Intergovernmental Oceanographic Commission
Reports of Meetings of Experts and Equivalent Bodies

IOC-WMO-UNEP-ICSU-FAO Living Marine Resources Panel of the Global Ocean Observing System (GOOS)

First Session
Paris, France
23-25 March 1998

GOOS Report No. 54

UNESCO

IOC-WMO-UNEP-ICSU-FAO/LMR-GOOS-I/3
Paris, 15 October 1998
English only

SC-98/WS/73

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1. INTRODUCTION

The Chairman Warren Wooster opened the meeting, which was held at UNESCO Headquarters, Paris, from 23-25 March 1998, and welcomed the Panel members (Annex I). He reminded the members that the objective of the Panel is to develop the Living Marine Resources (LMR) Plan for the Global Ocean Observing System (GOOS) taking into account the GOOS panels on Coastal and Health of the Oceans. He pointed out that the intent of LMR-GOOS is to provide observational services and forecasts to those concerned with the harvest, conservation and scientific investigation of living marine resources of the deep ocean and shelf seas.

2. ADMINISTRATIVE ARRANGEMENTS

The provisional agenda was discussed and here modified (Annex II) to reflect discussions at the meeting. John Pope agreed to serve as rapporteur. Documents previously provided to the Panel members were referenced (Annex III). The Panel considered the Terms of Reference and agreed they were acceptable (Annex IV). George Grice discussed logistic arrangements and thanked the Food and Agriculture Organization (FAO) for its financial support. Patricio Bernal informed the Panel that he could no longer continue as co-chairperson as he would become Executive Secretary of IOC on 1 April 1998.

3. GOALS, OBJECTIVES AND USERS

Prior to the Panel meeting the Chairman distributed a proposed statement of goals for the Panel and these were further considered at the meeting and the following agreed:

> **The goal of LMR-GOOS is to provide operationally useful information on changes in the state of living marine resources and ecosystems. The objectives are to obtain from various sources relevant oceanographic and climatic data, along with biological, fisheries and other information on the marine ecosystems, to compile and analyse these data, to describe the varying state of the ecosystems, and to predict future states of the ecosystems, including exploited species, on useful time scales. A consequence of these efforts should be the identification and development of the more powerful and cost-effective means for monitoring marine ecosystems required to meet the LMR-GOOS goal.**
>
> **The users of these data include international, regional and national regulatory agencies responsible for managing the state of the marine environment, wildlife, fisheries, shell fisheries and aquaculture; 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 research community and private sector organizations impacting ecosystems.**

The Panel agreed that in achieving its objectives the LMR-GOOS monitoring programme should attempt to provide information that:

(i) describes changes in ecosystems over time, including fluctuations in abundance and spatial distribution of species;

(ii) helps interpret the observed changes in relation to such factors as natural environmental variability, anthropogenic climate change (including increased ultraviolet radiation), predation/disease, and fishing activities; and,

(iii) contributes to forecasting of future states of marine ecosystems.

4. FOCUS OF LMR WITHIN GOOS

4.1 THE STATUS OF GOOS

The Director of the Global Ocean Observing System outlined the vision, mission and goals of the GOOS Programme and described the phased programme of implementation involving: (i) planning (including publication of the Strategic Plan); (ii) development of pilot projects such as NEAR-GOOS and EURO-GOOS and (iii) creation of the GOOS initial observation system from existing physical oceanographic observing systems. He indicated the need to develop complementing chemical and biological systems leading to an integrated interdisciplinary GOOS in due course. In the development of the LMR plan it will be important to identify what should be monitored to determine the present state of the ocean and to predict its future state. Users of the programme's products should be identified and a cost benefit analysis made. The plan should assist in developing the capacities of developing countries so that they can contribute to and benefit from the programme. It is likely that many existing monitoring systems will be placed under the GOOS umbrella. In the development of the implementation plan for LMR it is important to include a pilot programme as a demonstration of LMR observing systems and of the validity of the GOOS-LMR concept.

4.2 LMR, HOTO AND COASTAL GOOS

The Panel recognized the potential for overlap with the work of the Coastal and HOTO panels. Initially the LMR Panel will focus on deep ocean and shelf sea conditions dominated by oceanic processes. However, many processes and events that determine production of fishery resources occur in estuarine and coastal waters, so coordination of LMR Panel considerations with those of the Coastal and HOTO Panels is essential to ensure that these matters are fully taken into account.

The extent of the potential overlap is illustrated in the following discussion. There are a number of types of special coastal habitats that may be crucial (as nursery grounds and sites of other essential life cycle processes) for important living resources in many regions of the world. For example, it has been estimated that most of the marine fish landings off eastern United States are dependent on estuaries for at least one essential segment of their life cycles. Many of the valuable oceanic shrimp fisheries of the world may depend on nursery grounds located in estuaries, sea grass beds, or mangrove forests. A few very large estuarine systems may be crucial to a large percentage of the fished stocks in various tropical wide-shelf regions. Coral reefs may likewise be crucial nursery grounds for many important species.

To prevent overlap and duplication of effort, the Panel felt that detailed discussions of GOOS measurement strategies for such "critical coastal habitats" as estuaries, sea grass beds, coral reefs, mangrove forests, etc., should be undertaken by the GOOS Coastal Panel where specific expertise in these issues may be better represented. In view of the vital importance of these habitats, identification of trends in their condition may be among the most important LMR outputs of GOOS.

5. REVIEW OF PREVIOUS LMR MEETINGS

There have been two previous meetings relative to the development of a LMR Module for GOOS. The first one was an *ad hoc* Panel for Monitoring and Assessment of Living Marine Resources Module of GOOS (Costa Rica, 1993), and the other was a planning Workshop for the Living Marine Resources Module of GOOS (US, 1996). The Costa Rica meeting recommended the initiation of pilot projects to monitor small pelagics in two areas (Humboldt Current and Arabian Sea) where regime shifts have occurred. The panel also proposed that a long term global monitoring system be developed for critical coastal areas, recognizing that such a system would require substantial operational and analytical efforts. No monitoring protocols were specified.

The US workshop provided a comprehensive approach to obtaining information on marine ecosystems through the establishment of a global monitoring system for phytoplankton, zooplankton, fish and shellfish, fish larval and juvenile stages, mammals, birds and top predators with associated measurements of relevant meteorological and physical variables. Considerable emphasis was placed on the use of satellites, buoys, drifters and other remote sensing techniques for acquisition of environmental data.

Both of the above referenced reports provided important background information for the present Panel and provided a starting point for its discussions.

6. REVIEW OF EXISTING MONITORING PROGRAMMES

6.1 MONITORING PROGRAMMES

Panel members provided information concerning international monitoring programmes with which they were familiar, although it was recognized that there are other ecosystem observing programmes that are not included here. The Panel later requested IOC to provide a listing of current monitoring activities (see 6.2).

International Council for the Exploration of the Sea (ICES)

As part of the ICES activities many of the likely components of an LMR-GOOS programme are presently being undertaken. However, a comprehensive ecosystem monitoring programme of shelf seas in the North Atlantic has not been formally defined. There are a series of national programmes some of which are integrated with those of other countries to achieve specific programme goals. These activities have changed over time depending on interests of the researchers and the programme priorities. ICES, however, has given "ecosystem monitoring" a high priority since 1902 and a multi-parameter data base is maintained. The Cod and Climate change programme, ICES contribution to GLOBEC, and the present focus on the population dynamics of *Calanus* in the northeast Atlantic will provide important conceptual inputs into the definition of long term monitoring of marine ecosystems in the North Atlantic.

North Pacific Marine Science Organization (PICES)

PICES is an intergovernmental organization of the six countries bordering the northern North Pacific. It has a variety of scientific activities that will contribute to the scientific base for GOOS and for several years has had a working group looking at the most effective ways to monitor changes in physical forcing and ecosystem response in the region. That activity has recently been incorporated in the PICES-GLOBEC programme on Climate Change and Carrying Capacity, where it will support retrospective, modelling, and process studies.

Food and Agriculture Organization (FAO)

FAO's substantial database on world wide fish catches, and its regional areas, were described. It was pointed out that there are some limitations to defining exact areas of catch due to the large reporting regions and reporting by each country for its distant water fisheries fleet, and the data do not cover the total catch which includes discards and by catch as well as the landings typically reported to FAO.

Intergovernmental Oceanographic Commission (IOC)

The IOC programme on Harmful Algal Blooms (HAB) and the Global Coral Reef Monitoring Network (GCRMN) were described. The HAB Programme is designed to foster the effective management of, and scientific research on, harmful algal blooms in order to understand their causes, predict their occurrences, and mitigate their effect. The programme consists of three major elements: the educational element, the scientific element and the operational elements. Monitoring of Harmful Algal Blooms is conducted in several countries. The overall goal of GCRMN, a component of GOOS, is to provide individuals, organizations and governments with the capacity to assess the resources of coral reefs and related ecosystems and collaborate within a global network to document and disseminate data and information on their status and trends. Reef monitoring programmes are being implemented.

Sir Alister Hardy Foundation for Ocean Science (SAHFOS)

This plankton monitoring programme provides unique sets of data on the distribution and abundance of upper ocean plankton at ocean basin scales over long time periods, primarily through use of the towed Continuous Plankton Recorder. Plankton distribution can be examined on wide geographic scales and provides information on seasonal patterns, unusual events and long term changes.

Census of Fishes

A proposed census of fishes, initiated by the Sloan Foundation, is currently being considered by the marine scientific community. There appears to be developing interest in determining the biomass and size spectra of fish and adjacent trophic levels but the design of the programme is, as yet, undetermined. The emphasis is likely to be on technological improvements to biological monitoring, which should be particularly valuable to LMR-GOOS.

Global Ocean Ecosystem Dynamics (GLOBEC)

The GLOBEC programme was described especially in regard to its four objectives: to understand how multi scale physical processes force large scale changes in marine ecosystems, to determine the relationship between structure and dynamics in a variety of oceanic systems, to determine the impacts of global change on stock dynamics and to determine how changing marine ecosystems will affect the global earth system. There are international, regional and national programmes. It was recognized that while the GLOBEC programmes are of finite length, they will provide information on what should be monitored in the long term and how this should be done. It was considered important that GOOS and the GLOBEC programmes establish a formal linkage through the GLOBEC Scientific Steering Committee.

Joint Global Ocean Flux Study (JGOFS)

The Joint Global Ocean Flux Study (JGOFS) project, although approaching the end of its intensive field observation phase, has application to the LMR programme through: (i) extensive and unique biogeochemical and physical data sets on the status of the global ocean during the 1990's, which include regional process studies, time-series studies, surface ocean surveys and the synoptic view of ocean colour made from satellites; (ii) development of an integrated and quantitative view of biogeochemical cycles of carbon in the ocean indicating the roles of biota, physical transport, air-sea exchange and particle settling and remineralization; and (iii) elaboration of a hierarchy of coupled biogeochemical-physical circulation models of varying ecosystem complexity to describe natural variability and anthropogenic changes in the carbon cycle over decade to century time scales.

Large Marine Ecosystems (LME)

The LME programme and its modular components were described. There is currently ongoing LME monitoring in the Gulf of Guinea and the Yellow Sea, and LME projects are in various stages of active development in the Benguela Current region, the Baltic Sea, the Bay of Bengal and several other regions. The LME programme shares some common aspects with several of the GOOS modules, including the LMR-GOOS module. All have monitoring as a major focus. Unlike GOOS, the intended scope of the LME programme extends well beyond monitoring to include mitigation, public awareness, capacity building and governance issues. Unlike the LME programme, which is a collection of selected regionally focused projects, GOOS is planned as a comprehensive, integrated global system. Nevertheless, certain modules of some of the LME projects might be considered as pilot projects for LMR (and other) components of GOOS.

Helsinki Commission (HELCOM)

The HELCOM monitoring programme for the Baltic Sea was initiated in 1979. It is a ship based programme that includes measurements of nutrients, phytoplankton, zooplankton, benthos and hydrography. Climate driven variability in the ecosystem and under sampling of certain variables prevent detection of trends over time scales less than 20 years. Rate measurements in lower trophic levels were not suitable for monitoring purposes. To monitor trends and variability apparently measurements integrating larger time and space scales are preferable to precise discrete measurements.

Oslo-Paris Monitoring Programme (OSPAR)

The OSPAR Programme includes the co-ordination of several national programmes that monitor nutrients, phytoplankton, zooplankton and pollutants of the northeast Atlantic. Discussions are underway with respect to the possibilities of monitoring that could identify ecosystem changes caused by fishing and other human impacts on the environment.

6.2 REQUESTS TO IOC AND FAO

Recognizing that the above abbreviated comments on some existing monitoring programmes were incomplete and that there were undoubtedly others of which the Panel was unaware, the Panel directed the following request to IOC:

Several national, regional, and other international organizations have conducted, or now conduct, repeated observations designed to monitor the status of marine ecosystems or selected biological or physical components thereof. While some of these programmes are well known, e.g. California Co-operative Oceanic Fisheries Investigations (CalCOFI), others are known only locally. In addition, some programmes periodically assess the changing state of local ecosystems. An integrated set of these assessments could improve the understanding of marine ecosystems globally, as well as indicating areas whose present monitoring is inadequate. The Panel therefore requests that IOC compile and make available information on significant monitoring and assessment programmes of its member states.

The Panel also made an analogous request to FAO:

A number of national and regional bodies collect and analyse fishery statistics and make fishery assessments. An aggregation of these analyses would be invaluable in assessing population changes in the upper trophic levels of marine ecosystems. The Panel therefore requests FAO, the global centre for fishery statistics, to identify on a global scale the existing fishery analyses that could contribute to the desired meta-assessment and to advise on how it could best be organized and carried out.

7. DETECTING PATTERNS OF ECOSYSTEM CHANGE

The Panel agreed that to detect patterns and trends of living marine resources, systematic measurements are needed of ecosystems and processes that affect them. The information is needed as a function of time and space on appropriate scales. Table 1 represents a summary of the information required and the processes, conditions and variables that need to be determined.

Table 1. Ecosystem components and conditions for which information is desired (See elaboration of each item in text that follows).

I. Ecosystem components A. Top predators B. Commercial finfish C. Forage and nekton D. Benthos E. Zooplankton F. Phytoplankton	**II. Ecosystem conditions** G. Nutrient chemistry H. Temperature, salinity, dissolved oxygen I. Ocean velocity field J. Atmospheric forcing
Desired information (i) Abundance and distribution (ii) Reproduction, recruitment, growth (iii) Ecosystem role (iv) Causes of mortality	**Desired information** (i) Magnitude and distribution (ii) Causes of variations

I. Elaboration of Ecosystem Components

A. Top predators and other large species (seabirds, marine mammals, sharks and turtles).

While large species and top predators have in the past formed the basis of industries, their economic importance is now more limited. However, the health of their populations is of evident human concern both for economic and esthetic reasons and also because their position at the apex of the food chain makes them integrators of contamination and thus valuable indicators of ecosystem health. Other large species such as manatees, while not predators, are also included in this section because the information requirements are essentially similar to those required for the top predators.

(i) Abundance and distribution of these species are essential information. Since seabirds and marine mammals are air breathers, surveys based upon sightings are possible. These sighting surveys might be line transect surveys in the case of cetacea, haul-out site identification and counts in the case of pinnipeds, and breeding colony identification and counts in the case of seabirds. Seabird distributions may also be estimated by at sea observer programmes on ships of opportunity. Surveying the abundance of the larger sharks is difficult. One approach is to use by-catch data from commercial fisheries.

(ii) Reproduction. Studies of reproductive capacity are important, particularly where concerns exist that human activities may affect it. Examples of possible impacts might be the effects of contaminants on reproductive ability, such as caused by endocrine disrupters (Report of the Fourth Session of HOTO Panel, Singapore, October 1997), or the effect of fishing on forage species near breeding sites, which may influence chick or pup survival.

(iii) Ecosystem role. Top predators particularly at historic population levels generate significant predation mortality on lower trophic levels. They might perhaps also act as keystone species and serve to structure ecosystems. A further ecosystem concern is that abundance of top predators, e.g. the size of pinnipeds, can be sensitive to availability of prey.

(iv) Causes of mortality. Of particular concern are direct mortality rates induced by human activities such as hunting, incidental by-catch (particularly of cetaceans), boat collisions, etc. These are best determined by monitoring body counts. Other monitoring might include recording sites and counts of the strandings of marine mammals and wrecks of seabirds and of starvation-induced deaths. Tagging studies can illuminate migration and mortality processes. Photo identification can provide a powerful equivalent to tagging studies for marine mammals. These and tagging studies, including large smart tags, may elucidate abundance, migration and mortality questions.

B. Commercial finfish (pelagic and demersal)

Commercial finfish (fish used for human consumption) are of obvious economic importance and provide the resource underpinning of fisheries throughout the world. The common property nature of fisheries means that Governments are typically involved in their management, and that management in accord with the precautionary approach should be based upon an appropriate level of knowledge (see for example FAO 1995, Fish Tech. paper 350 pt. 1). This requires routine monitoring of each significant fish stock. Desired information are:

(i) Abundance and distribution. A knowledge of the stock abundance, often by size, relative to target and limit reference points for its biomass is an obvious need. Abundance is ideally measured in absolute terms and ideally also characterized by size or age. Techniques for obtaining this include sequential population analysis or depletion models based upon commercial catch data, fish aging data and commercial or research estimates of abundance trends. For some demersal species, bottom trawl surveys are frequently employed to estimate abundance; while for some pelagic or semi-pelagic species, acoustic estimation of abundance is an alternative or additional source of abundance information. Other estimators of abundance include egg surveys coupled with estimates of average adult fecundity and visual sighting surveys. Where absolute estimates of abundance are not feasible or where economic constraints prohibit the expensive sampling required for these methods, measures of relative abundance may be used. Examples of relative abundance indices are commercial catch per unit effort data by gear type and research vessel trawl survey catch rates. Where fishing effort is not available, total commercial catch may give an indication of biomass but one which is confounded with changes in exploitation level. The spatial distribution of fish stocks can also be of management significance in addition to the estimates of overall abundance. Stocks may become more or less widely distributed in different environmental conditions and this can influence how they are assessed and how they should be managed. It may also influence the jurisdiction of stocks if they change their distribution from the EEZ of one state to that of another or to the open ocean. Distribution may be measured by commercial catch data, commercial catch per unit effort data, research fishing surveys (particularly with trawls) and research vessel (or chartered commercial vessel) acoustic surveys. Size distribution (size spectra) of all commercial fish may also prove a valuable management tool. Sampling for size spectra often results from aggregation of results from species-specific surveys.

(ii) Reproduction. Failures of fish stocks are most often thought to be failures of reproduction, either due to removal of spawning biomass by excessive fishing or to changing environmental circumstances affecting either adult biomass and fecundity or larval survival. Monitoring reproduction is a means of obtaining early warnings of problems and an understanding of the processes underlying the ability of the fish stock to reproduce itself in the face of fishing pressure. Techniques for monitoring include the interpretation of the abundance estimation approaches described in (i) above plus studies of fish fecundity and of egg and larval survival processes.

(iii) Ecosystem role. Species in this group may have multiple roles in the ecosystem as predators, as prey and possibly as scavengers. The state of the marine ecosystem may influence individual fish stocks, and the way individual fish stocks are harvested may influence components of the marine ecosystem. Fish stocks may be influenced by the abundance of predator and prey species and by parasites and their secondary hosts. Appropriate monitoring may include the collection of stomach content data, condition factor, gonadal/somatic indices, indices of liver weight, etc. Abundance indices of important non-commercial species may also be indicated if these are significant predators or prey. Part of this and other monitoring will include the development of suitable mathematical modelling tools to convert data on what can be observed into estimates of the information that is needed. As a concommitant to fishing, commercial fishing may affect other marine biota by directly killing, by providing food in the form of discarded catch, offal and the products of non-catch mortality, by the effects of trade specific litter (particularly lost or discarded gear which may cause entanglement or ghost fishing), and by disturbing substrates. It may also affect other biota by changing the structure of the marine food chain.

(iv) Causes of mortality. Fisheries management is essentially a management of fishery induced mortality rates relative to those arising from other causes. Estimation of all significant mortality rates is therefore important. That generated by the fishery is of the first importance and is often obtained as a concomitant of the monitoring of abundance. For both the estimation of abundance and mortality, total commercial catch (both landed catch and discarded by catch) data are of the first importance. Other significant sources of mortality may include those from predation, disease or adverse environmental conditions. Suitable monitoring of these includes collecting stomach content and feeding data, conducting disease and parasite prevalence surveys and by recordings and appropriate investigations of anoxic and other fish kills. Tagging studies, sometimes including the use of smart tags, can be an alternative source of information on some mortality rates.

C. Forage and Nekton species (small pelagics, mesopelagics, squid, euphausids).

A number of these species have economic significance as the subject of fisheries and biological importance as sources of food to higher tropic levels. Many of these species are caught for fish meal and oil. Since these products are usually much less highly priced than fish for human consumption, the possibility of their harvest impacting that of commercial species may be of economic importance. Impacts of their harvest on top predators may also be of concern.

(i) Abundance and distribution. Much of the comment under commercial fish is also applicable to commercial species of small pelagics, mesopelagic fish and squid. However, since many of these species are annual or short lived species, monitoring methods are less often based upon sequential population analysis and more often based upon acoustic surveys, egg surveys or on depletion models of total catch. Since these species often have strong schooling behaviours, relative abundance estimates based upon commercial catch rates can be misleading. Stomach content of commercial fish species may be an alternative source of abundance data for some of these species. Distributional changes may be of particular concern for these species since they can react quickly to changing ocean conditions.

(ii) Reproduction. Comments under B apply.

(iii) Ecosystem role. These species typically act to transfer production from the plankton to higher trophic levels. Stomach content data of these species and of their predators may be important information in clarifying these processes. Some of these species may also prey on the egg and larval stages of commercial fish and shellfish.

(iv) Causes of mortality. Comments under B apply but these species may be dominated by predation mortality rather than by fishing mortality.

D. Benthos (commercial shellfish)

Benthos species such as crabs, crawfish, lobsters, prawns, shrimps, scallops, oysters, clams and whelks are frequently highly priced and of economic importance. Where they occur inshore they may also be of social significance as the basis of small scale fisheries.

(i) Abundance and distribution. Ideally these species would be monitored on the same basis as commercial fish. In some cases they form extensive stocks and are subject to fisheries similar to those for commercial fish (or even in fisheries with mixed catches of shellfish and commercial fish). In these cases similar monitoring approaches are indicated where they are possible. The lack of hard parts suitable for aging material may however be a limitation on the methods that can be used upon crustacea . In other cases these species, which often inhabit near-shore areas, form small local stocks subject to small local fisheries. These are less easy to monitor in a cost effective fashion. Monitoring through commercial catch rates may be one of the few practical options in these cases. Other options are diver surveys, beach surveys, research surveys, etc.

(ii) Reproduction. Reproduction studies have not so far been prominent for these species though some studies of larval drift have been made for some species.

(iii) Ecosystem role. These species may have roles as prey and a scavengers. Rather fewer will have roles as predators. The planktonic larval stages of some species may be particularly important as food sources. Some benthic species provide physical structure to the benthic environment.

(iv) Causes of mortality. As with commercial fish species, understanding of fishing mortality is important.

E. Zooplankton

Zooplankton includes the early life stages of fish, nekton and benthos as well as numerous species which permanently reside in the plankton and whose distribution is controlled mainly by currents. The residency of developmental stages in the plankton varies from days to months or longer, and the size of zooplankton varies from millimetres to jellyfish which may be over one-half metre in disk diameter alone. The smaller components are essential parts of the food chain leading to commercial fish while gelatinous zooplankton may provide an alternative food chain. The successful reproduction of some copepods, important food for developing fish larvae, is related to the timing and magnitude of spring phytoplankton blooms. Thus variations in zooplankton abundance and occurrence can effect the survival of higher trophic levels. At times swarms of gelatinous zooplankton may foul fish nets and there is evidence that fish avoid these areas. In other regions it has been reported that zooplankton are considerably less abundant where swarms of jellyfish occur but the interactions between the two are unclear. Thus the long term monitoring of this component of the ecosystem may well indicate wide scale processes that effect human activities.

Monitoring zooplankton is usually conducted by plankton surveys organized as time series and using towed or vertically hauled nets as the usual methods of collection. This includes the monitoring of standard sections such as the CalCOFI survey and the Continuous Plankton Recorder (CPR) survey, using ships-of-opportunity or survey vessels. Recent developments of automated techniques for sampling include multiple opening and closing nets with environmental sensors, video plankton recorders and acoustic and laser surveying instruments.

The variables that need monitoring are abundance, preferably by major taxa and size group, distribution (areally and vertically), reproduction and mortality. Secondary production estimates for zooplankton, although an important parameter, require controlled shipboard experiments on important species combined with field measurements of their abundance, fecundity and food.

F. Phytoplankton

Phytoplankton is the basis of life in the sea and changes at this level can affect all higher components of the food chain. Through toxic blooms, red tides and anoxia-inducing blooms phytoplankton can also give rise to risks to human health, to the survival of farm fish, shellfish, and top predators. Some of these questions are addressed by the IOC Harmful Algal Bloom Panel in its *Manual on Harmful Marine Microalgae* published in 1995. Phytoplankton can cause nuisances such as beach foaming and fouling of commercial fishing nets in some regions. Growth rates can be very high resulting in bloom conditions within days under favourable conditions of nutrients and light.

Monitoring of phytoplankton biomass is typically carried out by periodic measurements of extracted chlorophyll a from water samples, and the 14-C carbon method is used for determination of primary production. Automated florescence measurements for chlorophyll a can be made from underway vessels using continuous flow fluorometers, as well as from fixed or drifting buoys. Community composition is determined through cell counts in order to recognize microalgae species which could lead to harmful algal blooms. Natural populations can be also separated and identified at sea using flow cytometry techniques. Satellite sensors record ocean colour from which chlorophyll concentrations can be estimated and primary production roughly approximated.

II. Elaboration of Ecosystem Conditions

G. Nutrient Chemistry

The concentrations of inorganic compounds of several elements - e.g. nitrogen, phosphorus, silicon, iron - limit primary production in many oceanic locations, so knowledge of their concentrations and distributions can contribute to understanding of changes in the higher trophic levels. Concentrations are commonly measured by standard methods in discrete samples collected by water samplers. Underway shipboard sampling via pumping systems has been used with varying success. *In situ* measurements from towed instruments are currently under development. There are presently no methods available for remote sensing of these elements.

Repeated sampling (e.g. several day to monthly scale) of near-surface layer concentrations in areas of high and variable productivity (e.g. in coastal upwelling systems) may be one way to monitor potential production in such locations. On very much longer time scales (e.g. decadal), evidence should be sought for basic changes in fluxes (i.e. rates of supply to near surface layer). On these scales, changes in basic characteristics of nutrient/depth profiles in the upper permanent pycnocline may be essential information.

Logically, the presumed relation between changes in nutrient concentrations and in primary productivity is a reasonable hypothesis, and one that has guided classical biological oceanographic research to a substantial degree. However, until now there has been little documented success in relating variations in measured nutrient concentrations to substantial temporal variability in the biological ecosystem, with the result that there is little discriminatory power to separate major cause-effect linkages from mere co-variation. However, this may be simply the result of absence of appropriate information on nutrient variability.

One can say that the linkage of variability of nutrients or nutrient fluxes to variability in the biological ecosystem must mainly be through the effect on phytoplankton growth (primary production) and linked effects on distribution, concentration, and quality of phytoplankton cells. The likelihood that some of the information content may be more easily accessible at the level of the distribution and concentration of chlorophyll (easily sensed remotely), and through the likewise relatively easily sensed and modelled major physical driving forces for nutrient fluxes (wind-induced upwelling and turbulent mixing, tidal mixing, etc.) may influence the choice of the most appropriate allocation of resources in this instance.

H. Temperature, salinity, dissolved oxygen

The magnitude of temperature and the concentrations of dissolved salts (salinity) and oxygen are useful measures of physical structure and mixing as well as having inherent importance, for example in relation to the rates of biological and chemical processes. Certainly, temperature is the most easily measured environmental variable and as such forms a primary matrix for temporally and spatially continuous ocean monitoring, against which observations of other quantities more difficult to measure may be viewed and interpreted.

Temperature and salinity are commonly measured by instruments *in situ* (e.g. the CTD probe), giving continuous distribution vertically. Towed instruments, in some cases capable of profiling, can give continuous records horizontally. Dissolved oxygen has traditionally been measured in discrete samples, but oxygen sensors analogous to those for temperature and salinity are coming into use.

Sea surface temperature (SST) is commonly measured from satellites, giving large-scale continuous coverage in space with frequent repetitions of time. In addition to temperature itself, the delineated spatial patterns are potentially useful in diagnosing key processes (frontal structure, topographically-trapped water parcels and structures, etc.). The capability for satellite measurements of salinity has recently been demonstrated.

For SST, conventionally-achieved levels of accuracy and precision are generally adequate for use in specifying ecosystems. However, some consideration should be given as to whether the levels of accuracy over the decadal scales crucial for LMR-GOOS are preserved in the usual longer-term means and large-scale spatial composites.

A particular need for many aspects of LMR-GOOS is to define conditions at the floor of the continental shelf. Organisms in the pelagic environment are able to adjust their depth level to find acceptable conditions in a stratified environment. However, at the solid surface of the very gently sloping continental shelf floor, small vertical movements (meters) of the isopleths of key quantities may displace the intersections of those isopleths with the sea floor by large horizontal distances (e.g. up to tens of km), potentially displacing large segments of the extremely important biological community living at that interface. Well-founded procedures for merging various types of data (satellite, available vertical profiles, models, etc.) to extend the coverage to such depths would be extremely useful.

In certain shelf regions of the world's oceans, the distribution of low oxygen conditions on the continental shelf floor may have such dramatic effect as completely to overwhelm all other considerations. For example, it has recently been reported that two billion hake, a valuable commercial species off southwestern Africa, were recently destroyed in a single episodic outbreak of low oxygen waters over the shelf, completely disrupting the fishery and undoubtedly having major associated ecosystem effects (including documented sharp increases in mortality and corresponding declines in regional marine mammal populations).

I. Ocean velocity field

Ocean currents are responsible for advection of heat, dissolved materials, and particles (including fish larvae and other plankton), for mixing, and for formation of mesoscale structures such as eddies and fronts. Most marine organisms have complex life cycles with at least one planktonic stage. Many populations have developed highly adapted strategies for maintaining population under "normal" flow conditions. Highly anomalous flow conditions are thus expected to disrupt these strategies.

Horizontal flow can be measured directly at fixed locations (Eulerian measurements) or with drifters (Lagrangian measurements) and can be estimated indirectly, for example from the distribution of temperature and salinity. Remote sensing of sea surface height (altimetric measurements) can provide an indirect estimate of surface flow. Vertical flow, as in upwelling, is not presently measured directly, but is estimated from horizontal measurements.

Sea level measurements from coastal tide gauges and bottom mounted pressure sensors deserve mention here. In addition to providing information on ocean flow conditions, variations may also reflect alterations in the depth-integrated temperature and salinity fields. In general, such measurements are potentially highly useful for LMR-GOOS for all time scales of potential interest. New long-term implementation of sea level gauges on areas of coastline where such information is currently lacking, should be considered as a potentially cost-effective source of valuable information.

The difficulties in adequately specifying the richly-structured and variable ocean flow field may be mitigated to some degree by mechanistic modelling in conjunction with observations of more easily observed "tracers" of flow effects (SST, ocean color, etc.) and of the driving forces (wind, sea level height, etc.)

J. Atmospheric forcing

Surface ocean currents are largely wind-driven, and wind forcing is responsible for divergences associated with upwelling and with vertical mixing. Surface winds are commonly measured at discrete locations, e.g. from ships and shore stations and can also be measured (by scatterometer) from satellites. Atmospheric pressure measurements, usually from ships and shore stations, can be used for indirect estimates of surface winds and as indicators of large-scale processes, as in the Southern Oscillation Index (SOI), North Atlantic Oscillation (NAO) and indices of Aleutian Low behaviour. Meteorological agencies employ complex procedures for merging pressure and wind observations together with known physical laws to maximize continuity on short time scales. While the resulting data fields represent a potentially useful data source for LMR-GOOS, it should kept in mind that these methods are designed specifically to support short term weather forecasting and that the long term homogeneity of the time-series of archived data fields as indications of the more subtle longer term trends underlying the energetic synoptic-scale variability may be a minor consideration for these agencies. Also, the spatial spreading of information inherent in these methods may mask significant real spatial variability.

In terms of direct measurement systems, the time scale again may be a crucial consideration. For example, scatterometer measurements of meso-scale wind stress curl patterns will be valuable on the "atmospheric event" scales but may not adequately define more subtle seasonal and interyear variability. This is a severe problem because important linkages of wind to ecosystem process are most often nonlinear. Identification of significant interdecadal variations may ultimately depend on the very large-scale "integrating" indices (SOI, NAO, etc.), implying a corresponding loss in interpretability of process details.

These are important considerations for the design of LMR-GOOS because of the importance of valid indicators of atmospheric forcing as proxy, or "derived," indicators of quantities (e.g. ocean flow, nutrient fluxes, etc.) more difficult to measure.

Integrated analysis of ecosystem variation

Information on the causes of the distributions of separate classes of environmental parameters is also desired but is generally the result of analysis rather than of measurement. Changes in concentrations of nutrient elements can result from physical advection and mixing and from biological activity. At a given location, temperature and salinity can be changed by local processes (heat and water exchange) or by advection. Dissolved oxygen is modified by both physical and biological processes. Ocean currents are largely wind driven and their changes result from changes in wind forcing. Surface winds reflect large scale processes of heat exchange with the underlying surface, land or water, and changes in incoming radiation.

8. PLATFORMS FOR MONITORING

The variables specified in Table 1 can be measured from a variety of platforms, although for monitoring, some platforms are more cost-effective than others. Potential platforms include ships, buoys and aerospace remote sensors.

Ships. Research vessels are probably the most versatile platforms capable of measurements in all ecosystem categories and of conditions and processes affecting ecosystems. While they may be the only way to make some measurements, in general they are too expensive for use in routine monitoring. Ships-of-opportunity, on the other hand, are much more limited in their measurement capabilities but are highly effective monitoring platforms for the measurements they can make along the routes they travel. Fishing vessels through their routine operations and the analyses of their catches play an essential role in monitoring finfish, other forage and nekton, and benthos of commercial interest.

Buoys. Moored instruments are particularly effective for monitoring atmospheric forcing and *in situ* physical and chemical conditions. Recently their capabilities are being extended to include some biological measurements (bio-optical and bio-acoustical). Such buoys can provide essentially continuous measurements at fixed locations. This information is particularly valuable if those locations are critical pulse points representing conditions beyond the specific locations, or if onboard sensors allow sampling at a distance (e.g. using acoustic or optical devices). Drifting buoys can be used for measuring water motion along the path of drift, as well as some physical and chemical conditions for which appropriate sensors are available.

Aerospace Remote Sensors. Satellite platforms supported by several national atmospheric, oceanic, and space agencies now carry a variety of sensors that provide relatively continuous measurements in space and time of important physical variables (including color which can be analysed in terms of phytoplankton abundance, distribution, and production). These observations are for the most part constrained to the ocean surface but can provide continuity in space and time for the more discontinuous measurements from other platforms.

9. DEFINING MONITORING PRODUCTS

9.1 MONITORING AS A COMPONENT OF INFORMATION AND RESEARCH

Table 1 gives a broad division of ecosystem components and conditions and indicates the types of information that are appropriate to each. The ocean is a cryptic environment and it is often impossible to directly observe the information that is required about components of its ecosystems. Information required includes:

(i) appropriate monitoring of measurable factors;
(ii) appropriate modelling to convert monitored data into the estimates of interest;
(iii) suitable storage of data and model results to turn them into available information.

Thus, typically an observing programme must contain monitoring products, modelling products and data base products. However, the panel first focused upon monitoring products; and the definition of modelling and of data base products remain to be developed.

A relatively full observational programme should generate comprehensive descriptions of ecosystem change on decadal time scales over large geographic areas. However, even with an extensive and comprehensive monitoring programme, explanatory power of the causes of the observed changes will be limited. The current state of marine ecological theory permits only rudimentary interpretations of changes in ecosystems, as well as prediction of their future states. Therefore monitoring activities must be balanced with active research programmes focused on understanding of ecosystem structure and function. An ecosystem monitoring programme should be seen as an essential component of that research strategy, even in areas with limited funds.

9.2 DEFINITION OF MONITORING PRODUCTS

While Table 1 attempts to list all relevant classes of variables, the scope of an actual monitoring programme will depend on which of these classes are already adequately monitored regionally, which are considered most salient for the recognized problems of the region or system, and which can be incorporated in a designed monitoring programme at acceptable cost and using available methodology.

However, one can envision a vital monitoring base that should be in place in all coastal states, to which selected measurements can be added as appropriate. That base should include the following:

- coastal station measurements of sea level, surface temperature and salinity (where appropriate), winds, and atmospheric pressure;
- general knowledge of occurrence and life history of major marine species;
- measures of catch, effort, and size-frequency distribution of major commercial species.

For living marine resources it is apparent that additional products will be needed, but it is also clear that the most exacting uses of these monitoring products are found at a regional level rather than at a global scale. Some may be vital in one region and of less or little concern in another region. Clearly the Panel needs to develop a detailed definition of appropriate monitoring products and this needs to be considered at a regional level. At a minimum, an appropriate definition of monitoring products for a given region will require information on:

- the relevant ecological group, sub grouping, species or ecological condition to be monitored;
- the type of monitoring product required;
- its frequency of collection in time and space ;
- the accuracy (lack of bias) ;
- precision (Coefficient of Variation) ;
- whether it is already collected or not;
- whether its utility is conditional upon other data also being collected;
- the priority that should be assigned to its collection.

Information on these and other appropriate points should be characterised in as few variables as possible. This will allow the monitoring requirements for LMR-GOOS to be communicated to the GOOS Steering Committee (GSC) in a succinct and unambiguous (data base like) fashion. To move towards a detailed specification of these needs, the members of the Panel will first be consulted on the needs they perceive for those regions with which they are most familiar. This will help to refine an appropriate and unambiguous format for specification of monitoring products in a form that can be passed on to the GSC. To assist the consultation a suitable form (ideally to be completed in an EXCEL spread sheet) is shown in Table 2 (page 16) with an example of a specific monitoring product (groundfish survey monitoring of gadoids in the North Sea).

10. RETROSPECTIVE EXPERIMENTS

The utility of ecosystem monitoring can be challenged by considering why there have been limitations in understanding (and deficiencies in management actions) for geographic areas with extensive ongoing monitoring activities; such as the California Current, the mid-Atlantic Bight, Georges Bank, the Canadian Atlantic Continental Shelf, and the European Shelf (including the North Sea and the Baltic). In some cases these programmes may have missed critical components of ecosystems. More importantly, insufficient efforts may have been directed towards synthesis of the broad range of data that is available in these well studied areas. An ecosystem approach to the analysis of data has been either lacking or uncoordinated. As part of these regional ecosystem assessments, there is a need for basin scale ocean climate indices that may be important in the interpretation of local observations.

The concept of monitoring, analysis, and prediction could be tested in several well-sampled regions where significant ecosystem changes such as regime shifts have been observed. In selected regions, one could ask to what extent ecosystem changes could have been predicted from the observed variables. Could predictability have been improved if additional or different variables had been monitored? Was inadequate predictability a consequence of inadequate monitoring, inadequate analysis, or inadequate understanding? Such ecosystem "experiments" could throw light not only on the LMR-GOOS potential but also on the kinds of measurements that would be most valuable for LMR predictions, as well as helping to identify priorities for ecosystem research.

Proposed locations of such experiments (with name of responsible panel member) are:

Baltic Sea (von Bodungen)
CalCOFI area (Lluch-Belda, Laurs)
Japan Sea/East Sea (Zhang, Sugimoto)
Northwest Atlantic demersal stocks (Sinclair).
Northeast Atlantic (Pope)
Benguela (Hutchings)
Black Sea (Shiganova)

In addition, there could be important lessons for LMR-GOOS in the developing LME programme in the Gulf of Guinea (Koranteng).

The discussion of issues and formulation of monitoring methods and synthesis products was necessarily incomplete at this first meeting. Therefore, panel members agreed each to submit short papers in the next few months on the lacunae they see in the LMR-GOOS programme as formulated so far.

11. CAPACITY BUILDING

For appropriate global or regional monitoring of living marine resources to occur it will be essential to build the adequate capacity to do the work in all regions. Some problems may concern infrastructure while others may require the development of skills. In some cases, skills may be developed by educational exchanges. In other cases appropriate expertise does not exist anywhere. It will need to be encouraged by peer contacts between scientists from countries who have analogous expertise and scientists from countries who have hands-on knowledge of the real problems if not the means of their solution. Until the details of the LMR-GOOS programme are elaborated it is clearly premature to identify specific techniques for capacity building, but developing broader educational and peer contacts now can only be beneficial to the programme. Broad capacity building in systematics, in catch sampling, in at sea survey techniques and in model constructing are likely to prove beneficial in this respect.

To describe better the need for capacity building, it will be helpful for panel members to co-operate regionally in identifying existing capacity and to identify clear current gaps in capacity. Hence a subset of the LMR-GOOS panel will be requested to develop a standard proforma intersessionally for collecting information on the various types of capacity required and all panel members then cooperate to produce regional reports in time for the March 1999 meeting.

12. DATE AND VENUE OF NEXT MEETING

The next meeting of the Panel will be held at the ORSTOM Laboratory, Montpellier, France during the period 22, 23 and 24 March 1999.

Table 2. LMR-GOOS Programme. Table of Possible Regional Monitoring Products.
To be filled for selected marine regions (at a suitable scale for the proposed observations)

Region	E.g. North Sea										Region Code e.g. ICES IV
1	2	3	4	5	6	7	8	9	10	11	12
Serial # Please Number products	Major Ecological Group or Condition	Subgroups or Species or physical observations	Type of Information	Frequency in time	Frequency in space	Accuracy (no bias/ constant bias %)	Precision Give C.V. %	Available? Yes/No	Linkage to other Obs.	Priority (Vital/ HI/Med low/?)	Comment particularly on 11
#1 #2											
#3 .... #15											
#16	Example Commercial fish	Gadoids	Survey Catch rate by age	annual	1 haul per 30 min. By 30 min. Rectangle	Minimum variation in interannual bias	Circa 30%CV for ages 0-3	Yes	Catch no. at age	high while stocks heavily exploited	This data is used for routine abundance estimation. In particular it is used to estimate recruitment which is vital for Quota management
#17 etc.											

ANNEX I

LIST OF PARTICIPANTS

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ANNEX II

AGENDA

1. OPENING

2. ARRANGEMENTS

3. BACKGROUND, GOALS AND OBJECTIVES, STRUCTURE, AND STATUS OF GOOS ACTIVITIES OF OTHER GOOS PANELS: CLIMATE, HEALTH OF THE OCEANS, COASTAL OTHER RELEVANT ACTIVITIES AND PROGRAMMES: GLOBEC, JGOFS, OSLR/LME, FAO, ICES, PICES, LME, SAHFOS, ETC.

4. REVIEW COSTA RICA (12/1993) AND DARTMOUTH (3/1996) WORKSHOPS, RECOMMENDATIONS

5 CONSIDER GOALS AND OBJECTIVES

6. IDENTIFY POTENTIAL USERS OF PRODUCTS AND INDICES, DETERMINE THEIR REQUIREMENTS

7. DEFINE SCOPE OF LMR-GOOS RELATIVE TO OTHER PANELS AND PROGRAMMES

8. IDENTIFY RELEVANT PRODUCTS AVAILABLE FROM OTHER ACTIVITIES AND PROGRAMMES

9. IDENTIFY NECESSARY NEW PRODUCTS AND THEIR SPECIFICATIONS; CONSIDER HOW THEY MIGHT BE OBTAINED

10. CONSIDER DELIVERY OF PRESENT AND FUTURE PRODUCTS

11. DEVELOP PILOT/DEMONSTRATION PROJECT(S)

12. CONSIDER FUTURE ACTIVITIES AND DEVELOP ACTION PLAN FOR LMR-GOOS

ANNEX III

LIST OF WORKING DOCUMENTS

IOC - 1996	A Strategic Plan for the Assessment and Prediction of the Health of the Ocean:A Module of the Global Ocean Observation System, May 1996.
SCOR - 1996	Report of the Planning Workshop for the Living Marine Resource Module of the Global Ocean Observing System including Annex 6 - the Executive Summary Report of the First Session of the *ad hoc* panel for the Monitoring and Assessment of Living Marine Resource Module of the Global Ocean Observing System (GOOS), San José, Costa Rica, 2-10 December 1993. Centre for Marine Science and Technology, University of Massachusetts, Dartmouth, 1-5 March 1996.
IOC - 1997	GOOS Coastal Module Planning, Workshop Report No. 131.
IOC - 1997	The Principles for a Global Ocean Observing System (GOOS), June 1997.
IOC - 1997	Joint Scientific and Technical Committee for Global Ocean Observing System (J-GOOS), Fourth Session - Report of Meetings of Experts and Equivalent Bodies.
UNESCO - 1997	IOC-UNEP-IUCN Global Coral Reef Monitoring Network (GCRMN) Strategic Plan.
IOC - 1998	Strategic Plan and Principle for the Global Ocean Observing System (GOOS) - GOOS Report No. 41.

ANNEX IV

TERMS OF REFERENCE
GOOS LIVING MARINE RESOURCES (LMR)

The LMR Panel will be responsible for:

(i) the strategic development and detailed scientific and technical design of the observing system for the Living Marine Resources module, consistent with the overall principles of GOOS;

(ii) maintaining liaison with research (particularly GLOBEC and LOICZ programmes and monitoring activities (e.g. OSLR and FAO) to ensure that the monitoring and predictions carried out by LMR/GOOS are based on sound and contemporary scientific knowledge;

(iii) co-ordination with other modules of GOOS (in particular the COASTAL and HOTO modules) for the purpose of ensuring compatible strategic and scientific development of all components of GOOS;

(iv) design and development of the analysis and modelling "products" derived from the LMR observing system to address the needs of various user groups.

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

(i) identify the present and potential users of the data and products of a GOOS-LMR programme and ensure that the design and implementation of GOOS-LMR responds to their needs;

(ii) take into account the observation requirements of the other modules of GOOS in defining the LMR variables and observations needed, and stimulate numerical modelling and other studies 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;

(iii) assess the availability of relevant existing data and observing systems, and the capabilities and activities of developing coastal states, and ensure that these considerations are incorporated into the GOOS LMR design;

(iv) develop a plan for the design and implementation of an observing system which would provide the data required by LMR, consistent with data provided for the general underpinning of GOOS and the data fields being provided by the global and coastal implementation themes. Variables and parameters should be selected with reference to their importance for detection of changes in the structure, behaviour, and biodiversity of marine ecosystems, including the status of fishery resources;

(v) actively co-ordinate LMR planning with other GOOS module efforts by attendance at relevant HOTO, Coastal and OOPC meetings;

(vi) produce a detailed outline of the implementation plan for presentation to GSC-I and an implementation plan by late 1998.

ANNEX V

LIST OF ACRONYMS

CALCOFI	California Co-operative Oceanic Fisheries Investigations
CPR	Continuous Plankton Recorder
CTD	Conductivity-Temperature-Depth
EEZ	Exclusive Economic Zone
EURO-GOOS	European Global Ocean Observing System
FAO	Food and Agriculture Organization of the United Nations
GCRMN	Global Coral Reef Monitoring Network
GLOBEC	Global Ocean Ecosystems Dynamics
GOOS	Global Ocean Observing System
GSC	GOOS Steering Committee
HAB	Harmful Algal Blooms
HELCOM	Baltic Marine Environment Protection Commission
HOTO	Health of the Oceans
ICES	International Council for the Exploration of the Sea
ICSU	International Council of Scientific Unions
IOC	Intergovernmental Oceanographic Commission
IOCARIBE	IOC Sub-Commission for the Caribbean and Adjacent Regions
IUCN	World Conservation Union
JGOFS	Joint Ocean Flux Study
LME	Large Marine Ecosystems
LMR-GOOS	Living Marine Resources-GOOS
LOICZ	Land-Ocean Interaction in the Coastal Zone
NAO	North Atlantic Oscillation
NEAR-GOOS	North-East Asian Regional-Global Ocean Observing System
OOPC	Ocean Observations Panel for Climate
ORSTOM	Institut français de recherche scientifique pour le développement en coopération
OSLR	Ocean Science and Living Resources
OSPAR	Oslo-Paris Monitoring Programme
PICES	North Pacific Marine Science Organization
SAHFOS	Sir Alister Hardy Foundation for Ocean Science
SCOR	Science Committee on Oceanic Research

SOI	Southern Oscillation Index
SST	Sea Surface Temperature
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WMO	World Meteorological Organization