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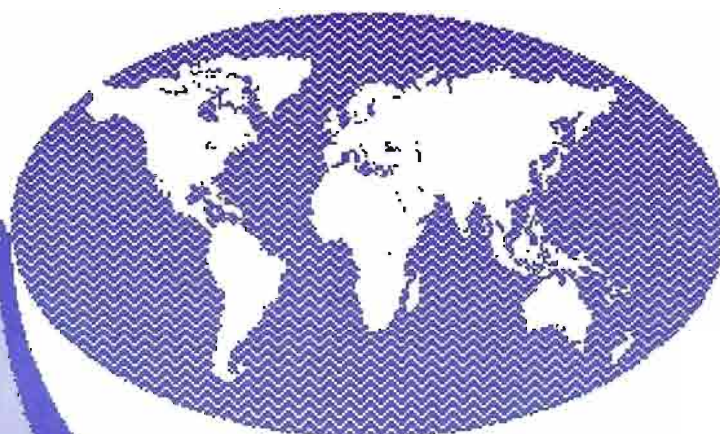
UNESCO

Marine Biodiversity and Ecosystem Function

A Proposal for an International Programme of Research

By

J.F. Grassle, P. Lasserre, A.D. McIntyre & G. C. Ray



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Marine Biodiversity and Ecosystem Function

A Proposal for an International Programme of Research

Meeting Report
of an
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by

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FOREWORD

This document is the culmination of a series of meetings arranged by IUBS/IABO in conjunction with Unesco. The initial stimulus originated some years ago from the SCOR Working Group n°67 on "Oceanography, Marine Ecology and Living Resources" which generated the IOC/FAO International Recruitment Experimental Programme (IREP), dealing with low diversity fisheries. In order to further develop the question of marine diversity, IABO brought together an *ad hoc* Group of Experts which met at Roscoff in September 1983, to examine the special problem of recruitment in high diversity systems. The Roscoff meeting concluded that the single problem of recruitment was not appropriate at that time, but recommended a programme emphasizing an experimental approach to the biological oceanography of high diversity systems to provide a basic understanding of their functioning. The meeting further addressed the question of biological interactions and environmental variability in determining the abundance of individual species in the community structure. As a follow up, IABO formed, in conjunction with the Unesco Division of Marine Sciences (COMAR) and IUBS a Working Group to deal with the concept of high diversity marine ecosystems. This WG met in Syracuse in 1987 and in Woods Hole in 1988, when it expanded its interests to biodiversity in general. Discussion of biodiversity in general were continued at an IUBS/SCOPE meeting held at the National Academy of Sciences, Washington, DC, in June 1989. "Ecosystem Function of Biological Diversity" was published in *"Biology International", Special Issue n°22* (1990).

Marine ecosystems, in particular, were considered at an Unesco and IUBS/IABO sponsored Discussion Group organised as part of the 4th International Congress of Systematic and Evolutionary Biology (ICSEB IV) held at the University of Maryland, College Park, in July 1990. The two day meetings on "Marine Biodiversity" were attended by 50 participants from 12 countries (Canada, Chile, France, Germany, Japan, Netherlands, New Zealand, Norway, Panama, UK, USA, Venezuela). Discussions included the definition of biodiversity (genetic and species levels, as well as habitat levels); differences between terrestrial and marine systems; biogeographic

generalizations; bacterial diversity; and the experimental ecosystem approach (mesocosms). The role of high diversity marine ecosystems (e.g., coral reefs) in the global carbon cycle was also considered. The temporal perspective provided by the fossil record can contribute to an understanding of the consequences of impending global diversity modifications. Furthermore, studies of current biodiversity will illuminate a number of issues in palaeobiology and palaeoclimatology. The participants emphasized that spatial and temporal dimensions of marine biodiversity need clarification and that there is little hard evidence linking species diversity and ecosystem function.

At the Round Table and at earlier meetings, ideas for an **International Marine Biodiversity Programme** were crystallised and further developed by the Task Force that met at the IUBS Secretariat in Paris, in November 1990, the results of which are the subject of this Report. We hope that the programme will be relevant to a series of interactions with ongoing IGBP activities, notably the Joint Global Ocean Flux Study (JGOFS) and the Land-Ocean Interactions in the Coastal Zone (LOICZ).

ACKNOWLEDGEMENTS

We are pleased to acknowledge our intellectual debt to our many colleagues who have provided us with the many ideas and insights evolving from the various meetings organised under the sponsorship of Unesco, IUBS/IABO, and SCOPE, notably: Bruno Battaglia; Rita R. Colwell; Ramon Margalef; Ernest Naylor; Tim R. Parsons; Marjorie L. Reaka-Kudla; Howard Sanders; and John Steele. Encouragement and suggestions received from Otto Solbrig, Francesco di Castri, Harold Mooney, Talal Younès, and Marc Steyaert are gratefully acknowledged. We would especially like to thank Mrs. Colleen Adam for her invaluable assistance in preparing the proofs.

INTRODUCTION

An international programme on marine biodiversity is required in view of the widespread evidence of human impact on the marine environment. The aim of this Report is: *to initiate an international, comparative research programme on biological diversity in the contexts of the structure and function of ecosystems and of global comparative biogeography.*

The objectives are:

1. To undertake long-term measurements on biodiversity as indicators of environmental change;
- 2 To present hypotheses appropriate to the development of the research programme;
3. To encourage support for education and training on coastal-marine biodiversity issues; and
4. To develop networks and logistics pursuant to programme development.

RATIONALE

Diversity is a basic property of life. It is clearly displayed at all levels of organisation in undisturbed natural ecosystems and is usually considered to be essential for the survival of these ecosystems. It provides the variability needed to cope with the changes implicit in nature.

In the past, these changes came entirely from natural events, which tended to permit recovery. Such events are either physical (often random or cyclic) perturbations, or biological interactions such as predation. In either case, diversity within ecosystems provides self-regulatory responses.

In comparatively recent times a new agent for ecological change has emerged in the form of people, and anthropogenic impacts are now seen to be of global significance. Unlike natural changes, human impacts are usually not random. Society targets selected species and habitats, and seldom allows them to recover. People tend to organise the world, increasing the complexity and extent of civilization while at the same time decreasing the diversity and complexity of nature. On land, for example, agriculture and

intensive stock-rearing reduce nature to monocultures, while urbanisation increases the diversity of our habitat, while eliminating much of that in the natural world.

Human impact on diversity is widely recognised. But, in the past overwhelming attention has been paid to the terrestrial realm, and has been focussed on the protection and preservation of individual plant and animal species that are under threat. While this is clearly desirable, it must be recognised that the concept of biodiversity encompasses a much wider range of issues, from the level of genes and genotypes through molecular diversity to variations in the structure and functioning of food webs and ecosystems, and the patterns of global distributions of life forms.

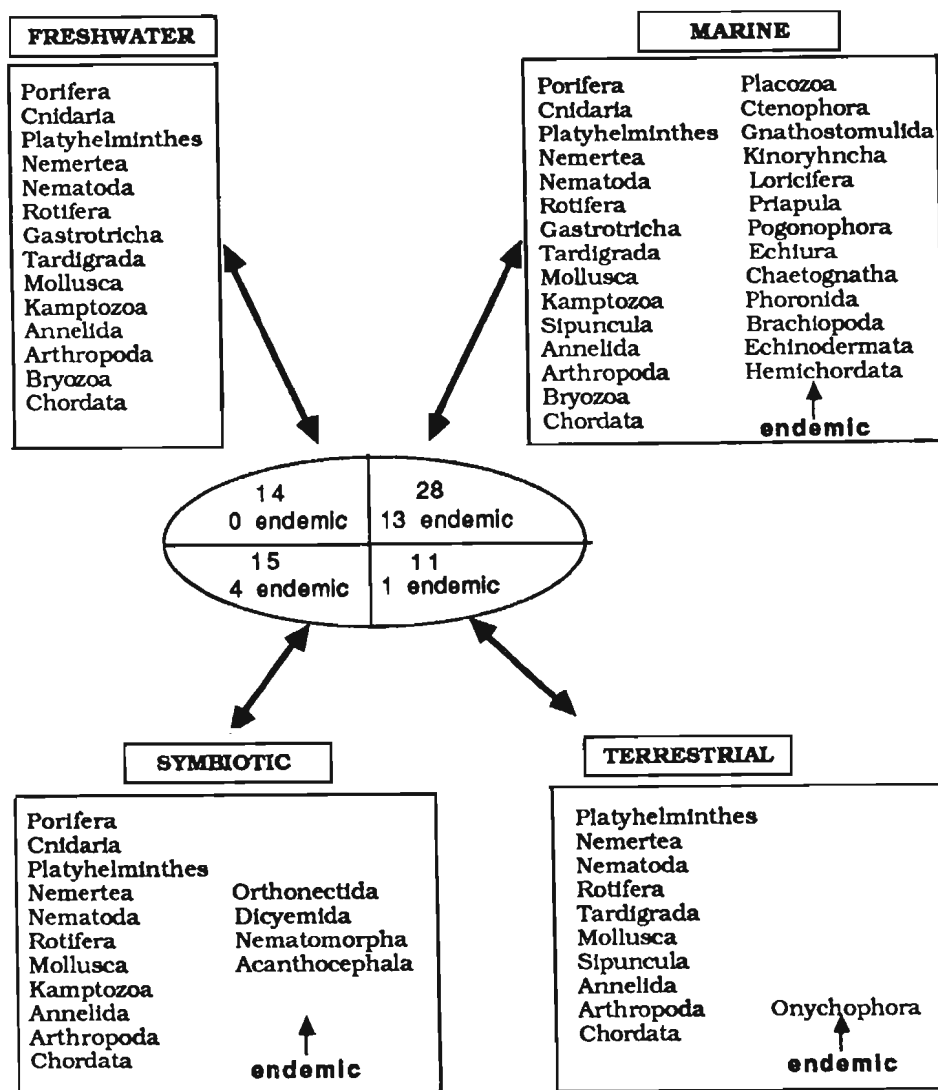
It is understandable that concern with these problems should initially have been associated with terrestrial systems because these systems are where human populations are concentrated. Indeed, until very recently it was considered that man could not change the seas, that exploitation of living resources could not possibly alter fish stocks, and that the oceans could easily absorb all our wastes. These views are no longer tenable. With the technical developments of recent times, our ability to find and catch fish is such that most exploited populations are under stress. Further, until recently, our exploitation of the sea's mineral resources was confined to shallow water, but now extends beyond the edge of the continental shelf. Also, wastes both from direct disposal and *via* runoff are altering marine ecosystems and habitats round the world.

Thus in the ocean, changes are taking place similar to those on land but they are less visible to the casual observer who cannot easily evaluate the world beneath the sea surface. Also, ocean ecosystems present significant differences from those on land, not least in the wider spectrum of variability within the seas, in the less marked boundaries between ecosystems, and in the biological adaptations needed to cope with seawater as a medium.

In the coastal zone, measurements and prognoses of changes in diversity are urgently needed to evaluate human activities, including fishing, industrial operations, mineral extraction and coastal development in general. In this zone, it must be recognised that the greatest impact of terrestrial processes on the ocean will be evident, as half the world's human population lives in coastal areas -- a proportion that is rapidly increasing.

At the phylum-level, marine diversity is greater than that for any other realm (Figures 1 and 2) there is no shortage of theory on marine biodiversity. For example, latitudinal species-diversity gradients have been proposed, but the empirical evidence is weak and contradictory. It has also been suggested that within-habitat marine diversity for soft bottoms is higher in the tropics than in boreal regions, but more strictly comparative studies could find no difference in macrobenthic diversity between sites in Java and in the U.K. For seaweeds (macro-algae), the most diverse systems are in the temperate, nearshore areas of California, Japan, southern Australia, the northern Atlantic, and the Brittany coast of France. Corals are highly diverse in the tropics where warm waters facilitate the production of calcium carbonate, but other taxa such as marine mammals are more diverse in high latitudes.

Figure 1: Distribution of Animal Phyla by Habitat.



In coastal systems, there are major differences in the structural and functional attributes of shallow-water marine ecosystems between high and low latitudes. These changes affect both benthic and planktonic communities, as well as the potential for interaction between these two realms.

Figure 2: Distribution of Algae Phyla by Habitat.

Phyla	Class	Habitat
PROCHLOROPHYTES		- picoplankton, mostly marine (discovered 1980s)
CYANOPHYTES	Cyanophyceae	- marine (50%) & FW (50%) - blue-green algae
RHODOPHYTES	Rhodophyceae	- 98% marine, few planktonic only one genus in FW
	Cryptophyceae	- marine & FW
	Dinophyceae	- Peridinian, marine 80%
	Raphidophyceae	- small group
	Euglenophyceae	- mostly FW
CHROMOPHYTES	Chrysophyceae	- small flagellate forms - Coccolithophoridae mostly FW toxic <i>Chrysochromulina</i>
	Tribophyceae	- <i>Vaucheria</i> , FW and brackish
	Diatomophyceae	- diatoms, marine & FW, benthic & pelagic, some toxic
	Fucophyceae (Pheophyceae)	- marine 90%
CHLOROPHYTES (green algae)	Ulvophyceae	- coral reefs (<i>Halimeda</i>), <i>Acetabularia</i> , <i>Cladophora</i> , <i>Ulva</i> , <i>Enteromorpha</i>
	Charophyceae	- FW
	Pleurostrophyceae	- mostly FW, marine planktonic
	Chlorophyceae	- mostly FW (<i>Volvox</i>), <i>Dunaliella</i> in hypersaline waters

Note: the most diversified habitats for marine macro-Algae are in the temperate area (e.g. Brittany, California, Japan, Southern-Australia).

In the deep sea, other differences occur and, for these environments our ignorance is even greater. The volume of the oceanic biosphere is at least two orders of magnitude greater than that of the land, and the area of the sea floor below 1000 meters depth is roughly twice the land area of the globe. Estimates of numbers of species in the deep sea may be too low by several orders of magnitude and it is now thought that the abyssal zone may represent a reservoir of animal diversity rivalling that of tropical land areas. While human activities continue to extend beyond the shelf edge, even those deep-sea reservoirs of biological diversity may be at risk.

Assessment of marine bacterial diversity has been especially neglected. Microorganisms form important parts of the bases of

marine food webs, and are crucial links in the transfer of energy and nutrients. One group of them --"picoplankton"-- were discovered only in the 1980s. Another recent discovery is of high diversity and abundance of viruses in the marine environment. They infect phytoplankton and may reduce productivity by as much as 80%. Plasmids possibly of terrestrial origin, may give natural bacterial communities significant antibiotic resistance and new tolerances to contaminants.

Given these considerations, it is clear that a global plan is needed to explain how man's activities affect marine biodiversity and to evaluate the consequences of diversity changes.

THE GLOBAL BIOGEOGRAPHIC CONTEXT

If we are to be able to predict the future consequences of environmental change -- e.g., global warming in particular climatic zones -- it is essential that comparative studies be undertaken so that regional differences may be properly documented, and so that the natural and/or anthropogenic mechanisms controlling them are understood. The functional significance of biodiversity gradients is not clear, even if it is shown that such gradients do, in fact, occur. Also, the relationship of species richness to such processes as productivity remains dubious; for example, high-productivity systems seem mostly to occur in areas of relatively low species richness, e.g., estuaries, upwelling areas, and sub-polar seas.

Every ecosystem can be characterized by its own species composition which, when compared with other systems, can reveal its particular ecological characteristics, including its ecological processes. This is perhaps most striking when comparing coral reefs characterized by scleractinian coelenterates, deep-sea benthos characterized by infauna, and the marginal sea ice characterized by marine mammals and birds. The question then becomes: what are the functional consequences of these biotic properties?

The IUBS/SCOPE Workshop on "Ecosystem Function of Biological Diversity" held in Washington DC, June 1989, developed the idea that strong links exist between biodiversity and ecological processes, that these links occur at different time and space scales, that species are the best indicators of environmental properties at local scales, that assemblages of species may offer clues to regional processes, and that a global comparative biodiversity component could help clarify these issues.

For marine and coastal systems, information on biogeographic patterns is woefully incomplete and the variability of these patterns is great, and perhaps chaotic over time. Nevertheless, it is essential that we take advantage of the knowledge at hand, while at the same time undertaking comparative research that emphasizes the relationships between diversity and process.

The patterns of biological diversity and their ecological and evolutionary determinants form the integrating focus for this programme. The understanding of patterns is the basis for siting of "observatories" and for monitoring the effects of global change. Thus, some hypotheses listed below are directed towards understanding biogeographic patterns.

HYPOTHESES

Specific hypotheses are necessary to give focus to this programme. The hypotheses proposed below will require further refinement as specific experiments and sampling programmes are defined. Also, biological data need to be incorporated into models of world ocean circulation and global biogeochemical cycles. For these models to be realistic, organisms must be considered as more than carbon or nutrient processors.

1. The spectrum of environmental variation is fundamentally different in marine and terrestrial ecosystems.

Marine environments have a spectral shift of environmental noise towards longer wave lengths. Variation in many marine systems may be chaotic. Physical extremes are less in some marine environments in comparison to terrestrial systems. Major perturbations on geologic time scales may also be less frequent in marine systems. *In situ* experiments in conjunction with continuous measurement of environmental variation on decadal time scales are needed to understand how the pattern of variation translates into functional properties and biodiversity of marine systems.

2. Biogeographic patterns of biodiversity and ecosystem function are determined by a combination of environmental patterns, i.e., single factor theories are not viable.

Whole theories have been predicted on: (a) latitudinal differences, (b) depth differences, (c) patterns of upwelling, (d)

physical energy in the system, (e) the degree of pelagic-benthic coupling, (f) proximity and magnitude of riverine input, (g) water mass distribution, and (h) inter-reactions with adjacent land areas. None of these theories has been adequately tested because large-scale sampling programmes have not been continued over long enough time periods and have tended to focus on relatively narrow objectives.

3. Offshore primary production and nutrient cycling are dominated by pelagic processes which determine biogeographic differences in biodiversity.

The pelagic habitat is far more important in open-sea systems than in coastal and terrestrial systems. The volume of the pelagic realm is orders of magnitude greater than benthic or land habitats. Nutrients for deep-sea communities are thought to be derived from production by near-surface plankton.

4. Increases in environmental heterogeneity in space and time, including disturbance, increase biodiversity, especially in the coastal zones.

The hierarchy of patch dynamics operating in marine systems is only beginning to be appreciated. Patterns of land use and habitat fragmentation are likely to be as important in coastal marine systems as in terrestrial systems.

5. Keystone species play a more important role in marine than in terrestrial ecosystems and this role is becoming more important on the lower latitudes.

Top carnivores and grazers have been shown to have consequences to ecosystems disproportionate to their abundance. Examples include the starfish *Pisaster* in rocky inter-tidal areas, the "crown-of-thorns" starfish on Pacific coral reefs and the sea urchin *Diadema* living on algae in Caribbean coral reefs.

6. Species introductions have major consequences for marine ecosystem function.

Organisms associated with oyster transplants, transfer in ship ballast water, accidental release of animals from laboratories and aquaria, and the building of canals have resulted in major changes in shallow systems in recent history. Some countries are considering stronger legislation to reduce the possibility of future introductions.

7. Extinctions are less likely to occur in marine than in terrestrial systems.

Despite the examples of marine extinctions in the fossil record, marine biologists are hard pressed to give more than a very few examples of extinctions in recorded memory of species not subject to exploitation. This may simply be because there are many fewer records of changes in species abundance in marine systems. Local extinctions may indicate which species are endangered on regional or larger spatial scales.

8. Increases in air and water-born pollutants (including terrestrially-derived disease species) and/or overfishing are presently resulting in widespread changes in marine systems.

Coral bleaching, "crown of thorns" starfish increases, *Diadema* die-offs, epidemic increases in dolphin and seal mortality may be related either to anthropogenic or natural processes. Lack of information on the spatial patterns of pollutant increase make tests of specific hypotheses impossible. Studies of fish populations in many regional seas show that overfishing has drastically altered species composition even though total biomass may not be affected, resulting in probable altered ecosystem states. Long-term measurements are needed to separate signal from noise.

9. Marine ecosystems and organisms have developed less robust internal processes to respond to the low magnitude short-term variations and this would result in a reduced ability to respond to large scale environmental changes.

In many marine ecosystems, environmental variability is small and extends over very long time scales due to the large thermal capacity and the long period exchange rates between deep and near-surface waters. Physical boundaries between ecosystems are less pronounced than for terrestrial systems.

10. Redundancy of genes and species is necessary for the long-term survival of marine ecosystems.

At the level of genes and species, biodiversity is orders of magnitude higher than needed to enable species and ecosystems to function efficiently, i.e. there is redundancy. Biodiversity may be needed to provide the raw material for natural selection to ensure long-term survival of species and ecosystems.

11. There is greater genetic variation at the molecular level within species in marine environments than in terrestrial ones.

Tests in genetic variation will only be one step relative to the possibility of major advances in ecological and evolutionary biology using molecular techniques. For example; recent developments in molecular systematics suggest that a "calculus of biodiversity" may be developed to compare the level of similarity in a taxonomic hierarchy with data on geographic distributions and evolutionary histories of species.

PROGRAMME DEVELOPMENT

The proposed **International Marine Biodiversity Programme** is intended to focus the attention of international and national organisations and agencies on the importance of this field. An understanding of marine biodiversity is indispensable for advances in all fields of biology, including ecology, fisheries and aquaculture, conservation and pollution. These areas of research are equally important for both developed and third world countries.

For the implementation of this scientific programme, we envisage a long-term programme of observational and experimental studies that can both achieve an acceptable standard of knowledge about marine biodiversity and test the above hypotheses. To do so, the programme should help:

- (1) Obtain a comprehensive knowledge of representative and threatened regions. Disturbance and degradation of coastal zones (coral reefs, mangroves, and many other near shore systems) is occurring as rapidly as tropical forest destruction. Study sites need to be chosen on the basis of biogeographic pattern covering tropical, temperate and boreal latitudes along transects that would explicitly address spatial variability across environmental gradients, at the regional scale, and on time scales of decades to centuries.
- (2) Develop comprehensive data bases on physical and chemical parameters and biological diversity. Computerized data banks are the most effective means of disseminating and making data available for scientific and management or societal purposes.

- (3) Ensure that relevant scientific expertise is available. Several factors have contributed to the present situation where professional taxonomists/systematists are not replaced : for example, the lack of research and teaching positions for systematists, lack of training grants, competition from other areas of biological oceanography. This situation can be changed: we must take advantage of the present-day "climate of opportunity" to set up training funds for young systematists and appropriate research-grant support. This is especially important for developing countries.

Programme development will involve a variety of communications and operations: liaison meetings, information exchange, interdisciplinary joint research and training projects.

A diagram of the proposed Programme, based on an observatory network, is shown in Figure 3. There are four basic elements organised around the central theme of biogeographic pattern:

1. Hypotheses and Models.

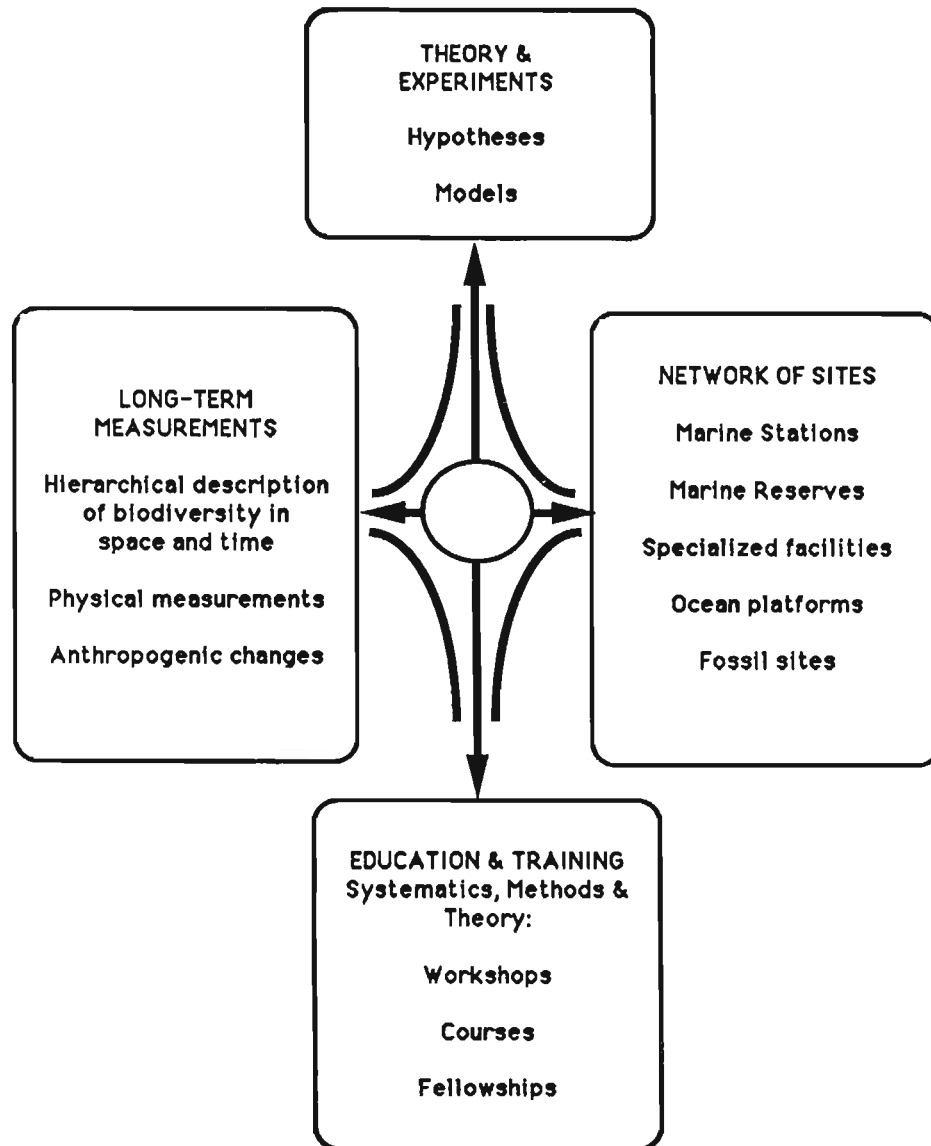
An initial set of hypothesis is enumerated above. The ultimate goal is a predictive theory concerning the functioning of marine systems. Tests of specific hypotheses and models will come from appropriate field experiments, carefully designed sampling programmes and whole system experiments using self-contained replicated ecosystems (mesocosms).

The programme should cover a wide range of marine ecosystems, in tropical, temperate and polar latitudes: pelagic systems; soft bottoms; rocky shores; coral reefs; mangroves and marshes; sea grass beds; coastal lagoons and estuaries; deep sea and hydrothermal vents.

2. Network of Sites.

The aim is to represent a wide geographic range of selected habitats by a network of **Regional Research Centres**. Information on variability is preserved in the unique data bases compiled over years, or even decades, of observations and recording, notably at marine laboratories, all over the world. This excellent data base with information on systematics, population genetics and ecology, physiology and toxicology and data on physico-chemical trends, can be used for the interpretation of significant long-term marine coastal biodiversity changes linked to global climatic changes.

Figure 3: Programme Plan on Marine Biodiversity



Note: The circle in the center represents biogeographic patterns.

For remote open-sea areas, advances in understanding will be possible through the establishment of long-term oceanographic stations, visited regularly. Deep-diving manned vehicles can be devoted to exploration of new regions of the sea-floor. High resolution television can be used as a substitute for direct observation from submersibles. Unmanned television systems of varying degrees of sophistication can precisely place sampling devices such as box cores with respect to small-scale features of the bottom or particular experimental treatments.

Mesocosms can be utilised to highlight our knowledge of the functioning of a range of marine ecosystems, including soft-bottom and hard-bottom communities. One purpose of the experiments could be to examine the effect of nutrient gradients on the natural distribution of species. Light, temperature, depth and other gradients could be imposed in the experimental ecosystem to simulate the effects of turbidity, eutrophication, thermonuclear discharge and dredging as anthropogenic perturbations to the natural habitat, respectively.

Marine reserve stations provide unique potential because they cover a variety of coastal ecosystems all over the world. Many of these laboratories also possess unique records of environmental and community variability, resulting from many years of study.

An important challenge to network development is to identify the long-term data sets available in the marine stations all over the world to point out which processes, communities, and state variables are best represented, and those where paucity of data recommend initiation of new long-term data sets. These data should not be analysed in isolation, but attempts should be made to interrelate them. Such studies could generate new hypotheses about processes, such as benthic/pelagic coupling and would provide added scientific justification for continuing the collection of these time-series data. In addition to historical data collected by marine laboratories, time series information could be supplemented from data on long-lived species; for example the growth bands of the bivalve *Arctica islandica*, which can live for more than 100 years. Another example is given by the long-term fluctuations of SW English Channel fisheries, and macroalgae (seaweeds) and bottom fauna in relation to temperature fluctuations over one century.

This Programme can be implemented, without delay, as a joint activity of the European network of Marine Research Stations (CEC/MARS network), the US National Association of Marine Laboratories (NAML), and other marine stations around the world. Their action might serve the following purposes:

- (i) Provide permanent site(s) where scientists can participate in long-term and short-term observational and experimental studies, where continuation of research is a characteristic of the site(s) and, at least partly, not dependent upon continuity of investigators;

(ii) Develop comprehensive regional transects because the location of one site will not be equally effective for answering all research questions or for monitoring all variables. It is important to recognize that the total array of measurements will come from all levels of the observatory system;

(iii) Provide logistically supported sites for the development of specialized instrumentation and for calibration of instruments;

(iv) Offer training with the appropriate instruments and sites of interest.

In order to make the network functional, a computerized network of communications would be developed among all sites. This could also be extended to form a geographical information system for integration and analysis of data. Geographic information system (GIS) technology has rapidly been developed in recent years. This should initially be at a regional scale of resolution. It would be particularly useful in this regard to analyse species ranges statistically to help define coastal and marine biotic provinces at several scales of resolution.

3. Long-term Measurements

The marine research community supports a wide range of research activities, all of which contribute to our understanding of biological diversity. These activities include collecting organisms and sampling populations, characterizing them using a variety of approaches, determining patterns of relatedness and distribution, and applying these patterns to general problems in systematic and evolutionary biology such as phylogeny, biogeography, and functional morphology. A better understanding of biodiversity is essential for research in many other fields, such as systems ecology and modelling, conservation, anthropology, economics, and resource management.

Most systematists divide their effort between field and laboratory work. The allocation of support between these different but complementary components should create a productive balance between collecting efforts, which provide material for systematic study, and conceptual issues, which provide the scientific justification for new and old collections.

Any inventory should justify the need for a dedicated collecting or inventorying effort on the geographic and logistic scale being proposed. One important question should be: are existing collections and inventories inadequate for pursuing the problems being considered and, if so, why? What special research or other considerations demand intensive collecting or inventory effort?

Surveys should place emphasis on the conceptual basis for the collection or inventory effort. Most survey projects lead to better descriptions and understanding of poorly known groups and geographic regions, so this cannot be the sole justification for survey plans. Future projects should propose concrete plans or provide direction for future research that will be facilitated by the new collections or inventories. Will the resolution of phylogenetic relationships of taxa be possible with the collected material? Can explicit tests be made of hypotheses about evolutionary processes, biogeography, palaeoclimatology, or extinctions?

Long-term studies on marine biota should not focus exclusively on their use as indicators of global climate change. It may also be useful to focus on shorter time scales, e.g., pollution effects. Relatively short time-series data may also be of value in this context, for example, a comparative study could be made of the time taken for communities of different types to recover from catastrophe. A workshop should be convened to itemize and evaluate the time-series data available, to discuss the production of an appropriate and accessible data base, and ways in which the data might be used.

Finally, basic physical measurements such as temperature, salinity, nutrient concentrations, oxygen, particle concentrations, tidal height are available for long periods at very few sites. Without such measurements, hypotheses (as well as management decisions) are developed in an "invisible present" where it is impossible to separate signal from noise. Descriptions of genetic diversity, species diversity and habitat diversity are needed at each individual site to represent spatial hierarchy of biological structure in marine systems. For example, many rigorous ecological experiments suffer from inadequate consideration of processes operating on a larger spatial scale. Many of the basic biological measurements such as recruitment rates, growth and longevity of individual species or grazing and predation pressures will require experimental approaches.

4. Education and Training

Systematists for many marine taxa are themselves an endangered species. The network of biodiversity sites will revitalize the role of museum specialists in major ecological and evolutionary studies and interdisciplinary programmes on global change. Workshops led by systematists would be held at field sites to provide the scientific background needed for accurate identifications of organisms. Workshops with molecular biologists would provide training needed to identify morphologically similar species and the basic taxonomy of microorganisms. Chemists would establish protocols and intercalibration exercises to ensure accurate chemical measurements. Physical oceanographers might provide training in how to obtain measurements needed to verify physical models and identify changes outside the normal range of expectation derived from the model.

Advanced training courses should be discussed. Possible candidates for courses are:

- (i) Flow cytometry. Flow cytometers are now installed in a growing number of marine laboratories, with a seagoing capability in at least some of these laboratories;
- (ii) Experimental ecosystem studies using mesocosms;
- (iii) Population genetics, molecular systematics, classical taxonomy, and phylogeny;
- (iii) Ecotoxicology and the use of tracers for pollution studies;
- (iv) Adaptive physiological strategies of marine organisms.

These advanced training courses would be at the post-graduate level for research workers, but it was also felt that some courses should also be more open for the training of technicians as well as young researchers, in cooperation with universities.

The Network will not replace the kinds of bilateral collaboration that already existed on a more informal level. It is recognized, however, that there are certain types of collaboration that it is difficult to get funding for, and that the International Marine Biodiversity Programme should endeavour to support :

ANNEX 1

Meetings on Marine Biodiversity and Lists of Participants

IABO/Unesco Working Group on High Diversity Marine Ecosystems. (INTECOL, Syracuse University, 8-16 August, 1986).

Participants: Pierre Lasserre (Roscoff, France); Jeffery Levinton (Stony Brook, NY, USA); Alasdair D. McIntyre (Aberdeen, UK); Ramon Margalef (Barcelona, Spain); Tim Parsons (Vancouver, Canada); Howard Sanders (Woods Hole, USA); Talal Younès (IUBS, Paris).

IABO/Unesco Working Group on High Diversity Marine Ecosystems. (Woods Hole Oceanographic Institution, Woods Hole, Mass., USA, 26-29 July, 1988)

Participants: Bruno Battaglia (Venice, Italy); Hal Caswell (Woods Hole, USA); J. Frederick Grassle (Woods Hole, USA); Pierre Lasserre (Roscoff, France); Alasdair D. McIntyre (Aberdeen, UK); Ramon Margalef (Barcelona, Spain); Tim Parsons (Vancouver, Canada); Howard Sanders (Woods Hole, USA); John Steele (Woods Hole, USA).

IUBS/SCOPE Workshop on Ecosystem Function of Biological Diversity. (Washington, D.C., 29-30 June, 1989)

Convenors: Francesco di Castri (Italy); Harold Mooney (USA)

Invited participants: J.J. Ewel (USA); J. Frederick Grassle (USA); David Hawksworth (UK); Vernon H. Heywood (UK); Pierre Lasserre (France); Thomas Lovejoy (USA); J.J. Magnusson (USA); Véronique Plocq (SCOPE); G. Carleton Ray (USA); I.S. Reshetnikov (USSR); J. Sarukhan (Mexico); Donald Stone (USA); and Talal Younès (IUBS).

LABO/IUBS/Unesco Round Table Discussion Group on Marine Biodiversity (University of Maryland, College Park, ICSEB IV, 6-7 July, 1990)

Convenors: Pierre Lasserre (Chairman, Roscoff, France); J. Frederick Grassle, (New Brunswick, NJ, USA); Alasdair D. McIntyre (Aberdeen, UK); G. Carleton Ray (Charlottesville, VA, USA).

Invited discussants: Juan Carlos Castilla (Santiago de Chile, Chile); Rita R. Colwell (College Park, MD, USA); Alain Guille (Banyuls-sur-Mer, France); Jeremy Jackson (Smithsonian, Panama); Ernest Naylor (St Petersburg, FL, USA); Tim R. Parsons (Vancouver, Canada); Daniel Prieur (Roscoff, France); Marjorie L. Reaka-Kudla (College Park, USA); Wielfrid Westheide (Osnabrück, West-Germany).

Other participants: Warren Allmon (Tampa, FL, USA); Paul A. Berkman (Columbus, OH, USA); James A. Blake (Woods Hole, MA); William Brostoff (Wellington, New Zealand); Robert Buddemeier (Lawrence, KS); Stephen Cairns (Smithsonian, Washington DC, USA); Bruce B. Colletty (Smithsonian, Washington, DC, USA); Hans-Uwe Dalim, (Oldenburg, West-Germany); J. Di-Ruggiero (Baltimore, MD, USA); James Edwards (NSF, Washington, DC, USA); Daphne Fautin (Lawrence, KS, USA); Kristian Fauchald (Smithsonian, Washington, DC, USA); Aline Fiala-Medioni (Banyuls, France); D. Gautin (Lawrence, KS, USA); Stephen J. Giovannoni (Corvallis, OR, USA); Judith Grassle (New Brunswick, NJ, USA); Paul E. Hargraves (Rhode Island, RI, USA); K. Kita-Tsukamoto (Tokyo, Japan); Dale Krause (Paris, France); Larry B. Liddle (New York, NY, USA); Yaeko Masuchi-Oyalzy (Baltimore, MD, USA); Jerry McCormick-Ray (Civille, VA, USA); Tom McIntyre (NOAA, Silver Spring, MD, USA); Nancy K. Mountford (Lusby, MD, USA); Alida Ortiz (Puerto Rico, USA); A. Pierrot Bulls (Amsterdam, The Netherlands); Donald C. Potts (Santa Cruz, CA., USA); R. H. Richmond (Guam, USA); Brian R. Rosen (Natural History, London, UK); Hector Severein (College Park, MD, USA); Usio Simidu (Nakano, Tokyo, Japan); Michael Sleight (Southampton, UK); J.D.D. Smith (Natural History, London, UK); Linda Stathoplos (Rhode Island, RI, USA); P.K. Tubbs, (Natural History, London, UK); W. Vader (Tromsø, Norway).

ANNEX 2

Glossary of Acronyms

CEC	Commission of the European Communities
COMAR	Coastal Marine Project (Unesco)
FAO	Food and Agriculture Organization
IABO	International Association for Biological Oceanography (IUBS)
ICSEB	International Congress for Systematic and Evolutionary Biology
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Programme: a Study of Global Change (ICSU)
IOC	Intergovernmental Oceanographic Commission (Unesco)
IREP	International Recruitment Experimental Programme (IOC)
IUBS	International Union of Biological Sciences (ICSU)
JGOFS	Joint Global Ocean Flux Study (SCOR/IGBP)
LOICZ	Land-Ocean Interactions in the Coastal Zone (IGBP)
MARS	Marine Research Stations network (CEC)
NAML	National Association of Marine Laboratories (USA)
SCOPE	Scientific Committee on Problems of the Environment (ICSU)
SCOR	Scientific Committee on Ocean Research (ICSU)
UN	United Nations
Unesco	United Nations Educational, Scientific and Cultural

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National Adhering Organizations

ARGENTINA- Consejo Nacional de Investigaciones Cientificas y Tecnicas

AUSTRALIA- Australian Academy of Science

AUSTRIA- Osterreichische Akademie der Wissenschaften.

BELGIUM- Académie Royale de Belgique

BRAZIL- Conselho Nacional de Pesquisas

BULGARIA- Bulgarian Academy of Sciences

CANADA- National Research Council

CHILE- Sociedad de Biología de Chile

CHINA- Association for Science and Technology, Beijing

CHINA- Academia Sinica, Taipei

CUBA- Academia de Ciencias

CZECHOSLOVAKIA- Czechoslovak Academy of Sciences

DENMARK- Det Kongelige Dansk Videnskabernes Selskab

EGYPT- Academy of Scientific Research and Technology

FINLAND- Societas Scientiarum Fennica

FRANCE- Académie des Sciences

GERMANY F.R. - Deutsche Forschungsgemeinschaft

HUNGARY- Academy of Sciences

INDIA- Indian National Science Academy

IRAQ- Scientific Research Council

IRELAND- Royal Irish Academy

ISRAEL- Academy of Sciences and Humanities

ITALY- Consiglio Nazionale delle Ricerche

JAPAN- Science Council of Japan

JORDAN- Yarmuk University, Irbid, Jordan

MONACO- Centre Scientifique de Monaco

NETHERLANDS- Koninklijke Nederlandse Akademie van Wetenschappen

NEW ZEALAND- The Royal Society of New Zealand

NORWAY- Det Norske Videnskaps Akademi

PHILIPPINES- National Research Council of the Philippines

POLAND- Academy of Sciences

SAUDI ARABIA- King Abdul Aziz City for Science & Technology

SOUTH AFRICA- Council for Scientific & Industrial Research

SPAIN- Consejo Superior de Investigaciones Cientificas

SWEDEN- Kungliga Vetenskapsakademien

SWITZERLAND- Swiss Academy of Sciences

UNITED KINGDOM- The Royal Society

U.S.A.- National Academy of Sciences- National Research Council

U.S.S.R.- Academy of Sciences

VENEZUELA- Consejo Nacional de Investigaciones Cientificas y Tecnicas

YUGOSLAVIA- Union of Biological Sciences