.), forcings, and boundary conditions.
- iv. Process studies provide new knowledge of dynamics. Dynamical adjustment and interpolation permits quantitative balance of terms studies (e.g. for energy, vorticity, productivity, carbon flux, etc.).
- v. Data driven simulations, including observation system simulation experiments (OSSEs) with sensitivity analyses, provide powerful means of estimating statistical quantities and designing arrays and sampling schemes.
- vi. Data assimilation is of critical importance for efficient operations, management, and monitoring.

The observation system simulations experiments are used:

- i. to *design* different components of a complex system,
- ii. to *optimize* the use of resources,
- iii. to *assess* the impact of data in nowcast and forecast,
- iv. to *understand* the interactions of system components,
- v. to *improve* overall system performance, and
- vi. to *validate* the system performance using quantitative error estimates.

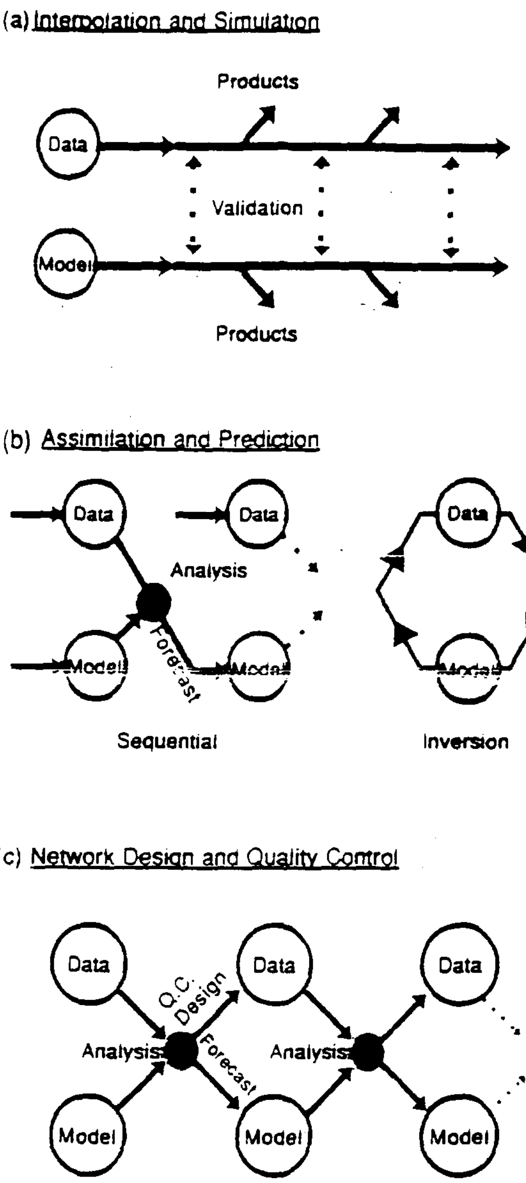
The role of data assimilation and OSSEs is schematized in Figure 2.

5.5 Data Assimilation in Interdisciplinary Ocean Science

Solutions to the fundamental interactive physical-biological-chemical problems of ocean science, identified as of primary importance decades ago, now are finally feasible. These include biogeochemical cycles and ecosystem dynamics in a climate and global change context.

There are very many more state variables involved in the biological and chemical dynamical models than in the physical models, and data are more difficult to acquire and must be expected to be sparser. Biological rate parameters (mortality, grazing, etc.) are not well known and are very difficult to measure directly *in situ*. For these reasons, data assimilation, including parameter estimation, is a critical necessity for interdisciplinary research, modeling, prediction, and monitoring.

FIGURE 2 A schematic of three methods for interfacing observations and models, in order of increasing sophistication. *(a)* Thee data are interpreted without the aid of a model, and the model is run without observed information. The interface is provided by a series of validation steps. *(b)* Either the data and model fields are merged in an analysis step, which then provides the basis for a sequential model prediction scheme, or the analysis field is obtained from an equilibrium calculation of the circulation based on observed and model constraints (inversions). *(c)* as in Figure 1*b*, but now the analysis also affects the data base, first though quality control and later through modifications to the observation network design based on the joint model-data analysis and forecast.



Biological dynamics introduces many new non-linearities (e.g. grazing), which have several important consequences for model formulation and data assimilation methodology. Biological "Reynolds stresses" or turbulent fluctuation correlation must be considered. This requires sub-gridscale parameterizations. Also, critical state variables and dominant scales of interest for the biological model must be determined. Critical variables aggregate species and/or stages as appropriate for the particular problem under study and are explicitly modeled. The interactions with lower and higher trophic levels than those explicitly modeled require parameterizations. The parameterization of predation by higher trophic levels is particularly important. The non-linearities will influence physical-biological-chemical dynamical linkages and the impact of various data types. The challenge of novel predictability issues needs careful research.

5.6 LMR Modelling: Summary and Conclusions

Predicting and monitoring for interdisciplinary ocean science management is now feasible and desirable. The development of the requisite forecast system (models, data assimilation schemes, observational network) for the physical-biological-chemical ocean requires planned and staged research and development efforts. The system is necessary to research physical-biological-chemical interactive processes, to predict and monitor the ecosystem, and to assess global change phenomena. Modular, relocatable, simple or complex versions, are possible. Such a system will provide a unique opportunity for accelerated research progress. It will also provide an efficient and effective approach to achieve the understanding of the physical-biological-chemical ocean and the consequent capability to predict and monitor, which is necessary for management of the ocean in the global change context, i.e., the LMR-GOOS module.

Interdisciplinary ocean modelling is of course in its infancy. The International GLOBEC program is carrying out and coordinating interdisciplinary modelling research which should directly input to some important aspects of the design of LMR-GOOS operational models. GLOBEC also has as a central focus the development of a research multiscale interdisciplinary prediction and monitoring system (Advanced Modeling/Observation System (AMOS), GLOBEC Special Contribution No. 2, 1996). Coordinated deployments of LMR-GOOS research/operational arrays could be an effective approach. The scope of the GLOBEC numerical modeling activity is presented in GLOBEC Report No. 6, Numerical Modelling (1994). In July 1995, the GLOBEC Numerical Modeling Working Group held a workshop on Interdisciplinary Model Formulation and Parameterization (GLOBEC Report No. 8, 1996), which considered: critical variables and dominant scales; zooplankton modeling (biological and physical processes, interactions, and energetics); ecosystem dynamics (biological and physical model structures and couplings). The next workshop is to be held in the near future on Interdisciplinary Data Assimilation and Observing System Simulation Experiments.

6. SCIENTIFIC AND OPERATIONAL DESIGN CRITERIA

6.1 Scientific and Operational Design Criteria

The main objective for LMR-GOOS as set out in this report is to "observe, monitor and predict ecological variables that underpin exploitable living marine resources, especially primary and secondary biological production". Other priority tasks range from detecting regime shifts to evaluating changes in biodiversity and issues of sustainable development.

The accomplishment of these tasks requires a coherent monitoring program. The monitoring function involves:

i. the use of a global network of sensors to generate data that can be assimilated into models,
ii. the development of dynamic multidisciplinary multiscale nested models relevant to the LMR, and
iii. using the models as a vehicle to develop various GOOS status reports and other products.

Some monitoring of living marine resources can be initiated immediately. This immediate monitoring will generate what might be called first-level models which will identify and lead to specific research related to process studies, alternate models, estimation and data assimilation. Emerging technology, such as supercomputing and the next generation of sensors, can considerably improve the process.

In other words, the development of the global LMR monitoring system (in concert with other GOOS modules) will be an interactive process where prototype systems are installed, tested and improved upon so that they reach full operational capacity progressively during the next decade.

In order to proceed, the proposed LMR Panel should have an early focus on the development of prototype observing systems. In this regard, the Panel needs to take account of three LMR strategic elements that could contribute to describing the state of ocean ecosystems: specific LMR sampling arrays, satellite operations, and existing or planned data collection efforts. Once the strategic elements are specified, it will be necessary to determine how they are combined to yield specific GOOS products.

The workshop recognized that in order to develop observational systems, it will be necessary to combine the operations of monitoring with simultaneous approaches to the scientific issues that could contribute to improving observational strategies. To do this, the workshop noted that it would be important to develop the monitoring system in such a way that in addition to achieving the monitoring goals, it can also contribute to the needs of global programs for scientific data and to the development of appropriate dynamic models.

Accordingly, the proposed LMR-GOOS Panel should provide specific advice to the Joint Scientific and Technical Committee for GOOS on:

- The LMR system requirements that would combine
  1) specific buoys, moorings, drifters and arrays stationed at critical locations,
  2) LMR relevant data with global coverage from satellites, and
  3) data from national and regional programs.

- Goals for satellite data acquisition for the next two decades.

- Optimum locations and specifications for particular moorings, buoys, ship sampling tracks and arrays taking account of:
  1) scientific and monitoring objectives,
  2) costs and benefits,
  3) alternative sensors, and systems and
  4) alternative deployment approaches.

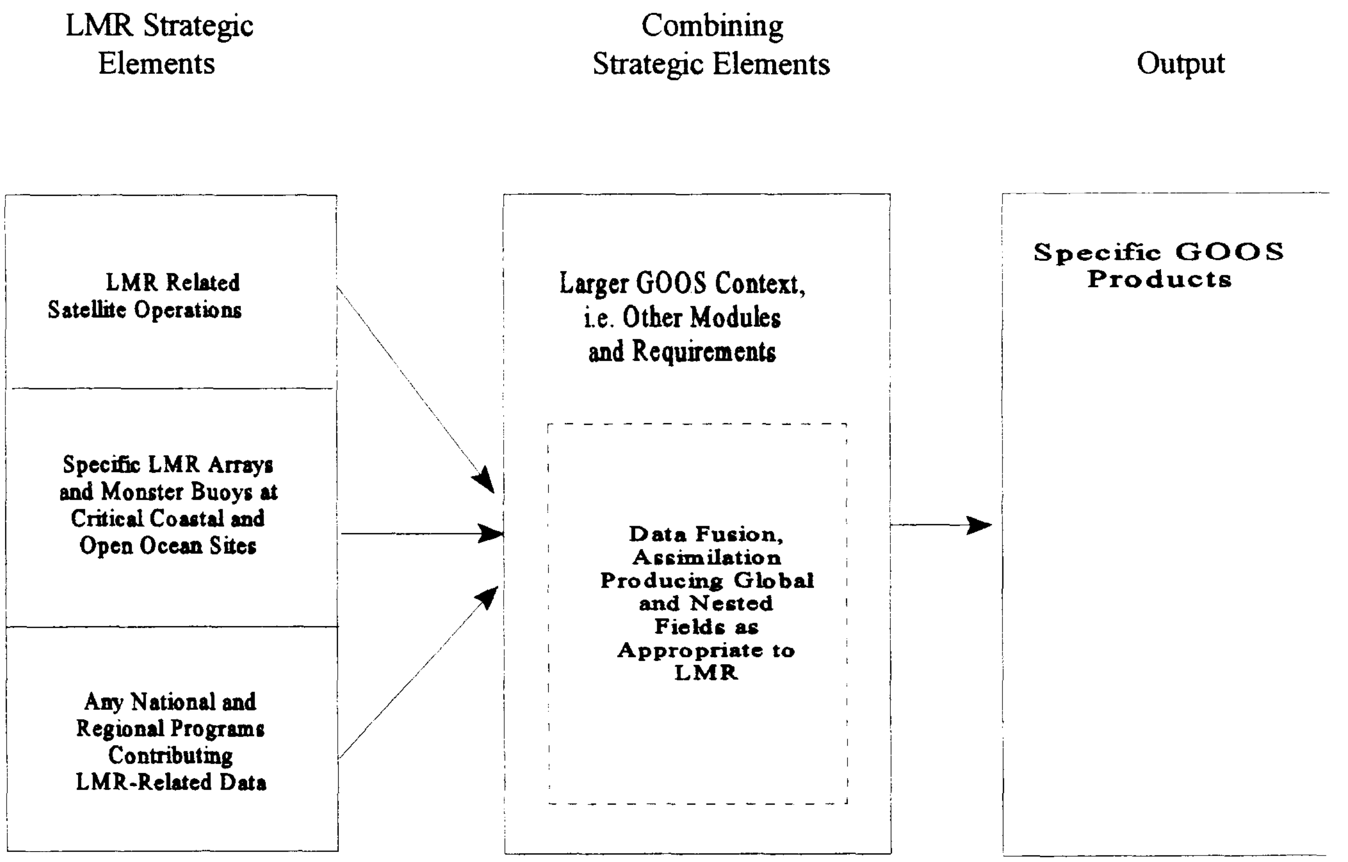
Adoption of this approach by the LMR Panel will produce a capability to qualitatively and quantitatively analyze alternative implementation strategies.

- Evaluation of data sets that might arise in national and regional programs and how these data would made available for central processing.
- Develop the specifics of data fusion, the selection of dynamic models and the physical and biological fields that would be produced.
- Evaluate how the data collection and modeling contribute to specific GOOS products required for LMR.
- Design of a TEMA-related component of planning.

FIGURE 3

B.J. Rothschild (3/4/96)

LMR OPERATIONS/RESEARCH MODULE



6.2 Observational Concept

The nested hierarchical observational framework already adopted for other GOOS modules is entirely appropriate for LMR, and is indeed even more necessary for living resources where the multiplicity of observations required and the high costs of sampling exacerbate the problems already identified from physical and chemical observations.

In the time available at the workshop, it was only possible to undertake a preliminary discussion of the possible structure of the operational program, but several important criteria for the location of long-term comprehensive monitoring stations were identified. These were:

- nature of the biological production regime
- biological productivity (emphasis on high productivity regions, with additional "controls" in low production regions)
- continuation and augmentation of existing monitoring programs
- establishment of monitoring stations in poorly observed areas
- coverage of high variability areas
- emphasis on areas of high societal importance

It is also envisaged that higher resolution observation programs will be implemented preferentially around long-term monitoring stations, and that transects will be selected to connect them. The selection of these stations and transects, and the activities to be carried out at each, is therefore crucial to the design of the observational array.

The workshop produced a preliminary list of strategically important ecosystems including:

- upwelling areas
- high latitude spring bloom areas
- high eddy energy areas
- oligotrophic areas
- the Southern Ocean
- equatorial regions

These tentative suggestions will however need to be elaborated by the LMR Panel, taking note of the requirements of other GOOS Panels in relation to array design.

Finally, the workshop noted that the definition of large marine ecosystems, especially in relation to their isolation and connectivity, is a subject of active current research, and that planning must take account of developments in this field. Indeed, the elaboration of the Science Plan and Implementation Plan for LMR (and of course for other GOOS modules) will need to proceed iteratively *en echelon*, with the scientific requirements leading.

7. TRAINING, TECHNOLOGY TRANSFER AND CAPACITY BUILDING

7.1 Background

Because of the global nature of GOOS, the full involvement of all nations, developed and developing, in both the northern and southern hemispheres, will be critical to its success. To maximize the benefits that developing countries can realize for monitoring and assessment of living marine resources of the Global Ocean Observing System, there will be a need for capacity building. This should include human resources development through education and training as well as enhancement of institutional infrastructures through the provision of laboratory equipment and communication facilities such as Internet connectivity.

7.2 Training and Education:

Training and education should be organized on short-term and long-term bases. Short-term training should be conducted through workshops, short courses, etc. and would emphasize practical aspects of the LMR-GOOS program for technicians and research scientists involved in its implementation. The monitoring aspects of GOOS in particular will require a large cadre of well-trained technicians.

The long-term training and education program should also have more strategic goals, including postgraduate research leading to the MS and Ph.D. degrees and visiting scientist or fellowship programs aimed at the development of joint research projects on monitoring and assessment of living marine resources. Secondments and reciprocal exchanges of senior scientists between organizations in the different hemispheres should also be encouraged as an effective means of transferring knowledge.

7.3 Institutional Infrastructure:

In order to share data globally, there will be a need to improve the capabilities of some key laboratories in developing countries that are involved in monitoring and assessment of living marine resources within the GOOS initiative. In particular, it will be important to introduce computer-based data, modelling and information systems if the large amounts of satellite data are to be fully utilised in the developing regions of the world.

Access to Internet is one requirement that, by itself, could greatly improve the ability to monitor and assess living marine resources in developing regions of the world. Most satellite data are received and stored in many locations in the developed world and access to these data centers via the Internet is critical to obtaining the information needed for assessment and predictions of fishery stocks.

7.4 Organization of Capacity Building:

The capacity building program of the LMR-GOOS should be implemented through the training and education activities of IOC, START, FAO and other regional and international agencies. In particular, the START mandate includes capacity building in support of global change programs within IGBP, WCRP and HDP, which include GLOBEC and other core projects dealing with the oceans. Following the UNCED recommendations in "Agenda 21", UNDP and UNEP have also instituted training programs for developing countries that include both coastal and marine ecosystems.

The training programs should be conducted, as far as possible, as part of the LMR-GOOS Pilot Studies. This will ensure that training will be relevant to the operational program and that trainees within the respective regions can continue monitoring and assessment for LMR-GOOS in a sustainable manner. Twinning of institutions in the North with those in the South should be encouraged to facilitate technology transfer. The suggestion of using recently retired northern hemisphere experts to spend some time in southern institutions should also be actively explored. Such experts can be utilised to prepare LMR-GOOS training modules that can be applicable to a particular region.

The Workshop considered that all of the issues addressed in this section should be referred to J-GOOS and I-GOOS as cross-cutting questions to be dealt with on a GOOS-wide basis. There is a greater chance of success if issues of Training, Education and Mutual Assistance (TEMA) are dealt with in an integrated way throughout GOOS rather than being left to the individual modules. The IOC is ideally situated to use its TEMA Committee to these ends.

8. SUMMARY

The discussions at the workshop resulted in the following scientific conclusions which should be developed in more detail in the early work of the proposed LMR Panel.

1. The **purpose** of LMR is to observe, monitor and predict the state of the marine ecosystem, on space and time scales of interest to actual and potential future users of LMR products, with particular emphasis on the capacity of the ocean to sustain human needs for living marine resources.

2. In principle the **scope** of LMR includes the whole of the marine biosphere. Wise and sustained use of living marine resources requires appropriate information on trophic levels that support and interact with a marine resource of particular interest. It therefore includes, but is not limited to, marine fish. In practice LMR will:

- identify information collected by existing agencies which is essential to LMR goals and make arrangements for it to be made available to GOOS.
- develop and implement strategies for acquiring information not collected by existing agencies, through observations and models, across all temporal and spatial scales relevant to LMR goals.
- concentrate, as a first priority, on providing large-scale information on the lower trophic levels which is not presently available.

The state of information on marine fish stocks on a global scale is however, seriously deficient and LMR-GOOS will need to work with fisheries agencies including FAO to generate a vigorous program of enhanced monitoring, surveys and assessment, exchange of information and development of indicators of resource status.

3. The **users** of LMR products will include:

- national and intergovernmental agencies concerned with the assessment and management of marine fisheries,
- the fishing industry, especially in relation to carrying capacity and to long term trends in fish populations associated with regime shifts or environmental degradation.
- the aquaculture industries, especially in relation to occurrence of harmful algal blooms.
- regulatory agencies and organizations concerned with the state and conservation of the marine environment, especially in relation to pollution,
- agencies concerned with climate change, and in particular the effect of marine biogeochemical processes on atmospheric carbon dioxide levels.

4. Preliminary suggestions for critical variables and the required spatial and temporal coverage, as well as the possible instrumentation which may be employed for **LMR-GOOS observations** are given in Sections 4 and 6. In summary, the observational array will comprise:

- use of space and aircraft remote sensing techniques, including satellite imagery for ocean color, SST, winds and altimetry, and shore-based remote radar and acoustical arrays to acquire synoptic or quasi-synoptic data on critical variables.
- extensive time-series of detailed observations at a number of fixed permanent locations for greater understanding of processes as well as critical ground-truthing of synoptic data sets.
- higher spatial resolution observations by means of arrays of buoys, moorings, drifters, ROVs, AUVs, and periodic surveys within limited areas of high interest (including CalCOFI-type surveys).
- deployment of operational sampling devices such as the Continuous Plankton Recorder (and its undulating progeny) and various acoustic and optical systems by ships of opportunity (especially those making routine transects).

5. A **pilot LMR-GOOS study**, possibly in conjunction with GLOBEC, should be given a high priority in order to develop the sampling and modeling capability required to fulfill LMR-GOOS objectives.

6. The **complexity** of the marine biosphere, due to the multiplicity of species and life-stages, and the non-linear interactions between spatial and temporal phenomena, ensures that uniform coverage with high

resolution observations will not be feasible in the foreseeable future. To generate a comprehensive data set, it will therefore be necessary to adopt both the nested hierarchical observational model already proposed for other GOOS modules (global observations at very coarse resolution, in conjunction with a hierarchy of more detailed observations in selected and much smaller regions of interest). It will also be necessary to accept that observations on individual species will only be feasible in very limited areas (or along selected transects), and that more extensive coverage will only allow for discrimination by size or gross trophic or taxonomic categories.

7. The presence within the biosphere of **multiple trophic levels** introduces an extra complication in the form of the predation closure problem, which is analogous to an open boundary in physical models. Similar techniques will have to be developed to allow for this major complication, but within the framework of data assimilation procedures it should be possible to estimate mortality rates suffered by the highest trophic level modeled, as well as its abundance, Such high-level analysis products should be of great utility in establishing an interface with (for example) operational fisheries models. There are even more difficult problems in dealing with the role of microorganisms in marine ecosystems and solutions will need to be developed for this important component of pelagic food webs.

8. The LMR module will interact strongly with the investigations to be carried out by **GLOBEC** and other programs. In particular, models, methods and understanding developed within GLOBEC, whose goal is the understanding of the dynamics of marine ecosystems, will serve as the basis of those required by LMR-GOOS for operational applications.

9. *Methods for **data assimilation** by combining observations with appropriate **dynamic models** must* continue to be developed to accommodate for the sparseness of biological observations and to control error propagation in dynamic models. Such models may extend from empirical models of minimal complexity for simple estimation of complete and synoptic fields (and their observational errors) to fully coupled physical and biogeochemical/ecosystem models where time-dependent prediction is the goal.

10. It is anticipated that the biological component of the **coupled interdisciplinary operational models** required for the large-scale interpretation of LMR-GOOS observations will be of a complexity comparable to current coupled N-P-Z/physical models, in that they will deal only with Nutrients, Phytoplankton and Zooplankton in the aggregate, although extensions to allow discrimination of size composition are conceivable. In areas covered by higher resolution and more extensive observations, more elaborate models will be necessary and desirable.

11. Products of the LMR-GOOS program are considered likely to **improve predictions** of trends in fish recruitment to a useful extent within the foreseeable future, especially in relation to large-scale systematic changes such as regime dynamics and shifts, whether natural or induced by climate change or other human impacts. It is likely that they will eventually assist in the more difficult problem of the explanation and prediction of interannual fluctuations in fish recruitment.

12. Where necessary, top predators (including marine mammals, sea birds, etc.) may be included in the integrated dynamic model. In other cases, such as the assessment of critical marine habitats, the LMR-GOOS program may also consist of observations made in pure **monitoring mode**. These will be assimilated using minimal/empirical modelling only, and with no prospect of anything more than empirical predictive capability in the foreseeable future.

13. The development of operationally deployable instruments capable of routine acquisition of data on the **characteristics of phytoplankton and zooplankton assemblages** (by size or broad taxonomic categories) should be an immediate priority for technology development for LMR-GOOS. These may include multi-frequency bioacoustic devices, and bio-optical and video techniques.

14. The development of analysis and data management techniques including especially **image analysis** technology for the rapid operational analysis of plankton samples, plankton video images and possibly even CPR silks, should also be encouraged as a high priority. Otherwise as the generation and maintenance of an adequate pool of trained manpower for such tasks will impose severe operational limits on the spatial and temporal coverage of data having reasonable taxonomic discrimination. Advanced analytical methods for treating acoustic data will also be required.

9. RECOMMENDATIONS TO J-GOOS

The workshop participants agreed on the following procedural recommendations to the next meeting of J-GOOS.

1. J-GOOS should consider how the following issues should be addressed within the overall framework of GOOS:

   - critical marine habitats
   - living marine resources in coastal waters (including issues of biodiversity and genetics)
   - harmful algal blooms
   - diseases in relation to the health of humans and marine biota

2. J-GOOS should consult with its sponsoring organizations on the establishment of mechanisms to ensure the appropriate involvement of other agencies, in particular FAO.

3. J-GOOS should facilitate the formation of close working relationships between LMR-GOOS and existing bodies responsible for the collection of data at the higher trophic levels (e.g. fisheries agencies, environmental organizations, etc.). Their collaboration is needed both as contributors of the data they collect and as users of LMR-GOOS products derived from observations made specifically as part of the LMR-GOOS program. Formal structures to facilitate these relationships may need to be elaborated, and such bodies should be represented on the LMR-GOOS Panel in order that they may contribute to the planning process.

4. J-GOOS should undertake responsibility for issues of training and capacity building as an integrated GOOS-wide activity rather than it being addressed separately by each module.

5. It is recommended that a formal LMR Panel be established to take forward the planning of the LMR module as outlined above. Selected LMR Panel members should be members, or corresponding members, of planning groups for related modules (e.g. HOTO, Coastal). Suggestions for revisions to the previous Terms of Reference for the Panel and a proposed list of initial tasks for the Panel are given in Annex VIII.

6. Earth observation from satellites and aircraft will be an essential tool given the need to observe broad areas of the ocean on a regular basis. The workshop supports the proposal of J-GOOS to establish a panel on satellites which should ensure the consideration of requirements and needs of the different GOOS modules. This panel should include a representative from the LMR module for the necessary liaison.

ANNEX I

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ANNEX II

Agenda

FRIDAY, MARCH 1, ALL DAY:

1.0 Opening, Administrative Arrangements and Introductory Remarks.

The Chairman, *Dr. John Shepherd*, will open the workshop and review its objectives. Participants will be invited to adopt the agenda as circulated or to propose amendments. A Rapporteur will be identified. Logistical and administrative arrangements will be reviewed by *Elizabeth Gross.*

2.0 The Development of GOOS to date.

2.1 GOOS historical background *Flemming*

2.2 The Costa Rica LMR meeting, December 1993 - a review of the results and subsequent actions *Alheit*

2.3 Recent developments - J-GOOS II, the status of scientific planning for other components of GOOS, etc. *McCarthy*

2.4 Discussion of present status of LMR-GOOS planning
A round table discussion intended to expose participants' views on the status of LMR planning to date, major gaps in the Costa Rica document and the next steps required to advance LMR. *all*

SATURDAY, MARCH 2, MORNING:

3.0 Present Needs and Capabilities for LMR-GOOS

3.1 Customer needs *Flemming*
The identification of user, or customer, needs for GOOS observations related to living marine resources is a key issue in planning any future observing system. The topic will be introduced and all participants should be prepared to contribute to this effort based on their expertise. This focus on user needs for LMR-GOOS should assist in identifying the required scientific elements of the system .

3.2 Current observational capabilities *Dickey et al.*
LMR-GOOS should begin by taking advantage of existing observational capabilities and ongoing monitoring programs, such as the Continuous Plankton Recorder and CalCOFI time series, as well as satellite observations of ocean color and other variables. Participants will be asked to identify those current activities which can contribute to an observational system for marine living resources.

3.3 Modelling and LMR-GOOS *Robinson et al.*
LMR-GOOS should incorporate various types of modelling activities in order to make use of large amounts of data and to generate predictions required by GOOS customers. In particular, J-GOOS-II recommended that the workshop should focus on "simulation of plankton dynamics by mathematical models that are constrained by observations". Current modelling capabilities and future directions will be reviewed.

3.4 Synthesis of the discussion of present needs and capabilities for LMR-GOOS. *Shepherd*

SATURDAY, MARCH 2, AFTERNOON

4.0 Recruitment forecasting *Rothschild et al.*

One of the areas where LMR-GOOS can take advantage of the scientific understanding being gained in GLOBEC is in the field of recruitment forecasting. The second session of J-GOOS charged this workshop to "consider the hypothesis that ocean ecosystem simulation models will, within twenty years, be capable of addressing explicitly the classical fisheries problem of recruitment/mortality and the design implication for the GOOS Living Marine Resources Module."

5.0 Formation of drafting groups , First drafting session *Shepherd*

Groups will be formed to draft sections of the report of the workshop and recommendations on the following topics (and others as may be identified by the participants): user needs, observations, modelling.

SUNDAY, MARCH 3, ALL DAY

Drafting continues as needed.

MONDAY, MARCH 4, MORNING

6.0 Review and discussion of the draft reports *Shepherd and drafting group leaders*

7.0 Composition of LMR

- variables
- sampling strategies
- areas of concentration (key locations)
- pilot studies
- critical habitats

8.0 Capacity Building (Training and Technology Transfer)

MONDAY, MARCH 4, AFTERNOON

9.0 Large Marine Ecosystems *Sherman*

10.0 Relationships with Other Organizations and Programmes

11.0 Recommendations to J-GOOS *Shepherd and McCarthy*

The workshop will consider its recommendations to the next session of the Joint Scientific and Technical Committee for GOOS (J-GOOS) which will take place in Paris from April 23-25 1996. In addition to scientific and technical issues relating to the planning of an component of GOOS for observations relating to living marine resources, recommendations on the need for a formal LMR-GOOS Panel, its terms of reference, membership and next steps to be taken in planning for LMR-GOOS may be appropriate.

TUESDAY MARCH 5, MORNING

13.0 Further drafting, final review of text and adoption of the report of the workshop.

ANNEX III

Outline for the LMR-GOOS Workshop as Drafted by J-GOOS II

Excerpted from IOC-WMO-ICSU/J-GOOS-II/3
Annex XII, Attachment 2

DRAFT WORKSHOP OUTLINE
for
GOOS Living Marine Resources

During J-GOOS2 discussions on the status of the Living Marine Resources, it was determined that further development of this module could be facilitated by the development of an over arching design that specifically considers current and emerging capabilities relating to observations and models. To this end a workshop was proposed to assess options for a design philosophy for GOOS Living Marine Resources based on observations designed: (1) to assess the state of the plankton, fish, coral reef populations, etc... (2) to verify ecosystem models, or (3) to provide a combination of (1) and (2).

Specifically the workshop will:

(a) assess customer needs for management of living marine resources;
(b) review current and anticipated capability achieved by the following methods:
  (i) direct monitoring of the plankton by such tools as ocean colour, continuous plankton recorded
  (ii) simulation of plankton dynamics by mathematical models that are constrained by observations
(c) assess the potential of the observation and modelling technology expected to become available early in the 21st century in meeting customer needs;
(d) consider the hypothesis that ocean ecosystem simulation models will, within twenty years, be capable of addressing explicitly the classical fisheries problem of recruitment/mortality and the design implication for the GOOS Living Marine Resources Module.

The J-GOOS committee determined that the organization of the GOOS Living Marine Resources workshop would be most effective if conducted in concert with GLOBEC. J-GOOS appreciates the offer of SCOR and the Secretary of IOC to involve the GLOBEC community in this endeavour. The conclusions and recommendations of this workshop will ne reported to the J-GOOS3 meeting in Spring 1996.

Arrangements

A four-day meeting to be held before Spring 1996

Participants

Circa 25 participants to be drawn from the following communities:

- Fisheries oceanography
- Biological oceanography
- Ecological modelling

J-GOOS Committee Representatives

J. McCarthy, G. Holland, J. Woods

ANNEX IV

List of Documents

BACKGROUND PAPERS AND WORKING DOCUMENTS

B1	Executive Summary, Costa Rica Meeting, December 1993.
B2	J-GOOS, Report of the Second Session, April 1995.
B3	GLOBEC Science Plan, October 1995.
B4	Initial Priorities for GOOS.
B5	GOOS Living Marine Resources Module, Background Information.
B6	Small Pelagic Fishes and Climate Change, Report of the First Planning Meeting GLOBEC Report No. 8.
B7	Small Pelagic Fishes and Climate Change (SPACC) Programme of GLOBEC. First Implementation Planning Meeting, Swakopmund, Namibia. 4-8 December 1995.
B8	Interdisciplinary Model Formulation and Parameterization, Report of the Second Meeting of the International GLOBEC Numerical Modelling Working Group, Nantes, France, July 17-20, 1995.
B9	Critical Variables and Their Observation. A document prepared by Tommy Dickey for the International GLOBEC Numerical Modelling Working Group Meeting. Nantes, France, July 17-20, 1995.
B10	IOC Workshop on Ocean Colour Data Requirements and Utilization. Sidney, Canada, 21-22 September 1995. IOC Workshop Report No. 119.
B11	GOOS Information Sheet.
B12	GOOS Reporting and Management Lines.
B13	Shepherd conceptual diagram of interrelationships of GOOS modules and scientific disciplines.
B14	E-mail message, Serge Garcia (FAO) to Rothschild, Shepherd et al., 2/23/96.
B15	Draft proposal for revisions of terms of reference for GOOS-LMR.
W1	List of Participants.
W2	Agenda.

ANNEX V

IOC Information Sheet on GOOS

THE GLOBAL OCEAN OBSERVING SYSTEM

Rationale

Today we are experiencing unprecedented pressures on our natural resources. Sustainable development of these resources is hindered by our inability to detect emerging environmental problems at an early stage when remedial measures are still possible. Nowhere is this inadequacy so pronounced as in the marine area. The global energy cycles and biological processes that are part of the natural system upon which all life depends are critically linked to the ocean. Governments collectively are only now beginning to recognize the complexity and interdependence of all aspects of this system. Systematic global observations of the world oceans are required to improve our knowledge and predictive capabilities which will be the basis for more effective and sustained use of the marine environment, with associated economic benefits.

Background

The Global Ocean Observing System (GOOS) was initiated by the Intergovernmental Oceanographic Commission (IOC). The World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP) and the International Council of Scientific Unions (ICSU) agreed to co-operate in this endeavor. The Second World Climate Conference (SWCC) and the United Nations Conference on Environment and Development (UNCED) encouraged nations to support the development of GOOS.

GOOS is aimed at establishing a global framework for systematic ocean observations to meet the needs of a wide range of users having immediate practical purpose as well as long term concerns such as :

- assessing the state of the marine environment, its health and its resources, including the coastal zone;
- detecting and forecasting climate variability and environmental changes;
- supporting an improved decision-making and management process - one which takes into account potential natural and man-induced changes in the ocean environment and the consequent effects on human health and resources.

The major elements of GOOS are operational oceanographic observations and analyses, timely distribution of data and products, data assimilation into numerical models leading to predictions, and capacity building within participating Member States to develop analysis and application capability.

GOOS will be developed on a sound scientific basis using the findings of existing, on going research programmes including WOCE, CLIVAR, GLOBEC, JGOFS and LOICZ. Operational programmes including IGOSS, IODE, GLOSS and MARPOLMON form a foundation. GOOS will utilize operational and cost-effective observing methods, both remote sensing and in-situ measurements obtained from ships, towed and anchored systems, drifting buoys, sub-surface floats and coastal stations.

Emphasis will be placed on the open exchange of data with data bases accessible to all participating countries.

The Planning presently encompasses five modules:

(i) Climate Monitoring, Assessment and Prediction; this module is common with the ocean component of the Global Climate Observing System (GCOS);
(ii) Monitoring and Assessment of Marine Living Resources;
(iii) Monitoring of the Coastal Zone Environment and Its Changes;
(iv) Assessment and Prediction of the Health of the Ocean;
(v) Marine Meteorological and Oceanographic Operational Services.

Organisation

A Joint IOC-WMO-UNEP Committee for GOOS (I-GOOS) serves as an intergovernmental forum for GOOS planning and development. This Committee established a Strategy Sub-Committee to:

- define the objectives, products and outcome of GOOS
- provide a broad plan of implementation
- set and review the priorities

Three implementation Panels under their authority are working on (1) products, (2) capacity building and (3) technical issues.

A Joint IOC-WMO-ICSU GOOS Technical and Scientific Committee (J-GOOS) provides advice to sponsoring agencies on technical and scientific aspects of GOOS design, planning and development.

For each module, scientific and technical Panels will be established aimed at designing and continuously reviewing the most efficient network of observations adequate to meet identified needs and provide answers to the issues raised by Member States. Continuous feedback will exist between implementation and scientific Panels.

Strategy

GOOS is being developed in a phased approach:

(i) a planning phase including conceptualization, design and technical definition:

(ii) operational demonstrations for each of the five modules including

- pilot projects for specific aspects of global scale phenomena
- integrated observing systems on a regional scale

(iii) implementation of permanent elements of the Global Ocean Observing System

(iv) continued assessment and improvement in the individual aspects of the entire system.

Emphasis will be placed in areas where practical applications can be obtained in a relatively short period of time.

Status and plans

- I-GOOS, its Strategy Sub-Committee (SSC) and J-GOOS established and functioning.
- Outline of a strategic plan provided by SSC.
- Scientific Panels: Health of the Ocean (HOTO) Panel developing a Strategic Plan
  Ocean Observations Panel for Climate (OOPC) established to provide a procedural plan consistent with provided scientific design
- Implementation Panels : Capacity Building Panel being established.
- Promote socio economic studies to help countries to identify the expected benefits of GOOS. Cost-benefits methodology and analysis to be undertaken with the help of OECD experts.
- Meeting of Heads of National Agencies planned in Washington to agree on priority elements of GOOS.
- Regional approach encouraged and two regional programmes being implemented (EuroGOOS and NEARGOOS)
- On-line www server providing general information on GOOS development established at IOC.

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updated on Jan 11 1996

ANNEX VI

Executive Summary Report of Costa Rica Meeting

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

EXECUTIVE SUMMARY OF THE FIRST SESSION OF THE *AD HOC* PANEL FOR THE MONITORING AND ASSESSMENT OF LIVING MARINE RESOURCES MODULE OF THE GLOBAL OCEAN OBSERVING SYSTEM (GOOS)

San Jose, Costa Rica, December 7 - 10, 1993

MODULE DESIGN AND FOCUS

The purpose of the Panel's meeting was to define and design a Module for the Monitoring and Assessment of Living Marine Resources (LMR) of the Global Ocean Observing System. The List of Participnts, Terms of Reference, and Recommendations are attached in Appendices I, II, and III, respectively.

As part of an earth observing system, the LMR Module should be oriented to applied-operational design and logistics. It should be pragmatic and produce observations on the state of living resources and the ecosystems within which they exist. The observations should be subjected to appropriate analyses that yield conclusive answers to significant questions. The scope of the Module should be global and focused on long-term and broad-scale monitoring. It should be reflective of the concerns and objectives of UNCED regarding climate change, both natural and/or man induced, and biodiversity. Further, it should concentrate on the monitoring of species abundance and trends in the context of regime shifts, ecosystem changes and resource sustainability.

Providing information for assessments and predictions of fishery stocks will be a principal goal of the Module. Currently, this is attempted at the local or national level, and to a much lesser extent at the regional level. The LMR Module will be concerned with augmenting and adding to the regional programs and expanding to a global effort. This will be done in several ways. First, information will be provided for globally focused bodies, like FAO, and regional bodies to conduct assessments of LMR and their environment. Second, the Module will provide specific data for use as inputs to regional and global models that can be used to detect or predict ecosystem changes, such as regime shifts. Third, critical issues or events can be focused on by the production of information products such as "red flag" reports.

INTEGRATION AND COORDINATION

The issues of change and persistence of LMR and the necessity to contribute information suitable for effective management is an enormous task requiting multiple disciplines and efforts. The long-term , broad-scale approach advocated for this Module establishes a basis for collaboration and integration with other monitoring and process-oriented programs. There is a rich history of monitoring fisheries and plankton. Observations have been collected that form long time series, span significant spatial scales, and use routine collection methods and standardized protocols. Examples are FAO, the primary agency responsible for monitoring the global status and trends of fisheries resources and critical habitats, and the Continuous Plankton Recorder Survey (CPR) which has monitored plankton annually in the North Atlantic since 1931.

Although this module will be concerned with applied functions of monitoring LMR, it is necessary to incorporate and build on the best available scientific knowledge. In that respect, it is important for the Module to coordinate with existing research or process-oriented programs. GLOBEC.INT, the International Global Ocean Ecosystem Dynamics Program, whose mission is to understand the effects of physical processes on trophodynamics and population regulation of zooplankton and related fishery resources, is an example of a science driven project.

REGIME SHIFTS

Recently, there has been a change in the perceptions of fishery scientists concerning the basic nature of fish population variability. The conventual view has been that fish populations inhabiting different marine ecosystems vary independently of one another largely in response to fishery exploitation, population density dependence, and a random component of environmental variability. However, the observations of the last two decades reveal that populations in distant parts of ocean basins may be pulsing in rhythm with one another on decadal or longer time scales. It presently is not clear what are the causal mechanisms for the biological changes. What is clear is that there frequently is an abrupt change in the level and structure of the environmental variables. These "regime shifts" can be defined as substantial qualitative changes in an ecosystem which often are characterized by changes in the dominance or replacement of certain fish species along with associated zoo- and phytoplankton populations.

There are several reasons why regime shifts deserve the focus of this Module within GOOS. First, these shifts account for a major portion of the temporal variation of ecosystem components as well as variation among the components themselves. Second, they imply broadly correlated and persistent changes rather than short term changes in one or two species at one or two locations. Third, adverse risk is amplified for resource based and related social systems affected by the magnitude of regime shifts.

Small pelagic fishes, such as sardines, anchovies and sprat, are excellent candidates for monitoring within the LMR Module of GOOS. Their annual catches are among the world's largest, they occur in the major ocean basins including the waters of many of the developing countries, and their variations are suggestive of regime shifts. There are valuable time series documenting decadal scale shifts for pelagic clupeoid species in boundary current regions. Therefore, the Panel recommends the establishment of pilot projects to monitor small pelagics in the Humboldt Current region and the Arabian Sea.

CRITICAL ECOSYSTEMS

Critical coastal ecosystem are areas with important economic resources and that provide substantial recreational activities. In addition, they are probably some of the most vulnerable ecosystems due to their close proximity to the land-sea interface and anthropogenic influences. Some of these ecosystems, such as coral reefs, mangroves and seagrass beds are an economic necessity to tropical developing countries because they contribute most of the protein to the diets of the growing populations as well as contributing to incomes through tourism. The Panel acknowledges the importance of these systems and recommends the long-term monitoring of coral reefs as a priority of the LMR Module of GOOS.

MONITORING

The monitoring of LMR is essential to GOOS if it is to fulfill a role of contributing to sustainable use. It can help form the scientific basis of conservation, harvesting and management decisions. Primary users are national governments, regional organizations and non-governmental environmental organizations.

Fisheries

Fishery assessments require data on biological characteristics, harvesting statistics and fishing activity. Fishery independent statistics also are desirable. The frequency of data collection in heavily exploited fisheries should be annually. The spatial scale of fishery monitoring should be sufficient to conduct assessments at the "stock" level (a group of interbreeding animals) and a "management unit" level (a fishery subject to a uniform set of regulations).

The LMR module should facilitate the routine assessment of important fishery resources on a global and regional scale because: 1. LMR are often global commodities such that the local status of resources often has global significance. 2. The effects of climate variability often are seen only on regional or global scales. 3. There is widespread interest on the part of governments, international policy makers and the public about the overall condition of fisheries.

The Panel recommends the following concerning fisheries monitoring and assessments: 1. Routine assessments of fisheries on regional and global scales need to be improved by addressing inadequacies in national efforts and making appropriate institutional arrangements to conduct coordinated assessments. 2. Lack of funding for resource assessments in developing countries is an acute problem that needs to be addressed. 3. FAO's activities in regional and global assessments, monitoring critical habitats, and assisting developing countries need to be augmented and integrated with this Module of GOOS. 4. Integration and cooperation with the World Bank's Global Environmental Fund (GEF) activities for Large Marine Ecosystems (LME) are desirable.

Plankton

Major applications for plankton monitoring information within GOOS are in resource and climate evaluations. Inter-annual variability of many resource species (i.e. recruitment) may be associated with or driven by tropodynamic linkages with plankton. In turn, plankton variability may be directly driven by linkages with physical (environmental-climate) forcing factors. In addition, plankton monitoring provides an independent baseline estimate of natural variability in the marine environment.

The Panel concurs that the overall goal of the Module for plankton monitoring is to characterize broad scale status and trends in zooplankton species composition and biomass. This should be done at the level of basin scale coverage and a range of time scales from seasonal to continuous multi-decadal.

FUTURE ACTIVITIES

1. The Panel suggested that the next meeting be held in La Paz, Mexico in July, 1994. This will be in conjunction with a GLOBEC.INT meeting on small pelagic fisheries, a recommended focal topic for the Module.

2. The Panel needs to elect a Vice-Chairman and consider augmenting the membership.

3. Relationships with other GOOS Modules, UN Programs, and external organizations need to be discussed.

4. The Panel needs to consider endorsement of specific monitoring technologies.

5. Information products need to be prioritized.

6. Costs and resource requirements for Module implementation have to be determined.

7. The Panel needs to devise a timetable for Module implementation.

8. A specific statement regarding the Panel's recommendations concerning training and technical assistance should be written.

FIRST SESSION OF THE *AD HOC* PANEL FOR THE MONITORING AND ASSESSMENT OF LIVING MARINE RESOURCES MODULE OF THE GLOBAL OCEAN OBSERVING SYSTEM (GOOS)
San Jose, Costa Rica, December 7 - 10, 1993

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FIRST SESSION OF THE *ad hoc* PANEL FOR MONITORING AND ASSESSMENT OF LIVING MARINE RESOURCES MODULE OF THE GLOBAL OCEAN OBSERVING SYSTEM (GOOS)

San Jose, Costa Rica, 7-10 December, 1993

TERMS OF REFERENCE

(i) Provide advice to the Global Ocean Observing System Scientific and Technical Committee on the development of a Module for Monitoring and Assessment of Living Marine Resources.

(ii) Specify the deliverables and products for user needs.

(iii) Identify present and potential users of existing data of GOOS Living Marine Resources information and relate Module design and operations to their needs.

(iv) Define the sampling requirements and observations necessary for Living Marine Resources with particular reference to: 1. global focus 2. routine collection 3. cost effectiveness 4. existing programs 5. data management.

(v) Develop a written plan for the design and implementation of an operational collection and monitoring system of Living Marine Resource parameters relevant to climate change, ecosystem-biodiversity change and fluctuations in renewable resources. The plan should be based on the best scientific knowledge.

(vi) Incorporate, in so far as possible, elements of training, mutual assistance and capacity building for developing countries into planning and implementation.

(vii) Effectively integrate developing coastal states, within the range of their capabilities, into the System and its operations and include regions where appropriate data have not been previously collected.

(viii) Be cognizant of and coordinate with appropriate Living Marine Resource research programmes and organizations to ensure that Module recommendations and activities are up to date and relevant.

(ix) Be fully responsive and cooperative to all other panels and committees within GOOS as well as all coordinating bodies and cooperating Agencies. Mechanisms for coordinations should be specified.

(x) Produce the final draft plan by the end of March 1994.

FIRST SESSION OF THE *ad hoc* PANEL FOR MONITORING AND ASSESSMENT OF LIVING MARINE RESOURCES MODULE OF THE GLOBAL OCEAN OBSERVING SYSTEM (GOOS)

San Jose, Costa Rica, 7-10 December, 1993

PANEL RECOMMENDATIONS

1. The Panel recommends as an immediate priority a focus on interdecadal variability in marine ecosystems. As a first step, it recommends that two pilot projects for this GOOS module be initiated in the Humboldt Current and the Arabian Sea. Particular reference should be given to the well-documented regime shifts of small pelagic fish populations in these ecosystems. The pilot studies should include a trial extension of continuous plankton sampling technologies to these regions.

2. The Panel recognizes that global coverage requires extensive operational sampling and analytical efforts outside those ecosystems specifically recommended as GOOS pilot studies. We recommend that IOC contact organizations including PICES for the North Pacific, ICES for the North Atlantic and CCAMLR for the Southern Ocean for collaboration.

3. A sub-panel should be formed to develop and coordinate a long-term global monitoring system of <u>critical coastal ecosystems</u> which would create a globally coordinated monitoring network involving national managers and scientists so they can exchange physical, biological and socio-economic data with regional and global data bases. This will require an internationally organized system (GOOS) of nationally based programs.

4. The Panel recognizes that FAO is the lead UN Agency for sustainable use of fishery resources. It strongly recommends that FAO be invited to cosponsor the GOOS- LMR Module, and to submit its views on a strategy to strength capability for regional and global assessments of fishery resources in relationship to sustainable use, global climate variability, and biodiversity.

5. Recognizing that the World Bank Global Environmental Fund (GEF) has committed funding to multiyear studies of "Large Marine Ecosystems" (LME) off West Africa and the Yellow Sea, that these LME Studies include elements that are similar to elements of GOOS, and that the GEF might be a funding option for implementation of GOOS in developing countries, the Panel recommends that the organizers of LME studies be invited to submit information on these studies and views on their relationship to GOOS.

6. The GOOS Program Office should use the opportunity of the Third WESTPAC IOC Regional Subsidiary Body meeting which will be held in November 1994 in Indonesia to explain the GOOS- LMR plans and activities so as to invite ideas about the usefulness of GOOS for this region. Moreover, other such opportunities should be sought.

ANNEX VII

IOC Background Paper

Background:

The Memorandum of Understanding between the sponsoring agencies for GOOS was agreed in September 1993, and the first meeting of an *ad hoc* Panel appointed to discuss the LMR-GOOS Module was held in Costa Rica on 7-10 December 1993. The Joint Scientific and Technical Committee for GOOS (J-GOOS) had not yet been established. Several documents were prepared for the Costa Rica meeting, and an Executive Summary was published and circulated. An analytic final report was drafted but not published. J-GOOS was set up in 1994, and held its second meeting in April 1995. The Intergovernmental Committee for GOOS (I-GOOS) also held its first two meetings in the period 1994-1995. By the time of the second meeting of J-GOOS it had been decided that the Panels analyzing the design of each GOOS Module should report to J-GOOS, and J-GOOS II accordingly suggested that the Terms of Reference for the LMR Module Panel should be reviewed at a Workshop Meeting, and that the output from the Costa Rica Meeting should be studied carefully as the basis for further progress. The Executive Summary report from the Costa Rica meeting was circulated as a briefing document for the Workshop (and is attached as Annex 6 to this Report) Furthermore, an updated background paper presented at the workshop in order to provide information on more recent developments is found in Annex 7 (this annex).

GOOS LIVING MARINE RESOURCES MODULE
Background Information

This document was produced by IOC in consultation with SCOR and GLOBEC and is meant to serve as background information stimulating the discussion among the participants at the GOOS Living Marine Resources Workshop in Dartmouth, Massachusetts, USA, 1-5 March 1996. Sections of this document are taken from different documents presented subsequently to the First Session of the *ad hoc* Panel for the Monitoring and Assessment of the Living Marine Resources (LMR) Module of GOOS (San Jose, Costa Rica, 7-10 December 1993). This document now includes *inter alia* sections from the draft report written by Geoffrey Laurence on LMR as the Technical Secretary for the above-mentioned Meeting and sections of a report submitted to IOC by Jürgen Alheit covering descriptions of GLOBEC sub-programmes. Furthermore, IOC has added information on the Continuous Plankton Recorder Survey, Harmful Algal Bloom Programme and Remote Sensing.

INTRODUCTION

Today's environmental problems require an identification, understanding, and monitoring of the effects of human activities on natural resources. This is especially true for the oceans, where close proximity of increasing population centres and the relentless exploitation of natural resources causes unprecedented pressure. The most effective way to mediate this situation is to improve our knowledge and predictive capabilities to allow a proper balance between the sustainable use of the ocean's resources and the economic, social, and political requirements of the world community.

The Global Ocean Observing System (GOOS) has been proposed by the Intergovernmental Oceanographic Commission (IOC) in cooperation with UNEP and WMO. It is designed to provide a long-term data base of relevant ocean observations collected within a globally coordinated strategy. The data will be used to identify, understand, analyze, and predict coastal and ocean processes, marine environmental changes, and interactions with the atmosphere and terrestrial systems. GOOS is expected to be based on the integration of existing research and monitoring programs. All the world's interested nations are being asked to support GOOS within their capabilities.

The establishment of a LMR Module of GOOS is important in view of the current exploitation of the marine environment. This is particularly true for developing countries, where the need for a reliable and sustainable access to highly nutritional food provided by the marine living resources is of vital interest. Consequently, the organization and management of the marine environment is not only needed in coastal zones but also for the oceans in general.

Furthermore, this management of living marine resources shared between the countries at a regional and global level requires coordination and following cooperation. IOC could, in this regard, serve as a facilitator and through the GOOS-LMR module provide a way to achieve knowledge on the state of the marine environment. Decisions as to what kind of observations would be appropriate in terms of living marine resources should be taken from the recommendations of this workshop.

INSTITUTIONAL FRAMEWORK

As proposed at the Second Session of J-GOOS in 1995 and agreed by the Second Session of I-GOOS in 1995, a joint GOOS-GLOBEC Workshop on the Development and Design of the Living Marine Resources Module for GOOS should be organized. The workshop was scheduled for spring 1996, with invitations to about 25 experts with interdisciplinary backgrounds related to living marine resources such as; fisheries oceanography, biological oceanography and ecological modelling. The draft outline of the workshop was presented in the J-GOOS-II report, Annex XII. Here it was specifically noted that the workshop should:

* assess the customer needs for management of living marine resources;
* review current and anticipated capability achieved by methods to monitoring plankton by tools such as ocean color and continuous plankton recorder (CPR);
* consider simulation of plankton dynamics by mathematical models that are constrained by observations;
* assess the potential of the observation and modelling technology expected to become available early in the 21st century in meeting customer needs;
* consider the hypothesis that ocean ecosystem simulation models will, within twenty years, be capable of addressing explicitly the classical fisheries problem of recruitment/mortality and the design implications for the GOOS Living Marine Resources Module.

Furthermore, it was recommended that the organization of the GOOS-LMR workshop would be most effective if conducted in collaboration with GLOBEC. It was suggested at the Second Session of J-GOOS to consider linking the LMR-GOOS Module with the GOOS Coastal Ocean Module, since there is an overlap between the two modules.

The LMR Module of GOOS was adopted by IOC along with *inter alia* modules for climate, marine meteorologic and oceanographic services. At the Eighteenth Session of the IOC Assembly, FAO expressed its interest to cooperate with the Living Resources Module of GOOS. In view of further developments of this Module, it was emphasized the importance of strengthening the linkage between relevant IOC activities and the fisheries community.

The willingness of FAO to participate in the *ad hoc* Panel of Living Marine Resources was also declared at the Second Session of I-GOOS. At same Session "the representative of ICES highlighted the role that the marine information products delivered by this organization can play within the framework of the implementation of this module. He welcomed the collaboration with

GLOBEC. ICES is a lead sponsor of the GLOBEC Cod and Climate Programme and is in the process of establishing a North Atlantic Cod and Climate Project Office to be manned by a Professional. This office will provide an important focus for the involvement of ICES in GOOS activities". At the Second Session of J-GOOS consideration was given to stock assessment. It was recommended that this should be left with FAO and other bodies with existing responsibilities in the area.

The draft strategic plan of the *ad hoc* Panel was reviewed by J-GOOS at its Second Session and it was noted that very little progress was made since the previous session. At present, the panel is not active. However, the Terms of Reference and draft recommendations for the LMR module were produced and can be found in the Summary Report of the First Meeting of the *ad hoc* Panel of LMR.

A SPECIFIC FOCUS ON LIVING MARINE RESOURCES

Finfish and shellfish are not the only living marine resources, but they, alone, provide justification for the LMR module. The global commercial catch has increased more or less steadily for the last three decades. Global revenues to fishermen are about $70 billion (1/3 of marine oil and gas), and provide more animal protein than poultry, beef, or lamb.

Most scientists agree that the recent leveling of worldwide catch indicates that global fish stocks are now fully, or over-exploited, and that a significant long-term increase is unlikely. In fact, FAO reports about 1/3 of the stocks it tracks as being heavily or over-exploited, or depleted. It is also noteworthy that there is insufficient information to judge the status of a large number of stocks.

Providing information for assessments and predictions of fisheries stocks used for input to management decisions should be a major effort of the GOOS LMR module. Currently, this goal is attempted at the local or national level for individual stocks and management decisions. For example, several different types of data are assimilated in resource assessment models that hindcast, nowcast, and forecast population trajectories.

In addition to local assessment uses of GOOS LMR data, two types of regional and global assessments are envisioned:

First, panels of experts will conduct regional and global assessments of LMRs and their environment. Currently, the Food and Agricultural Organization of the United Nations (FAO) and its regional bodies conduct regular assessments of fishery resources (by summarizing data available from local sources), but these assessments are limited by inadequacies in existing monitoring programs, difficulties in access to timely and comprehensive resource assessments, and the lack of consideration of the efforts of climate variability. GOOS-LMR will correct many inadequacies in data collection. Also, institutional arrangements should be made to strengthen and expand regional and global assessments, to make full and timely use of all the available information and expertise.

The second type of assessment and prediction activity of the GOOS-LMR Module will use specific data streams as inputs to regional and, ultimately, global models. Initially, these will be statistical models that can be used to detect or predict ecosystem changes such as regime shifts.

In the future, GOOS data streams will be used as input to more basic ecological process programs, such as dynamic models of primary and secondary production like those being developed by JGOFS and GLOBEC. These models are relevant to sustainable use, global change and climate variability.

There is another reason to broaden the scope of the LMR module of GOOS from traditional taxonomic groups of higher trophic level animals. There is increasing concern about the overall biodiversity of the biosphere, including the oceans. The Convention on Biological Diversity, signed at the United Nations Conference on Environment and Development (UNCED), calls for monitoring of components of biological diversity. One rationale for this concern is that biodiversity is a storage bank of genotypes for a rigorous selective adaptation to future environmental change within the evolutionary process. Another, more pragmatic one, is that biodiversity reflects the number of biochemical options (i.e., genetic diversity) that are available as raw material for future products of emerging biotechnology industries. In this sense, all of the biota of the oceans are living marine resources. There may be some critical marine habitats (e.g., coral reefs, mangroves) where those problems are an issue. Biodiversity monitoring will be a priority in these critical habitats. In this regard there is an obvious link to the coastal component of GOOS.

Another aspect of the global trend in fisheries yield is the shift from developed to developing countries. The latter now accounts for over half of the global yield. This means that the LMR module of GOOS will depend on broad participation by the global community of nations.

The term LMR applies to more than fish, and so, too, should the LMR module of GOOS. Marine mammals, sea turtles, sea birds, and plankton are important components, either for direct usage, or as linkages with fisheries through trophic interactions. In most cases they interact with fisheries, either through predator/prey interactions or by catch (i.e., unintentional catch along with target species of fish).

The users of the living marine resource module of GOOS will need observations on more than just the resources. In order to use wisely the higher trophic level animals, information on the ecological variables that influence them is also required. Ultimately, the goal is to use this information for predictions, but it is also useful to help evaluate alternative hypothesis about the current and past state of LMRs.

The conclusion is that the LMR module of GOOS should measure the state variables of marine ecosystems that either characterize the system's value to humans, or help to explain or predict the state of the system. Of course, this definition of the module is too broad to be of practical use in selecting a parsimonious set of observations for a GOOS module. Developing and refining design criteria to prioritize the collection and use of observations is a critical step.

INTEGRATION WITH INTERNATIONAL PROGRAMMES RELEVANT TO GOOS-LMR

The establishment of a GOOS Living Resources Module requires multidisciplinary coordination and organization to ensure an effective management. Consequently, an extended coordination and access to data provided by other global programmes are obviously important. To provide the participants with an overview of some of the most relevant programmes that may relate to GOOS-LMR, we have enclosed here a short individual description. However, this is only a short list and further suggestions for coordination with other relevant programme are most welcome and it is in fact anticipated to be an outcome of the Workshop.

As already stated in the Terms of Reference of the previous *ad hoc* Panel on LMR, the identification of, and coordination with the user group, is important.

Fisheries related programmes

The spatial scale of fisheries monitoring should be sufficient to conduct assessments at the "stock" level (i.e., groups of animals that mix and interbreed) and "management unit level" (fishery subject to a uniform set of regulations). Ideally, stock and management units correspond. The size of stock and management units ranges from entire ocean basins from some highly migratory, large, pelagic fishes, to a few square kilometers for localized shellfish beds. Monitoring programs are designed to provide data for resource assessment models (model driven). These models hindcast and nowcast population abundance, and forecast far enough ahead to support fishery management decisions.

Monitoring of fishery resources is an essential element of GOOS, if it is to fulfill its goal of contributing to sustainable use. The relevance of climate change and how this effects fishery resources is likewise important. This problem is scientifically questioned in several of the GLOBEC field programmes. Fishery resources also contribute an important component of marine biodiversity.

Relevant FAO and ICES existing or developing programmes on fisheries monitoring will have to be taken into account in the development of this component of the GOOS-LMR Module.

FAO is the principal body concerned with a world-wide focus on fisheries. Its particular interests include fisheries in sensitive critical habitat areas such as coral reefs, mangroves, large tropical estuaries, upwelling systems, sea grass beds, lagoons, etc. In addition, FAO is the UN Agency with the mandate for monitoring status and trends in fishery resource populations on a global basis. FAO has eight regional fisheries commissions established to facilitate this.

There is a number of regional organizations that deal with fisheries, either directly by setting regulations, and/or indirectly by monitoring stocks and providing scientific or assessment information for management purposes. Primary examples of these regional organizations include:

1. *CCAMLR - The Convention on the Conservation of Antarctic Marine Living Resources*, negotiated within the Antarctic Treaty, manages all living organisms within the area south of the Antarctic Convergence.

2. *ICES - The International Council for Exploration of the Sea* provides scientific advice for management of living resources in the North Atlantic with a focus on the Eastern region.

3. *NAFO - The Northwest Atlantic Fisheries Organization* deals with the region implicit in its name.

4. *PICES - The North Pacific Marine Science Organization* is a newly formed regional organization concentrating on living marine resource issues in the North Pacific.

5. *ASEAN - Living Coastal Resources Project* - this program monitors coastal resources of the Southeast Asia region.

In addition, there are organizations concerned with single species or species groups such as the International Pacific Halibut Commission and the International Tropical Tuna Commission. Finally, a majority of the world's countries have some level of nationalized monitoring and assessment effort.

Critical marine ecosystems

On a global level the loss of habitats seems to be occurring at a very fast rate. It is obvious that the first step would be to map critical marine habitats, for some of which the location is partially or totally unknown. Information on both the location and the state of health of these ecosystems would help decision-makers develop rational policies, especially at the national level. This would be specifically aimed at the sustainable use of natural habitats, as well as their preservation. Furthermore, the decision-making community should be informed on priorities in research activities, in order to address scientific uncertainties, e.g. those related to the role of marine biodiversity in ecosystem functioning. The establishment of monitoring systems for marine critical habitats would allow, from a scientific viewpoint, to collect information for carrying out further investigations.

Critical Marine Ecosystems are areas with important resources and significant services. However, they are probably the most sensitive and vulnerable ecosystems due to their location at the land-sea interphase. Some of these ecosystems are economically vital and are an asset to tropical countries since they contribute most of the protein to the diet of growing populations, as well as income through tourism.

Priority should be accorded to coral reef ecosystems, estuaries, temperate and tropical wetlands, including mangroves, sea grass beds, other spawning and nursery areas, as underlined in the comprehensive plan of action "Agenda 21" developed by UNCED in 1992. Also lagoon, sandy beach and rocky shore ecosystems can be considered as critical.

The important resources and services provided by critical coastal ecosystems are summarized as follows:

1. *Coral reefs* - Spawning and nursery ground for fish and invertebrates; mollusc and fish production; shoreline protection; beach sand replenishment; tourism and recreation; algal harvesting; aquaculture; ornamental species; biodiversity; building materials.

2. *Mangroves* - Fishery resources; breeding and spawning ground for fish and invertebrates; net transfer of production to coastal fisheries; nursery ground for coastal and estuarine species; shoreline protection; beach timber; fuel; tanning and other chemicals; sediment and nutrient filter; aquaculture.

3. *Sea grass beds* - Net transfer of production to coastal fisheries; feeding habitat for marine turtles, marine mammals and fishes; nursery grounds for coastal fisheries; nutrient and sediment filter.

4. *Estuaries and deltas* (including associated mud flats and embayments); fisheries production; nursery and spawning areas for many coastal fish; nutrient influx to aquaculture.

5. *Beaches* - Nesting habitat for birds and sea turtles; fish habitat; recreation and tourism; mining of sand.

6. *Bays, gulfs, and semi-enclosed areas (including fjords)* - Fish and invertebrate production; aquaculture; recreation and tourism; breeding and spawning ground for many marine organisms.

Physical changes induced by natural and anthropogenic disturbances make an early and definitive impact on coastal ecosystems. These ecosystems are good indicators of changes in the environment due to their ecological nature.

The IOC has presently two monitoring systems related to critical marine habitats, one on coral reefs (under development) and the other on sea grass beds (under design). They are both global monitoring systems.

The Global Coral Reef Monitoring Network (an IOC, UNEP, WMO and IUCN joint exercise) was developed as part of the Coastal Zone Module of GOOS. But it definitely overlaps the objectives of the LMR Module, and important information for the LMR Module can and should be taken from the Global Coral Reef Monitoring Network activity.

This activity was originally designated because coral reefs have a pan-tropical distribution and are ideal indicators of climate change (since their major components - the benthic corals - are highly sensitive to environmental forcing). For this reason, through their careful monitoring, it should be possible to distinguish climate from anthropogenic impacts or biotic interactions.

In the field of sea grass bed monitoring, the IOC is designing a global sea grass bed network, with a strong monitoring component. The exercise is still at an early stage, but will hopefully lead to the development of a monitoring network for the collection of continuous information on sea grass beds through the monitoring of a few selected physical and biological parameters.

During the last two decades considerable scientific progress has been made in the study of sea grass beds and in understanding their role as natural ecosystems. Today it is well known that sea grass ecosystems play a significant and unique ecological role in most of the coastal zones in tropical as well as in temperate areas. Furthermore, they are increasingly recognized as an important marine living resource.

Since 1993 IOC has been collecting information from various countries on their resources and needs in the fields of sea grass bed research, management, and related training and education, as an initial response to UNCED's requests. Data have also been gathered on the location of sea grass beds, their state of health and natural/anthropogenic environmental changes in the areas where they are located. These data are presently being processed. The exchange of information among sea grass bed laboratories and other institutions, which is being promoted by IOC, will avoid duplication of research efforts on sea grass ecosystems and promote scientific co-operation.

IOC is also assisting in the training of researchers and technicians from developing countries by dissemination of information on planned training courses and in-house training possibilities offered by laboratories and other institutions. Training courses on how to record marine biodiversity, including sea grass ecosystems, will be organized in the near future.

Collection of information on the state of health and the dynamics of sea grass beds, the processing of those data and information, their elaboration and presentation in an accessible format, will advise on the rational utilization of these living resources.

GLOBEC and GOOS-LMR

The programme Global Ocean Ecosystem Dynamics, GLOBEC is one of the Global Change Core Projects of the International Geosphere-Biosphere Programme (IGBP). It is sponsored by SCOR (Scientific Committee on Oceanic Research), IOC and IGBP. ICES (International Council for the Exploration of the Sea) and PICES (North Pacific Marine Science Organization) are sponsors of important regional components of GLOBEC, namely Cod and Climate Change (ICES) and Carrying Capacity and Climate Change (PICES).

One of the aims of GLOBEC is eventually to be able to predict the impact of climate change on the living resources in the oceans. Sub-components of GLOBEC are addressing the scientific problems concerning the impact of the future climate variability on the marine ecosystem and its living resources.

To be able to answer these questions, it is considered important to ensure comprehensive and continuous measurements of oceanographic data, e.g.: atmospheric, physical, chemical and biological oceanic parameters. It is one of the tasks of GLOBEC to determine which variables should be measured and to develop new observational and sampling systems. Consequently, future research and monitoring conducted under the GLOBEC programme could form a scientific basis which could be beneficial for several components of GOOS. In view of these developments, cooperation between the two programmes should be established with respect to the LMR module.

GLOBEC programme structure

The GLOBEC Core Programme activities consist of Working Groups and several major field study components. The three scientific working groups focus upon:

- Zooplankton Population Dynamics and Physical Variability
- Numerical Modeling, Sampling and Observation Development
- Retrospective Data Analysis.

The task of the Working Groups is to provide advice and to provide a theoretical basis. The four major field research programmes are:

Cod and Climate Change Programme (CCC)

In CCC, ICES and GLOBEC have joined to develop an innovative programme to advance understanding and prediction of variability in cod recruitment, both in the short term (annual recruitment forecast) and in the long term (climate effects) (Rothschild *et al.* 1995). The core question investigated by CCC is the effect of climate variability on cod stock fluctuations (Rothschild *et al.* 1995). Cod was chosen as the target of this initiative as it is a commercially important fish species on the international scale, its biology is well known and supported by ample databases, it has a pan-Atlantic distribution and its abundance and distribution have been shown to be sensitive to specific past examples of environmental variability (GLOBEC 1993, Rothschild et al. 1995). The key elements of the CCC programme are (I) analyses of historical data bases, (ii) process-oriented studies, (iii) monitoring activities (CPR survey), and (iv) advanced modelling/observation system development (GLOBEC 1993, Rothschild *et al.* 1995). The participants in CCC are a number of ICES member states. CCC is overseen and regularly reviewed by an ICES-GLOBEC Working Group. The objectives and the programme description are published in GLOBEC Report No. 4 (1993). A great deal of research is already underway, even if it was not primarily designed with the CCC programme in mind (Rothschild *et al.* 1995). However, co-ordination between the different regional structural components of CCC is weak as the project lacks a secretariat. It is expected that this situation will improve rapidly when ICES establishes its own GLOBEC-CCC Office. Developing countries are not involved in CCC(it is, after all, a North Atlantic effort) and IOC-OSLR does not actively participate either.

GLOBEC Southern Ocean Programme (SO-GLOBEC)

The Southern Ocean environment is especially vulnerable to global climate change, because many of the dominant plant and animal populations are critically dependent upon the sea-ice environment. The SO-GLOBEC programme is focussed on understanding how physical forces influence population dynamics and predator-prey interactions between key species (GLOBEC 1994). Science Plan and Implementation Plan for SO-GLOBEC are published in GLOBEC report No. 5 (1993) and GLOBEC Report No. 7 (1994). The research plan addresses four elements: time series surveys, process-studies, modeling efforts and data management. The first field studies were to be initiated in 1995. A comparative ecosystem approach will be adopted whereby the field studies will be conducted in the Antarctic peninsula region, the eastern Weddell Sea and the Indian Ocean sector of the Southern Ocean. The SO-GLOBEC countries are most of those which are already carrying out research in Antarctica. This includes some developing countries, however, their participation is unclear. SO-GLOBEC will have a steering committee and a secretariat which will be attached to a major research institution. So far, active participation of IOC-GLOBEC is not foreseen, but might be feasible by supporting developing countries in the region. SCOR has provide travel support to enable one or two scientists from South America to participate in SO-GLOBEC planning meetings and SO-GLOBEC will be represented at the IOC Southern Ocean Forum later this year by the Past-President of SCOR.

PICES-GLOBEC Climate Change and Carrying Capacity (CCCC)

There is growing evidence that biological productivity in the North Pacific responds to decadal scale shifts in atmospheric and oceanic conditions by alternating between periods of high and low productivity (Rothschild *et al.* 1995). Large scale changes in pelagic fish production suggest that coastal production is linked to variations in climate. 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. Paleosedimentary records indicate that such inter-decadal fluctuations have been characteristic of the California Current system for the last 2000 years. PICES and GLOBEC agreed in 1993 to organize CCCC in the temperate and sub-arctic regions of the North Pacific Ocean (Rothschild *et al.* 1995). The CCCC Programme focusses on coupling between atmospheric and oceanic processes, their impact upon production of major living marine resources and how they respond to climate change on time scales of decades to centuries. It includes retrospective analyses, development of numerical models, ecosystem process studies, the development of observation systems and data management (PICES-GLOBEC 1995, Rothschild *et al.* 1995). The ultimate goal is to forecast the consequences of climate variability on the ecosystems of the sub-arctic Pacific. Comparative studies of ecosystems along the continental margins of the sub-arctic Pacific will be of particular importance (PICES-GLOBEC 1995). Countries participating in CCCC are Canada, China, Japan, Korea, Russia and USA. The programme is guided by an Implementation Group. A Science Plan and an Implementation Plan (PICES-GLOBEC 1995) have been established. The initial studies began in 1995. IOC-OSLR does not actively participate in CCCC. However, consideration should be given to assist the Chinese and Russian efforts. Also, although Mexico is not part of the sub-arctic Pacific region, a certain association to the CCCC Programme would make sense as the pelagic resources off Baja California and of the Gulf of California are affected by the same basin-scale atmospheric and oceanic forcing as the sub-arctic living marine resources.

Small Pelagic Fish and Climate Change (SPACC)

Fishery records extending back hundreds of years, paleoecological records for thousands of years, and genetic assessments over evolutionary time all indicate great variations in the productivity of small pelagic fish populations (sardines, anchovies, scads, herrings, mackerels, sprat, menhadens, and others). Because such populations are relatively transient in the evolutionary sense, they may be particularly sensitive to climate variability. The goal of SPACC is to understand and ultimately predict climate-induced changes in the fish production of marine ecosystems. In addition to having broad economic importance, small pelagic fishes are an ideal subject for the study of climate variability and ocean forcing because they are globally distributed, constitute a third of the global marine fish catch, and respond rapidly to changes in ocean forcing because of their brief lives and short, plankton-based food chains (Hunter and Alheit 1995). SPACC was initiated in mid-1994 and 20 countries from Asia, North-America, South-America, Europe and Africa have joined this initiative. A Science Plan has been established (Hunter and Alheit 1995) and the Implementation plan will be finalized by mid-1996. SPACC is a comparative study of the impact of climate variability on those ecosystems where small pelagic fishes play an important role, e.g. eastern boundary currents, western boundary currents, semi-enclosed seas. The three major research components are: Retrospective investigations (including paleoecology), process-oriented studies and modeling. To assure worldwide participation in its comparison of ecosystems, SPACC will emphasize inexpensive core measurements that can be made in most countries, while maximizing the use of advanced technologies. This means that training, education and mutual assistance is a major programme element. It is expected that IOC will be actively involved with this programme component.

In addition to the above-mentioned internationally coordinated field programmes, a growing number of national programmes [e.g. US-GLOBEC, CHINA-GLOBEC, CANADA-GLOBEC, JAPAN-GLOBEC, MARE COGNITUM GLOBEC (Norway) and BIOS (UK)] include parts of the above programme areas and are contributing to the international GLOBEC effort.

Common Features of the Major GLOBEC Field Projects

The common theme of the four major field programmes of GLOBEC is the comparative study of the impact of climate variability and change on different marine ecosystems and their response to it. The focus is on zooplankton and each programme has the same suite of programme elements:

* retrospective investigations
* process-oriented studies
* modeling
* application of advanced technology
* data management.

Plankton programmes

It is recognized that the inter-annual variability in the recruitment of many resource species must be closely associated with concomitant patterns of variability in the planktonic ecosystems, particularly the zooplankton. In turn, planktonic variability is likely to be a response to changes in the physical environment generated largely by climate-induced oceanic interactions in the upper water column. This, in itself, can be considered to be a rationale for monitoring planktonic populations in the context of this LMR Module of GOOS. However, it must also be recognized that plankton population monitoring provides an independent baseline estimate of natural variability in the marine environment.

Although many fisheries operations are limited regionally (often for socio-economic, as well as ecological reasons), monitoring programmes associated with planktonic systems must include wider basin-scale as well as regional programmes. Operations at different scales must be complementary, thus providing spatial context, enhanced interpolation and regional specificity.

The primary goal of GOOS zooplankton monitoring could be to characterize large-scale anomalies in zooplankton biomass and species composition in many parts of the ocean and at time scales ranging from seasonal to multi-decadal. In order to obtain the basic GOOS zooplankton information, broad spatial coverage and temporal sustainability of the programme are more important requirements than are major advances in sampling technology or statistical design.

At the present level of understanding, sub-regional and intra-seasonal "patchiness" in zooplankton abundance and composition are noise that should be filtered out by appropriate stratification and averaging procedures. Future developments in programmes like GLOBEC may allow use of information on small-scale distributional overlap (species-species and species-physical environment).

Existing planktonic monitoring can be classified in relation to the spatial extent of the individual surveys. Essentially, they could be sub-divided into point surveys where the data relate to a single site, regional surveys where a specifically defined area is covered, and basin-wide surveys in which the coverage is defined by coastal borders of oceanic basins.

The Continuous Plankton Recorder Programme, CPR

The Sir Alister Hardy Foundation for Ocean Science (SAHFOS) was established in 1990 to operate the Continuous Plankton Recorder, CPR Survey. IOC is supporting the activities of CPR through its co-operation with SAHFOS in exploring possibilities on the establishment of new activities and routes. CPR has now been operating for decades in the North Sea and the North Atlantic and represents a very important tool for GOOS and in particular the LMR module.

By the use of "Ships of Opportunity" the CPR Survey is built up of a network of samples collected along the shipping routes. The sampling is at a fixed depth, and the monthly sampling intervals allows the resolution of seasonal, as well as spatial, and long-term temporal patterns.

Essentially, the data obtained by the CPR are limited to abundance and species composition. Environmental sensing equipment has been fitted to CPRs providing simultaneous information on environmental variables. In addition, CPRs can be made to undulate within the upper water column and thus resolve vertical structure. The results provided by the CPR Survey, has proven to be of great value for several global programme with obvious relevance for the assessment of questions related to climate change.

Increase in CPR's importance and impact coincides with its integration, not only with endeavors to put in place systematic operational programmes such as GOOS, but also research programmes in general. In this respect, the link between CPR, GLOBEC and other IGBP Core Programmes is very important.

Harmful Algal Bloom Programme

In view of the global interest in problems of phytoplankton blooms, red tides and the associated mass mortality of marine organisms, the Harmful Algal Bloom (HAB) Programme Office was established in 1993. It is located at the IOC Secretariat, UNESCO Headquarters in Paris.

The programme has, since its establishment, developed into an important activity of IOC. Major achievements so far are:

* The publishing of the IOC newsletter on toxic algae and algae blooms "Harmful Algal News" (2500 subscribers).
* The establishment of regional IOC Science and Communication Centers on Harmful Algae, the first one held in Copenhagen, Denmark in 1995 and the second anticipated to be operational in Vigo, Spain in the near future.
* Implementation of several training courses on taxonomy of harmful marine phytoplankton and toxin chemistry and toxicology for scientists from developing countries.
* Implementation of several workshops on: training requirements in the fields of eutrophication and harmful algae and on algal blooms and mass mortality of marine organisms.
* Establishment of an ICES-IOC Working Group on Dynamics of Harmful Algal Blooms and

a SCOR-IOC Working Group on the Physiological Ecology of Harmful Blooms.

During the Third Session of the IOC-FAO Intergovernmental Panel on Harmful Algal Blooms (Paris, 6-9 June 1995), the intersessional action plan focussed around five Task Teams:

* Algal Taxonomy
* Aquatic Biotoxins
* Design and Implementation of HAB Monitoring Programmes
* HAB Project Development
* Transfer of Phytoplankton by Ballast of Ships

Furthermore the Panel endorsed or agreed on the action to be taken in relation to:

* A HAB Training and Capacity Building Programme
* Availability of marine biotoxin standards and reference materials to be developed in particular for developing countries
* Computerized taxonomy databases

As a follow up to UNCED, activities were recommended on long-term monitoring of changes in phytoplankton species composition and addressing the role of UV-radiation in the ecology of marine phytoplankton.

Remote Sensing

Satellites provide the most consistent and uniform global and regional data sets for use in global comparative studies. At the most basic level satellite remote sensing will give estimates of SST and surface pigment concentration over large areas. For the systematic comparisons important to the LMR community, however, it is important that the satellite sensor data be processed consistently over all regions of interest.. At present, receiving stations in some countries receive and archive satellite data only offshore of their own borders or from subsets of their territory. Cooperative arrangements should be made to assure complete coverage of the large scale areas of interest and global consistency of the data processing.

The Coastal Zone Color Scanner (CZCS) showed us that much can be learned about the ocean ecosystem from an examination of ocean color data. Ocean color data are essential for monitoring and fostering our understanding of important ocean biological processes (sources and sinks for trace gases and for carbon dioxide, sustainability of fisheries, health of coastal resources, direct effects of biology on the physics of the ocean, etc.) From the CZCS data, we learned that there is a need for improvements in spectral coverage, sensitivity, and a new approach leading to improved final data products; improved data validation in coastal and optically complex waters; improved software and algorithms; and improved data processing and distribution systems. In order to facilitate these activities within the ocean color community and to respond to the launch of new ocean color sensors, IOC recently formed the International Ocean Color Coordination Group with support from the Committee on Earth Observation Satellites (CEOS). Close coordination between this group and the LMR panel will be important.

In a more general sense, there is a need for international cooperation in remote sensing to reduce expenses, avoid duplication and produce better products. Improved coordination will maintain continuity across sensors at important wavelengths, promote enhanced capabilities and provide for better calibration and validation. There is a critical need for continuation of inter-calibration round robins, multi-sensor calibration and validation campaigns, integration of *in-situ* and remotely sensed data streams, development of multi sensor products, and facilitation of data provider/user cooperation. Improved communication between data centers and users would lead to more data reaching the data centers.

To focus on the broader range of remote sensing requirements, GOOS is proposing to form an *ad hoc* panel on satellites to collect and consolidate satellite requirements drawn from each of the modules for presentation to the remote sensing community through CEOS and other relevant bodies. This panel will require a representative from the LMR module to act as a liaison between the LMR panel and the remote sensing panel.

ANNEX VIII

Suggested Revised Terms of Reference for the LMR Panel

A meeting of an ad hoc Panel for Monitoring and Assessment of the Living Marine Resources Modules of the Global Ocean Observing System (GOOS) (December 1993) proposed amendments to the Terms of Reference for an LMR Panel. These were included without further changes in the J-GOOS II Report of April 1995. The Workshop proposed that J-GOOS should establish a formal scientific panel for the Living Marine Resources module of GOOS. The following terms of reference are recommended for this panel and are followed by a list of suggested preliminary tasks.

The LMR Panel will be responsible for:

- The strategic development and detailed scientific and technical design of the Living Marine Resources module of GOOS.
- Maintaining liaison with research and monitoring activities to ensure that assessments and predictions of the living resources of the oceans are based on sound and contemporary scientific knowledge
- Coordination with other modules of GOOS for the purposes of ensuring compatible strategic and scientific development of all components of GOOS.

In particular, the LMR Panel should take the following actions as soon as possible:

- Identify the present and potential users of the data and products of a GOOS Living Marine Resources programme and ensure that the design and implementation of GOOS-LMR responds to these needs.
- Specify the deliverables and products of GOOS-LMR to meet user needs. Where necessary, conduct surveys, workshops or other enquiries to establish what products are needed, and how the products may be delivered to users as rapidly as required.
- Taking into account the physical variables and parameters likely to be measured to meet the requirements of the other modules of GOOS, the LMR Panel should define the variables and observations needed uniquely to support the objectives of the LMR Module, with special attention to accuracy, calibration of observing procedures, quality control and spatial and temporal resolution of sampling.
- Data sets required for the LMR Modules should be specified in terms of
  (1) requirement for globally consistent data where relevant
  (2) standard methods for routine and repeated observations
  (3) cost effectiveness of different methods
  (4) recognition of observing systems already in place, nationally and internationally
  (5) data management systems needed to transmit, process and distribute data and information
  (6) necessary technology developments
  (7) utility for diagnostic and forecasting models
- Develop a written plan for the design and implementation of an observing system which would provide the data required by LMR, in addition to the data provided for the general underpinning of GOOS, and the data required by other Modules. Variables and parameters should be selected with reference to their importance for analysis of climate change,

ecosystem and biodiversity changes and variations in primary productivity and renewable resources including fisheries.

- The Panel should make recommendations concerning the development and evaluation of methods for processing LMR data, protocols for the identification of significant trends and changes, techniques for monitoring, methods for data assimilation in diagnostic and forecasting models, mechanisms for distributing and archiving data sets, and the promising directions for developing new ecosystem models.

- Incorporate, in so far as possible, elements of training, mutual assistance and capacity building for developing countries into planning and implementation.

- Integrate activities in developing coastal states, within the range of their capabilities, into the observing system and its operations and include regions where appropriate data have not been previously collected.

- Produce an outline draft plan or synopsis by December 30, 1996 and a final Science Plan by late 1997.

ANNEX IX

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ANNEX X

Acronyms

ASEAN	Association of Southeast Asian Nations
AUV	Automated Underwater Vehicle
AVHRR	Advanced Very High Resolution Radiometer
BEP	Benguela Ecology Programme
CalCOFI	California Cooperative Fisheries Investigation
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CCC	GLOBEC/ICES Cod and Climate Change Programme
CCCC	GLOBEC/PICES Climate Change and Carrying Capacity Programme
CPR	Continuous Plankton Recorder
FAO	United Nations Food and Agriculture Organization
GEF	World Bank, Global Environmental Facility
GLOBEC	SCOR/IOC/IGBP Global Ocean Ecosystem Dynamics
GOOS	Global Ocean Observing System
HAB	Harmful Algal Bloom Programme
HDP	International Human Dimensions (of global change) Program
HOTO	"Health of the Oceans" module of GOOS
I-GOOS	Intergovernmental Committee for GOOS (IOC/ICSU/WMO/UNEP)
ICES	International Council for the Exploration of the Sea
ICLARM	International Center for Living Aquatic Resources Management (Philippines)
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Program
IOC	Intergovernmental Oceanographic Commission
IUCN	International Union for the Conservation of Nature
J-GOOS	Joint Scientific and Technical Committee for GOOS (IOC/WMO/ICSU)
JGOFS	SCOR/IGBP Joint Global Ocean Flux Study
LME	Large Marine Ecosystems
LMR	Living Marine Resources
LOICZ	Land-Ocean Interactions in the Coastal Zone (IGBP Core Project)
NAFO	Northwest Atlantic Fisheries Organization
NMWG	GLOBEC Numerical Modeling Working Group
NOAA	National Oceanic and Atmospheric Administration
OECD	Organization for Economic Development
OSLR	Ocean Science in Relation to Living Resources (IOC)
PICES	North Pacific Marine Sciences Organization ("Pacific ICES")
ROV	Remotely Operated Vehicle
SARP	Sardine Anchovy Recruitment Project (of IOC/OSLR)
SCOR	Scientific Committee on Oceanic Research
SO-GLOBEC	GLOBEC Southern Ocean Programme
SOS	GLOBEC Working Group on Sampling and Observation Systems
SPACC	GLOBEC Small Pelagic Fish and Climate Change
START	System for Analysis, Research and Training (of IGBP, WCRP and HDP)
TEMA	Training, Education and Mutual Assistance in Marine Sciences
UNCED	United Nations Conference on Environment and Development (1992)
UNDP	United National Development Program
UNEP	United Nations Environment Program
WCRP	World Climate Research Program
WMO	World Meteorological Organization

IOC Workshop Reports

The Scientific Workshops of the Intergovernmental Oceanographic Commission are sometimes jointly sponsored with other intergovermental or non-governmental bodies. In most cases, IOC assumes responsibility for printing, and copies may be requested from:

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1	CCOP-IOC, 1974, Metallogenesis, Hydrocarbons and Tectonic Patterns in Eastern Asia (Report of the IDOE Workshop on); Bangkok, Thailand, 24-29 September 1973 UNDP (CCOP), 138 pp.	E (out of stock)
2	CICAR Ichthyoplankton Workshop, Mexico City, 16-27 July 1974 (UNESCO Technical Paper in Marine Sciences, No. 20).	E (out of stock) S (out of stock)
3	Report of the IOC/GFCM/ICSEM International Workshop on Marine Pollution in the Mediterranean; Monte Carlo, 9-14 September 1974.	E, F E (out of stock)
4	Report of the Workshop on the Phenomenon known as 'El Niño'; Guayaquil, Ecuador, 4-12 December 1974.	E (out of stock) S (out of stock)
5	IDOE International Workshop on Marine Geology and Geophysics of the Caribbean Region and its Resources; Kingston, Jamaica, 17-22 February 1975.	E (out of stock) S
6	Report of the CCOP/SOPAC-IOC IDOE International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific; Suva, Fiji, 1-6 September 1975.	E
7	Report of the Scientific Workshop to Initiate Planning for a Co-operative Investigation in the North and Central Western Indian Ocean, organized within the IDOE under the sponsorship of IOC/FAO (IOFC)/UNESCO/EAC; Nairobi, Kenya, 25 March-2 April 1976.	E, F, S, R
8	Joint IOC/FAO (IPFC)/UNEP International Workshop on Marine Pollution in East Asian Waters; Penang, 7-13 April 1976.	E (out of stock)
9	IOC/CMG/SCOR Second International Workshop on Marine Geoscience; Mauritius, 9-13 August 1976.	E, F, S, R
10	IOC/WMO Second Workshop on Marine Pollution (Petroleum) Monitoring; Monaco, 14-18 June 1976.	E, F E (out of stock) R
11	Report of the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions; Port of Spain, Trinidad, 13-17 December 1976.	E, S (out of stock)
11 Suppl.	Collected contributions of invited lecturers and authors to the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions; Port of Spain, Trinidad, 13-17 December 1976.	E (out of stock), S
12	Report of the IOCARIBE Interdisciplinary Workshop on Scientific Programmes in Support of Fisheries Projects; Fort-de-France, Martinique, 28 November-2 December 1977.	E, F, S
13	Report of the IOCARIBE Workshop on Environmental Geology of the Caribbean Coastal Area; Port of Spain, Trinidad, 16-18 January 1978.	E, S
14	IOC/FAO/WHO/UNEP International Workshop on Marine Pollution in the Gulf of Guinea and Adjacent Areas; Abidjan, Côte d'Ivoire, 2-9 May 1978.	E, F
15	CPPS/FAO/IOC/UNEP International Workshop on Marine Pollution in the South-East Pacific; Santiago de Chile, 6-10 November 1978.	E (out of stock)
16	Workshop on the Western Pacific, Tokyo, 19-20 February 1979.	E, F, R
17	Joint IOC/WMO Workshop on Oceanographic Products and the IGOSS Data Processing and Services System (IDPSS); Moscow, 9-11 April 1979.	E
17 Suppl.	Papers submitted to the Joint IOC/WMO Seminar on Oceanographic Products and the IGOSS Data Processing and Services System; Moscow, 2-6 April 1979.	E
18	IOC/UNESCO Workshop on Syllabus for Training Marine Technicians; Miami, U.S.A., 22-26 May 1978 (UNESCO reports in marine sciences, No. 4 published by the Division of Marine Sciences, UNESCO).	E (out of stock), F, S (out of stock), R
19	IOC Workshop on Marine Science Syllabus for Secondary Schools; Llantwit Major, Wales, U.K., 5-9 June 1978 (UNESCO reports in marine sciences, No. 5, published by the Division of Marine Sciences, UNESCO).	E (out of stock), E, S, R, Ar
20	Second CCOP-IOC Workshop on IDOE Studies of East Asia Tectonics and Resources; Bandung, Indonesia, 17-21 October 1978.	E
21	Second IDOE Symposium on Turbulence in the Ocean; Liège, Belgium, 7-18 May 1979.	E, F, S, R
22	Third IOC/WMO Workshop on Marine Pollution Monitoring; New Delhi, 11-15 February 1980.	E, F, S, R
23	WESTPAC Workshop on the Marine Geology and Geophysics of the North-West Pacific; Tokyo, 27-31 March 1980.	E, R
24	WESTPAC Workshop on Coastal Transport of Pollutants; Tokyo, Japan, 27-31 March 1980.	E (out of stock)
25	Workshop on the Intercalibration of Sampling Procedures of the IOC/ WMO UNEP Pilot Project on Monitoring Background Levels of Selected Pollutants in Open-Ocean Waters; Bermuda, 11-26 January 1980.	E (superseded by IOC Technical Series No. 22)
26	IOC Workshop on Coastal Area Management in the Caribbean Region; Mexico City, 24 September-5 October 1979.	E, S
27	CCOP/SOPAC-IOC Second International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific; Nouméa, New Caledonia, 9-15 October 1980.	E
28	FAO/IOC Workshop on the effects of environmental variation on the survival of larval pelagic fishes. Lima, 20 April-5 May 1980.	E
29	WESTPAC Workshop on Marine Biological Methodology; Tokyo, 9-14 February 1981.	E
30	International Workshop on Marine Pollution in the South-West Atlantic; Montevideo, 10-14 November 1980.	E (out of stock) S
31	Third International Workshop on Marine Geoscience; Heidelberg, 19-24 July 1982.	E, F, S
32	UNU/IOC/UNESCO Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the context of the New Ocean Regime; Paris, France, 27 September-1 October 1982.	E, F, S
32 Suppl.	Papers submitted to the UNU/IOC/UNESCO Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the Context of the New Ocean Regime; Paris, France, 27 September-1 October 1982.	E
33	Workshop on the IREP Component of the IOC Programme on Ocean Science in Relation to Living Resources (OSLR); Halifax, 26-30 September 1963.	E
34	IOC Workshop on Regional Co-operation in Marine Science in the Central Eastern Atlantic (Western Africa); Tenerife, 12-17 December 1963.	E, F, S
35	CCOP/SOPAC-IOC-UNU Workshop on Basic Geo-scientific Marine Research Required for Assessment of Minerals and Hydrocarbons in the South Pacific; Suva, Fiji, 3-7 October 1983.	E
36	IOC/FAO Workshop on the Improved Uses of Research Vessels; Lisbon, Portugal, 28 May-2 June 1984.	E
36 Suppl.	Papers submitted to the IOC/FAO Workshop on the Improved Uses of Research Vessels; Lisbon, Portugal, 28 May-2 June 1984.	E
37	IOC/UNESCO Workshop on Regional Co-operation in Marine Science in the Central Indian Ocean and Adjacent Seas and Gulfs; Colombo, 8-13 July 1985.	E
38	IOC/ROPME/UNEP Symposium on Fate and Fluxes of Oil Pollutants in the Kuwait Action Plan Region; Basrah, Iraq, 8-12 January 1984.	E
39	CCOP (SOPAC)-IOC-IFREMER-ORSTOM Workshop on the Uses of Submersibles and Remotely Operated Vehicles in the South Pacific; Suva, Fiji, 24-29 September 1985.	E
40	IOC Workshop on the Technical Aspects of Tsunami Analysis, Prediction and Communications; Sidney, B.C., Canada, 29-31 July 1985.	E
40 Suppl.	First International Tsunami Workshop on Tsunami Analysis, Prediction and Communications, *Submitted Papers;* Sidney, B.C., Canada, 29 July - 1 August 1985.	E
41	First Workshop of Participants in the Joint FAO/IOC/WHO/IAEA/UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region (WACAF/2); Dakar, Senegal, 28 October-1 November 1985.	E
43	IOC Workshop on the Results of MEDALPEX and Future Oceanographic Programmes in the Western Mediterranean; Venice, Italy, 23-25 October 1985.	E
44	IOC-FAO Workshop on Recruitment in Tropical Coastal Demersal Communities; Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986.	E (out of stock) S
44 Suppl.	IOC-FAO Workshop on Recruitment in Tropical Coastal Demersal Communities, *Submitted Papers;* Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986.	E
45	IOCARIBE Workshop on Physical Oceanography and Climate; Cartagena, Colombia, 19-22 August 1986.	E
46	Reunión de Trabajo para Desarrollo del Programa "Ciencia Oceánica en Relación a los Recursos No Vivos en la Región del Atlántico Sud-occidental"; Porto Alegre, Brazil, 7-11 de abril de 1986.	S
47	IOC Symposium on Marine Science in the Western Pacific: The Indo-Pacific Convergence; Townsville, 1-6 December 1966.	E
48	IOCARIBE Mini-Symposium for the Regional Development of the IOC-UN (OETB) Programme on 'Ocean Science in Relation to Non-Living Resources (OSNLR)'; Havana, Cuba, 4-7 December 1986.	E, S
49	AGU-IOC-WMO-CPPS Chapman Conference: An International Symposium on 'El Niño'; Guayaquil, Ecuador, 27-31 October 1986.	E
50	CCALR-IOC Scientific Seminar on Antarctic Ocean Variability and its Influence on Marine Living Resources, particularly Krill (organized in collaboration with SCAR and SCOR); Paris, France, 2-6 June 1987.	E
51	CCOP/SOPAC-IOC Workshop on Coastal Processes in the South Pacific Island Nations; Lae, Papua-New Guinea, 1-8 October 1987.	E

No.	Title	Languages
52	SCOR-IOC-UNESCO Symposium on Vertical Motion in the Equatorial Upper Ocean and its Effects upon Living Resources and the Atmosphere; Paris, France, 6-10 May 1985.	E
53	IOC Workshop on the Biological Effects of Pollutants; Oslo, 11-29 August 1986.	E
54	Workshop on Sea-Level Measurements in Hostile Conditions; Bidston, UK, 28-31 March 1988	E
55	IBCCA Workshop on Data Sources and Compilation, Boulder, Colorado, 18-19 July 1988.	E
56	IOC-FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP); Cleveland, Australia, 24-30 July 1988.	E
57	IOC Workshop on International Co-operation in the Study of Red Tides and Ocean Blooms; Takamatsu, Japan, 16-17 November 1987.	E
58	International Workshop on the Technical Aspects of the Tsunami Warning System; Novosibirsk, USSR, 4-5 August 1989.	E
58 Suppl.	Second International Workshop on the Technical Aspects of Tsunami Warning Systems, Tsunami Analysis, Preparedness, Observation and Instrumentation. *Submitted Papers*; Novosibirsk, USSR, 4-5 August 1989.	E
59	IOC-UNEP Regional Workshop to Review Priorities for Marine Pollution Monitoring Research, Control and Abatement in the Wider Caribbean; San José, Costa Rica, 24-30 August 1989.	E, F, S
60	IOC Workshop to Define IOCARIBE-TRODERP proposals; Caracas, Venezuela, 12-16 September 1989.	E
61	Second IOC Workshop on the Biological Effects of Pollutants; Bermuda, 10 September-2 October 1988.	E
62	Second Workshop of Participants in the Joint FAO-IOC-WHO-IAEA-UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region; Accra, Ghana, 13-17 June 1988.	E
63	IOC/WESTPAC Workshop on Co-operative Study of the Continental Shelf Circulation in the Western Pacific; Bangkok, Thailand, 31 October-3 November 1989.	E
64	Second IOC-FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP); Phuket, Thailand, 25-31 September 1989.	E
65	Second IOC Workshop on Sardine/Anchovy Recruitment Project (SARP) int he Southwest Atlantic; Montevideo, Uruguay, 21-23 August 1989.	E
66	IOC *ad hoc* Expert Consultation on Sardine/Anchovy Recruitment Programme; La Jolla, California, U.S.A., 1989.	E
67	Interdisciplinary Seminar on Research Problems in the IOCARIBE Region; Caracas, Venezuela, 28 November-1 December 1989.	E (out of stock)
68	International Workshop on Marine Acoustics; Beijing, China, 26-30 March 1990.	E
69	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica; Leningrad, USSR, 28-31 May 1990.	E
69 Suppl.	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica; *Submitted Papers*; Leningrad, USSR, 28-31 May 1990.	E
70	IOC-SAREC-UNEP-FAO-IAEA-WHO Workshop on Regional Aspects of Marine Pollution; Mauritius, 29 October - 9 November 1990.	E
71	IOC-FAO Workshop on the Identification of Penaeid Prawn Larvae and Postlarvae; Cleveland, Australia, 23-28 September 1990.	E
72	IOC/WESTPAC Scientific Steering Group Meeting on Co-Operative Study of the Continental Shelf Circulation in the Western Pacific; Kuala Lumpur; Malaysia, 9-11 October 1990.	E
73	Expert Consultation for the IOC Programme on Coastal Ocean Advanced Science and Technology Study; Liège, Belgium, 11-13 May 1991.	E
74	IOC-UNEP Review Meeting on Oceanographic Processes of Transport and Distribution of Pollutants in the Sea; Zagreb, Yugoslavia, 15-18 May 1989.	E
75	IOC-SCOR Workshop on Global Ocean Ecosystem Dynamics; Solomons, Maryland, U.S.A., 29 April-2 May 1991.	E
76	IOC/WESTPAC Scientific Symposium on Marine Science and Management of Marine Areas of the Western Pacific; Penang, Malaysia, 2-6 December 1991.	E
77	IOC-SAREC-KMFRI Regional Workshop on Causes and Consequences of Sea-Level Changes on the Western Indian Ocean Coasts and Islands; Mombasa, Kenya, 24-28 June 1991.	E
78	IOC-CEC-ICES-WMO-ICSU Ocean Climate Data Workshop Goddard Space Flight Center; Greenbelt, Maryland, U.S.A., 18-21 February 1992.	E
79	IOC/WESTPAC Workshop on River Inputs of Nutrients to the Marine Environment in the WESTPAC Region; Penang, Malaysia, 26-29 November 1991.	E
80	IOC-SCOR Workshop on Programme Development for Harmful Algae Blooms; Newport, U.S.A., 2-3 November 1991.	E
81	Joint IAPSO-IOC Workshop on Sea Level Measurements and Quality Control; Paris, France, 12-13 October 1992.	E
82	BORDOMER 92: International Convention on Rational Use of Coastal Zones. A Preparatory Meeting for the Organization of an International Conference on Coastal Change; Bordeaux, France, 30 September-2 October 1992.	E
83	IOC Workshop on Donor Collaboration in the Development of Marine Scientific Research Capabilities in the Western Indian Ocean Region; Brussels, Belgium, 12-13 October 1992.	E
84	Workshop on Atlantic Ocean Climate Variability; Moscow, Russian Federation, 13-17 July 1992.	E
85	IOC Workshop on Coastal Oceanography in Relation to Integrated Coastal Zone Management; Kona, Hawaii, 1-5 June 1992.	E
86	International Workshop on the Black Sea; Varna, Bulgaria 30 September - 4 October 1991.	E
87	Taller de trabajo sobre efectos biológicos del fenómeno «El Niño» en ecosistemas costeros del Pacífico Sudeste; Santa Cruz, Galápagos, Ecuador, 5-14 de octubre de 1989.	S only (Summary in E, F, S)
88	IOC-CEC-ICSU-ICES Regional Workshop for Member States of Eastern and Northern Europe (GODAR Project); Obninsk, Russia, 17-20 May 1993.	E
89	IOC-ICSEM Workshop on Ocean Sciences in Non-Living Resources; Perpignan, France, 15-20 October 1990.	E
90	IOC Seminar on Integrated Coastal Management; New Orleans, U.S.A., 17-18 July 1993.	E
91	Hydroblack'91 CTD Intercalibration Workshop; Woods Hole, U.S.A., 1-10 December 1991.	E
92	Réunion de travail IOCEA-OSNLR sur le Projet « Budgets sédimentaires le long de la côte occidentale d'Afrique » Abidjan, Côte d'Ivoire, 26-28 juin 1991.	F
93	IOC-UNEP Workshop on Impacts of Sea-Level Rise due to Global Warming. Dhaka, Bangladesh, 16-19 November 1992.	E
94	BMTC-IOC-POLARMAR International Workshop on Training Requirements in the Field of Eutrophication in Semi-Enclosed Seas and Harmful Algal Blooms, Bremerhaven, Germany, 29 September - 3 October 1992.	E
95	SAREC-IOC Workshop on Donor Collaboration in the Development of Marine Scientific Research Capabilities in the Western Indian Ocean Region; Brussels, Belgium, 23-25 November 1993.	E
96	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; Zanzibar, United Republic of Tanzania, 17-21 January 1994.	E
96 Suppl. 1	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; *Submitted Papers* 1. Coastal Erosion; Zanzibar, United Republic of Tanzania 17-21 January 1994.	E
96 Suppl. 2	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; *Submitted Papers* 2. Sea Level; Zanzibar, United Republic of Tanzania 17-21 January 1994.	E
97	IOC Workshop on Small Island Oceanography in Relation to Sustainable Economic Development and Coastal Area Management of Small Island Development States; Fort-de-France, Martinique, 8-10 November, 1993.	E
98	CoMSBlack '92A Physical and Chemical Intercalibration Workshop; Erdemli, Turkey, 15-29 January 1993.	E
99	IOC-SAREC Field Study Exercise on Nutrients in Tropical Marine Waters; Mombasa, Kenya, 5-15 April 1994.	E
100	IOC-SOA-NOAA Regional Workshop for Member States of the Western Pacific - GODAR-II (Global Oceanographic Data Archeology and Rescue Project); Tianjin, China, 8-11 March 1994.	E
101	IOC Regional Science Planning Workshop on Harmful Algal Blooms; Montevideo, Uruguay, 15-17 June 1994.	E
102	First IOC Workshop on Coastal Ocean Advanced Science and Technology Study (COASTS); Liège, Belgium, 5-9 May 1994.	E
103	IOC Workshop on GIS Applications in the Coastal Zone Management of Small Island Developing States; Barbados, 20-22 April 1994.	E
104	Workshop on Integrated Coastal Management; Dartmouth, Canada, 19-20 September 1994.	E
105	BORDOMER 95: Conference on Coastal Change; Bordeaux, France, 6-10 February 1995.	E
105 Suppl.	Conference on Coastal Change: Proceedings; Bordeaux, France, 6-10 February 1995	E
106	IOC/WESTPAC Workshop on the Paleographic Map; Bali, Indonesia, 20-21 October 1994.	E
107	IOC-ICSU-NIO-NOAA Regional Workshop for Member States of the Indian Ocean - GODAR-III; Dona Paula, Goa, India, 6-9 December 1994.	E
108	UNESCO-IHP-IOC-IAEA Workshop on Sea-Level Rise and the Multidisciplinary Studies of Environmental Processes in the Caspian Sea Region; Paris, France, 9-12 May 1995.	E
108 Suppl.	UNESCO-IHP-IOC-IAEA Workshop on Sea-Level Rise and the Multidisciplinary Studies of Environmental Processes in the Caspian Sea Region; *Submitted Papers*; Paris, France, 9-12 May 1995.	E
109	First IOC-UNEP CEPPOL Symposium; San José, Costa Rica, 14-15 April 1993.	E
110	IOC-ICSU-CEC Regional Workshop for Member States of the Mediterranean - GODAR-IV (Global Oceanographic Data Archeology and Rescue Project) Foundation for International Studies, University of Malta, Valletta, Malta, 25-28 April 1995.	E

No.	Title	Languages
111	Chapman Conference on the Circulation of the Intra-Americas Sea; La Parguera, Puerto Rico, 22-26 January 1995.	E
112	IOC-IAEA-UNEP Group of Experts on Standards and Reference Materials (GESREM) Workshop; Miami, U.S.A., 7-8 December 1993.	E
113	IOC Regional Workshop on Marine Debris and Waste Management in the Gulf of Guinea; Lagos, Nigeria, 14-16 December 1994.	E
114	International Workshop on Integrated Coastal Zone Management (ICZM) Karachi, Pakistan; 10-14 October 1994.	E
115	IOC/GLOSS-IAPSO Workshop on Sea Level Variability and Southern Ocean Dynamics; Bordeaux, France, 31 January 1995.	E
116	IOC/WESTPAC International Scientific Symposium on Sustainability of Marine Environment: Review of the WESTPAC Programme, with Particular Reference to ICAM Bali, Indonesia, 22-26 November 1996.	E
117	Joint IOC-CIDA-Sida (SAREC) Workshop on the Benefits of Improved Relationships between International Development Agencies, the IOC and other Multilateral Intergovernmental Organizations in the Delivery of Ocean, Marine Affairs and Fisheries Programmes; Sidney B.C., Canada, 26-28 September 1995.	E
118	IOC-UNEP-NOAA-Sea Grant Fourth Caribbean Marine Debris Workshop; La Romana, Santo Domingo, 21-24 August 1995.	E
119	IOC Workshop on Ocean Colour Data Requirements and Utilization; Sydney B.C., Canada, 21-22 September 1995.	E
120	International Training Workshop on Integrated Coastal Management; Tampa, Florida, U.S.A., 15-17 July 1995.	E
121	Atelier régional sur la gestion intégrée des zones littorales (ICAM); Conakry, Guinée, 12-22 décembre 1995.	F
122	IOC-UNEP-PERSGA-ACOPS-IUCN Workshop on Oceanographic Input to Integrated Coastal Zone Management in the Red Sea and Gulf of Aden Jeddah, Saudi Arabia, 8 October 1995.	E
123	Second IOC Regional Science Planning Workshop on Harmful Algal Blooms in South America; Mar del Plata, Argentina, 30 October - 1 November 1995.	E, S
124	GLOBEC-IOC-SAHFOS-MBA Workshop on the Analysis of Time Series with Particular Reference to the Continuous Plankton Recorder Survey; Plymouth, U.K., 4-7 May 1993.	E
125	Atelier sous-régional de la COI sur les ressources marines vivantes du Golfe de Guinée ; Cotonou, Bénin, 1-4 juillet 1996.	F
126	IOC-UNEP-PERSGA-ACOPS-IUCN Workshop on Oceanographic Input to Integrated Coastal Zone.	E
127	IOC Regional Workshop for Member States of the Caribbean and South America GODAR-V (Global Oceanographic Data Archeology and Rescue Project); Cartagena de Indias, Colombia, 8-11 October 1996.	E, S
128	Atelier IOC-Banque Mondiale-Sida/SAREC-ONE sur la Gestion Intégrée des Zones Côtières ; Nosy Bé, Madagascar, 14-18 octobre 1996.	E, F
129	Gas and Fluids in Marine Sediments, Amsterdam, the Netherlands; 27-29 January 1997.	E
130	Atelier régional de la COI sur l'océanographie côtière et la gestion de la zone côtière ; Moroni, RFI des Comores, 16-19 décembre 1996.	F
131	GOOS Coastal Module Planning Workshop; Miami, USA, 24-28 February 1997.	E
132	Third IOC-FANSA Workshop; Punta-Arenas, Chile, 28-30 July 1997	S/E
133	Joint IOC-CIESM Training Workshop on Sea-level Observations and Analysis for the Countries of the Mediterranean and Black Seas; Birkenhead, U.K., 16-27 June 1997.	E
134	IOC/WESTPAC-CCOP Workshop on Paleogeographic Mapping (Holocene Optimum); Shanghai, China, 27-29 May 1997.	E
135	Regional Workshop on Integrated Coastal Zone Management; Chabahar, Iran; February 1996.	E
136	IOC Regional Workshop for Member States of Western Africa (GODAR-VI); Accra, Ghana, 22-25 April 1997.	E
137	GOOS Planning Workshop for Living Marine Resources, Dartmouth, USA; 1-5 March 1996.	E