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Marine Laboratory Networks for the Study of the Biodiversity, Function and Management of Marine Ecosystems

Edited by

Pierre Lasserre, Alasdair D. McIntyre, John C. Ogden, G.Carleton Ray and J. Frederick Grassle

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Marine Laboratory Networks for the Study of the Biodiversity, Function and Management of Marine Ecosystems

An International Marine Biodiversity Programme (IMBP):
a Contribution to the *Diversitas* Programme

by

Pierre Lasserre
Division of Ecological Sciences, UNESCO
1 rue Miollis, 75015 Paris, France

Alasdair D. McIntyre
63 Hamilton Place
Aberdeen AB24BW, UK

John C. Ogden
Florida Institute of Oceanography
St. Petersburg, Florida 33701, USA

G.Carleton Ray
Department of Environmental Sciences
University of Virginia, Charlottesville, VA 22903 USA

J. Frederick Grassle
Institute of Marine and Coastal Sciences
Rutgers University, New Brunswick, N.J. 08903-0231, USA

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I. CONCEPT AND GOALS

Following the Rio United Nations Conference on Environment and Development (UNCED), in June 1992, maritime countries are more and more committed *inter alia* to the integrated management and sustainable use of coastal areas, including provision of the scientific basis for assessment and observation for the application of preventative approaches. A scientific understanding of biodiversity is indispensable for advancing sustainable conservation and management of coastal-marine systems and their living resources. This understanding must be placed within the context of the physical and chemical environmental patterns that define natural coastal and marine regions, and also must relate directly to the changes brought about by evolving human societies and their resource uses, perceptions, and values. Therefore, the major intent of this proposed International Marine Biodiversity Programme (IMBP) is to help define the relationships among science, conservation, and management through research undertaken among regional networks of coastal and marine laboratories, and to transfer the knowledge gained to policy-making bodies and to management agencies.

Research on questions of regional to global scale, such as the sustainability of biological diversity within large marine ecosystems, needs to capitalize on existing region wide studies and international systematics collections. Scientists now recognize, for example, that huge quantities of carbon are processed by a diversity of marine organisms and that observations must be made on a global scale to understand carbon fluxes between the ocean and atmosphere. Consortia of nations and national laboratories, clearly identified for the main biogeographical regions of the world, would be well placed for development of cooperative research networks, which could undertake such large-scale studies. Several such networks are already in place. The proposed IMBP has as one of its major objectives the facilitation and broadening of these networks, centred about existing coastal-marine laboratories, and it is part of the "Diversitas" Programme.

1. Programme history.

The *Diversitas* programme was jointly launched by IUBS, SCOPE, and UNESCO in 1991 in response to scientific questions that had been raised about the functional importance of biological diversity (Simpson, 1988; DiCastri and Younès, 1990; Solbrig, 1991a,b). This programme is particularly relevant to the driving priority for society as a whole to achieve "sustainability" of resource use. The concept of sustainability has been expressed in a number of ways, one being the use of ecosystems "in a manner that satisfies current needs without compromising the needs or options of future generations" ('Brundtland report', WCED, 1987). Whereas this definition, and even the very concept of sustainability, is controversial (ESA, 1993), it is nevertheless clear that issues of sustainability must involve research on biological diversity on an international level

(Lubchenco et al, 1991; Huntley et al, 1992).

Diversitas has identified three major themes, each of which responds to global conservation and sustainable-use needs: (1) the ecosystem function of biodiversity; (2) the origins and maintenance of marine biodiversity; (3) inventorying and monitoring of biodiversity. These themes subtend the International Convention on Biological Diversity, and singles out for particular attention the following issues:

- identifying factors which determine biological diversity and their changes in the short and long-term;
- evaluating, modelling and predicting the impact of human activities on biological diversity and on ecosystem function at local to regional levels;
- inventory and monitoring of biological diversity over the long term; and
- sustainably using biological resources to meet the needs of human societies from economic, ethical and cultural points of view.

Diversitas has a strong marine component, which responds to the lack of a major umbrella scientific programme that can bring coastal and marine scientists together in an international programme of research and training to address these issues and to help solve the conservation and management problems that have become so evident and urgent. Although biodiversity may be a good measure of the health of the oceans, and therefore relevant to the problems of their management, the investigation of marine biodiversity poses specific and conservation challenge because of the great size and difficulty of access to marine ecosystems. Moreover, the scale of marine systems and the mixing, dispersion, and transport that occur in the oceanic medium require different thinking and investigative processes (Angel 1992; Grassle et al. 1991; Lasserre 1992; Norse 1993; Ray 1991). Understanding the ecological role of biodiversity in ecosystem function is particularly important for the management of coastal-marine systems as the majority of the world's peoples live in the coastal zone. Most major cities are on or near estuaries. Despite the importance of assessing human impacts on the oceans, this vital portion of our planet remains the least known.

2. Structure of the IMBP.

Following the themes that have been spelled out for *Diversitas* as a whole, we propose that the implementation of IMBP involves four basic components (Grassle et al, 1991: figure 1):

a. ***Networks of Sites.*** Coastal marine laboratories and field stations, together with their associated logistical capabilities — personnel, ships, remote-sensing capabilities, collections, etc. — provide entry points into the marine environment. These laboratories are the major sources of information about coastal-marine environments and resources, and are also in an excellent position to address public concerns, as well as those of local marine industries. Marine laboratories and coastal-marine scientists presently operate mainly independently, but through accelerated information exchange, common definition of scientific issues, and increased use of new technologies, they could quickly provide the public and managers with a clearer view of the marine environment. By developing a common data base, many of the conflicts based on differing perspectives and methodologies could also be resolved.

b. ***Long-term measurements.*** Major developments in observing and modelling marine biodiversity will require descriptive information on several temporal and spatial scales, from local to regional and global, and from sub annual to decadal and longer. Physical and chemical properties of near-shore environments, such as temperature, salinity, ocean currents, upper ocean stratification, remotely sensed colour and temperature, nutrients, carbon dioxide, oxygen, chlorophyll, bioluminescence, and particle concentrations, can now be measured continuously using newly-developed sensors. New *in situ* optical and acoustic techniques have been developed to measure spatial distribution of species or higher taxa. There needs to be parallel effort and new developments in the identification and description of species and genetically isolated sub populations of species, which are the basic units of evolution. Systematic investigations will lead to the development of integrated models of physical and biological processes to provide a more precise description of biotic patterns organised in hierarchy of time and space scales.

c. ***Theory and experiments.*** Major advances in understanding ecological processes in intertidal environments, coral reefs, and the deep sea have come from a combination of descriptive observations and theory-based hypotheses, which have been tested using in situ and ex situ experimental manipulations. These advances need to be integrated into the larger framework of oceanic models and the natural patterns of physical and chemical variation. Development of hypotheses is particularly important for this programme component, and we describe some possible areas of emphasis below.

d. ***Education and training.*** These dual roles must remain fundamental to research in general, but especially in research on conservation and management. Fortunately, the bulk of marine laboratories are, by virtue of their association with universities and museums, *de facto* education and training institutions. Students learn about the marine environment through classes, field trips, and research at marine laboratories. Through modern communications technology, the marine environment can also be brought into the classroom through interactive television and real-time transfer of data.

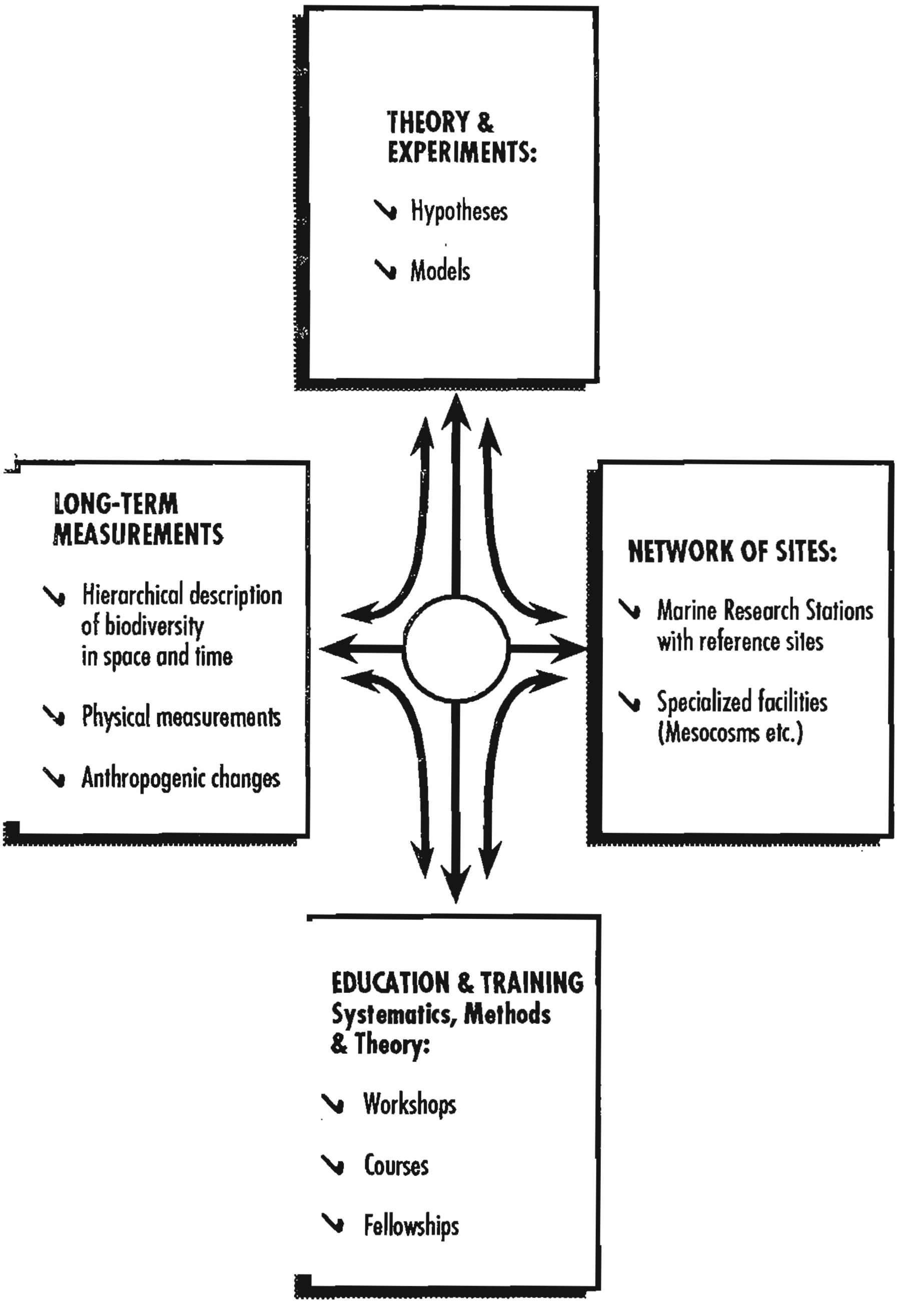

FIGURE 1

From: Grassle J.F., P. Lasserre, A.D. McIntyre & G.C. Ray (1991).
Biology International, IUBS, sp. issue N° 23.

Note: the circle in the center represents biogeographic patterns

II. BACKGROUND

1. A brief history.

A number of countries are developing national scientific programmes on marine biodiversity and consider that these programmes should be built on the procedures and principles of the *Diversitas* programme. This programme is joined with other international programmes, which have also been instituted in response to the dramatic and urgent management issues facing humankind, in a comprehensive programme of Earth System Research, organized under the auspices of the ICSU (Perry et al, 1993). As such, *Diversitas* is side-by-side with the world Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP), and the Human Dimensions of Global Environmental Change Programme (HDP).

With respect to the IMBP itself, formulation began with a series of meetings arranged in the 1980s by International Association of Biological Oceanographers (IABO -- a member organization of IUBS) and UNESCO. These culminated in a round table discussion at the International Congress of Systematics and Evolutionary Biology (ICSEB) at the University of Maryland in 1990. A later meeting at IUBS, Paris, resulted in the publication of a preliminary proposal linking marine biodiversity and ecosystem function, it included theoretical and experimental research, with short-term and long-term objectives, as well as educational and training aspects (Grassle et al. 1991). At the IUBS General Assembly in Amsterdam in 1991, the IMBP formally became part of Diversitas. A Task Force was established within the context of the IUBS/SCOPE/UNESCO *Diversitas* Programme to assess the contribution of marine science to the global biodiversity initiative with respect to marine coastal, offshore and deep ocean areas. That Task Force met in Paris in April 1992 and built on the earlier IABO proposal for an integrated programme on marine biodiversity. This initiative was followed up when members of the IABO/IUBS/UNESCO Task Force in marine biodiversity joined with their colleagues on terrestrial biodiversity at a joint meeting on "Inventorying and Monitoring Biodiversity" in October 1992 at the La Selva Biological Station in Costa Rica. The IABO activities on biodiversity since the 1991 publication were reviewed at a meeting at Rutgers University, USA in February 1994 and a new publication is in press (*Biology International*, special issue).

A further series of meetings (Guadeloupe, March 1993: and Rutgers University, February 1994) has developed the present plan of research in response to the development of *Diversitas*. Concurrently, four marine ecosystem types have been selected by SCOPE for detailed consideration, as follows:

(1) *Biodiversity in Upwelling Systems.* Vancouver Island, Canada, September 1992; Organizers J.C. Castilla (Chile) and J. Lubchenco (USA).
(2) *Ecosystem Function of Marine Biodiversity in Estuaries, Lagoons, and Nearshore Coastal Systems.* Pointe-à-Pitre, Guadaloupe, March 1993; Organizers P. Lasserre (France) and S. Nixon (USA).
(3) *Biodiversity and ecosystem function on coral reefs.* Key West, USA, November 1993.

Organizers J. Ogden (USA), B. Salvat (France), and T. Done (USA).
(4) *Biogeography and Ecosystem Function of Pelagic Systems.* Amsterdam, Netherlands, October; Organizers M. Angel (UK) and A.C. Pierrot-Bults (Netherlands).

Each symposium/workshop addressed the following issues: diversity and ecosystem attributes (infra-specific level, species, population, and functional groups); impact of change on biodiversity; assessing the role of biodiversity on ecosystem function; and biogeographic patterns.

2. Biodiversity of the Marine Realm.

The biodiversity of marine life is probably as great as, or greater than, that found on land, but is far less well documented. At the phylum level, marine biodiversity is twice that of the land's; of the 33 described phyla, 13 are known only from marine environments (May, 1988). Important phyla are exclusively marine (i.e. endemic), for instance, Echinoderms, Ctenophores, Chaetognaths, Pogonophores, Brachiopods. Most of these occur in benthic environments. If plants and protista are also considered, 88% of all phyla are found to be marine. For the moment, the functional role played by the vast taxonomic territory of classes, orders, families, and genera is virtually ignored (Lasserre, 1992). For species, the diversity of marine systems is probably not as great as that found on the land. However, little-explored marine habitats are a major source of novel discoveries of unknown high-diversity reservoirs world-wide. The diversity of deep-sea sediments, may be comparable to that observed in tropical rain forests (Grassle, 1991). Briggs (1994) suggests that there are fewer than 200,000 species of marine multi-cellular organisms. The paper is an interesting contrast to other estimates.

The diversity of marine micro-organisms, i.e. algae, bacteria, fungi (including yeasts), protozoa and viruses is greatly underestimated (Hawksworth and Colwell, 1992). The recently discovered 'picoplankton' (comprising pico-eucaryotes, cyanobacteria and prochlorophytes) is recognised as the largest numerical component of the phytoplankton in the ocean and may play a major role as a sink for atmospheric carbon dioxide (Campbell et al. 1989). Current investigations of phylogenetic systematics using molecular probes has begun to incorporate the vast taxonomic territories of classes, families and genera which where virtually ignored. It is now important to utilize widely the new molecular techniques to forge new links between biodiversity and ecology. Recent methodological developments, such as advances in the application of recombinant DNA techniques, in conjunction with comparative samplings will expand our capabilities to monitor marine biodiversity and to reveal which characters may be an adaptation to environmental conditions.

It is generally assumed that terrestrial species diversity decreases with increasing latitude, but for coastal-marine systems, this is debatable (Clarke, 1992; Lasserre, 1992; Rex et al 1993; Rohde, 1992) and strictly comparative studies using reliable sampling strategies and appropriate observation scales, sampling and modelling are needed (Frontier, 1985; Warwick and Ruswahuri, 1987). For seaweeds (macro-algae), the most diversified systems are in the temperate, nearshore areas of California, Japan, Southern Australia, the Northern

Atlantic, and the Brittany coast of France (Lasserre, 1992). Mesoscale landscape diversity of the coastal zone may actually increase with increasing latitude, at least for the Northern Hemisphere (Ray, 1991). One major objective of *Diversitas* is to examine linkages between biodiversity and ecosystem function. No conclusive link has yet been established between species diversity and sustainability or productivity in the marine environment. In fact, oceanic regions of high productivity are usually species-poor with short, simple food chains.

3. Uniqueness of the Marine Environment.

The physical and biological factors that are thought to control biodiversity differ between terrestrial and marine environments. Physical forcing in the oceans and the mobile, three-dimensional nature of the ocean environment are dominated by atmospheric-oceanic interactions and by climate. Ecological interactions over very large spatial scales are more difficult to define in this fluid, oceanic environment. This is in marked contrast to benthic and coastal systems such as estuaries, coral reefs, and benthic sediments, which exhibit a very wide variety of multi-scale interactions.

The oceans cover 71% of the earth's surface and they have provided the major global environment for the evolution of life forms for most of evolutionary history. However, it is essential to distinguish coastal seas and benthic environments from the fluid portion of the ocean. The coastal oceans, over the continental shelves, occupy only about 6-7% of the Earth's surface, but contribute about 25% of the world's biological productivity and more than 95% of its fisheries. This relatively small fragment of Earth "has a powerful effect on the composition of both the atmosphere and global biogeochemical cycles" (Holligan and de Boois, 1993). Furthermore, it must be clear that greater understanding of the functional role diversity plays in these diverse marine systems is a requirement for their proper conservation and sound management.

The coastal zones and oceans provide many environments where species have evolved to conditions not found on land. In the sea, life has adapted to high pressures, high temperatures, and to low oxygen levels. Some ecosystems, e.g. deep-sea vents, are not driven by photosynthetic primary production, but by chemical synthesis (Grassle, 1986; Tunnicliffe, 1991). The organisms living in these environments offer possibilities for novel biotechnological applications. Also, opportunities should not be lost to observe astonishing and unpredictable evolutionary modifications. The uniqueness and great variety of marine systems, therefore, can provide rigorous tests and new insights into theories relating diversity to ecosystem function and sustainability, most of which have been developed for the terrestrial realm. One very clear example of the importance of the study of marine biodiversity is that of microbial processes, which may control the function and dynamics of pelagic ecosystems (Jumars 1993). Planktonic microbes, down to 0.2 mm in size, have been the focus of intensive investigations by marine scientists during the past two decades. They include non-photosynthetic bacteria, at least two types of photosynthesizing prokaryotes, and eukaryotic phototrophs. The original idea of a basically linear food chain from diatoms to copepods to fish has given way to an extremely complex model of trophic interactions within a microbial food web (Sherr and Sherr, 1991). By using recently developed molecular techniques, a group of microorganisms abundant in hot springs and hydrothermal vents has been shown to be a separate kingdom. The Archaea have now been shown to be abundant in most deep-sea habitats (DeLong 1994). Most of these microorganisms are chemosynthetic, however their functional importance remains uncertain. Thus, microbial diversity and its significance should be intensively investigated in the marine environment in order to gain insight into productivity and sustainability. Due to the dominant role the oceans play in whole-Earth processes, it follows that microbial biodiversity may be essential for maintenance of global ocean health. Are we missing important early warning signals of declines in the health of regional seas because of our ignorance?

4. Human Impacts.

The vast extent of the oceans, the presumably "open" nature of these ecosystems, and the dispersal mechanisms of many marine organisms have been thought to ameliorate human perturbations. These factors have been assumed to reduce threats of extinction and also to mitigate against pollution. However, these assumptions are based on insufficient knowledge of the relationships of biodiversity to environments and of the nature of marine "boundary" conditions and controls.

For example, statements about the "open" nature of marine systems may reflect properties of scale. Certainly, gradients that distinguish marine ecosystems are less obvious in a fluid environment than is the case for terrestrial systems. Nevertheless, the deep sea exhibits high patchiness (Grassle, 1991; Grassle and Maciolek, 1992), and strong gradients, i.e. ecotones, are both numerous and complex in coastal-marine systems (Holligan, 1990). Boundary conditions are especially strong in estuarine and coastal waters, which are also particularly subject to large scale habitat degradation, over-exploitation of biological resources, and disturbance of species relationships.

Human impacts have been most keenly felt in the regional seas of developed, industrialized regions, mostly in north temperate zones that have been most subject to intense human pollution, habitat alteration, and overfishing for the longest periods of time. More recently, lesser developed nations in tropical regions have been affected, where, for example, more than 50% of mangrove ecosystems have already been lost world-wide and where coral reefs are now threatened. The global depletion of regional seas is now apparent through studies of "large marine ecosystems" (LMEs) that have been conducted during the past decade (Sherman et al, 1993). However, the role of biodiversity *per se* has not been examined with respect to human perturbation in LME studies.

As in terrestrial systems, marine species biodiversity is a consequence of the dynamics of speciation and extinction. The inevitability of change, particularly that caused by human activities, underlies present concerns for the maintenance of biodiversity. We may distinguish changes on short time/space scales (e.g. species loss), medium scales (e.g. habitat loss) and longer scales (e.g. climate change); each poses different challenges to the maintenance of diversity. Each also poses challenges to ecosystem health and biological integrity.

As will be apparent from the discussion below on laboratory networks, the scales of human perturbation of coastal-marine systems are primarily regional. Local, nearshore studies indicate many effects of removal of species, for example the effects of "keystone" species on community structure (Paine 1966, 1980). However, local community-level studies cannot address the regional-spatial dimensions at which most coastal-marine systems operate and that even determine the distributions of many marine organisms, even those of shore communities (Roughgarden, 1988). The intent of IMBP is to concentrate mainly on such large-scale, regional ecosystem functions of biodiversity.

III. MARINE LABORATORY NETWORKS

There is a critical need to define more clearly the roles of marine laboratories in environmental research and management and in this context, to develop a more effective interplay between research and management processes. Within the context of reinforcing present activities, the conservation and sustainable use of coastal biodiversity might be approached through reinforcement of presently established coastal and marine protected areas and the strengthening of linkages among marine reserves at regional and sub-regional levels. However, expert consultation among scientists, managers, and policy makers is necessary to explore ways and means of putting into practice a multi-dimensional approach to conservation and sustainable use of marine resources.

1. The concept.

It is clear that our understanding of the distribution of marine biological diversity, and therefore its conservation and management, will require studies at unprecedented geographic scales. One reason for this is the very wide distribution and multiple habitat requirements of the majority of marine organisms. This is due to the planktonic larval life and potential for wide distribution of many invertebrates and fishes, and also to the ocean-wide migrations of tunas, billfishes, turtles, sea birds, seals, and whales. Furthermore, the dynamics of biological diversity is often driven by ecological processes that operate on long time scales.

The marine laboratories of the world have great potential as an infrastructure and focus for programmes in research, training and education, and the conservation of marine biological diversity. Regional marine laboratories encompass the geographic scale of environmental and ecological gradients and their region-wide data sets are fundamental to help structure comparative studies of marine biological diversity and its relationship to ecosystem function.

Coastal and marine laboratories are found in virtually every coastal country, often in relatively undisturbed locations, with ready access to many representative coastal habitats and organisms. The great majority of marine laboratories are tied to academic institutions or museums with long-standing traditions in the study of marine organisms, training of scientists and managers, communication and exchange with other marine laboratories, and environmental impact assessment. Many are government-supported with strong mandates for resources management. Their continuity of research and management sets marine laboratories apart from other institutions. They either possess or have direct access to unique, long-term data sets that form a critical baseline against which human impact may be assessed and interpreted.

2. Existing networks.

While marine laboratories are found within different countries or regions with different cultures, they have a common scientific culture and traditions which predispose them to cooperative programmes and to networking. For example, the 27 marine laboratories of the Association of Marine Laboratories of the Caribbean (AMLC) have held annual scientific meetings for almost 30 years. More recently, 80 European marine laboratories have joined together in the Marine Research Stations Network (MARS) and U.S. marine laboratories have formed the National Association of Marine Laboratories (NAML), as well as regional groups such as the 35-member Southern Association of Marine Laboratories (SAML).

a. ***The CARICOMP Example.*** The Caribbean Coastal Marine Productivity (CARICOMP) programme provides an example of the organization of a regional network of marine laboratories for the investigation of marine biodiversity (Ogden 1987). It began in 1985 with the support of UNESCO's Coastal-Marine Programme (COMAR), in response to a widely perceived need for regional understanding of the long-term dynamics of coastal ecosystems upon which increasing human impact was superimposed. Any marine laboratory willing to sign a Memorandum of Understanding pledging logistic support and personnel to the programme was eligible to join. In return, CARICOMP's Steering Committee pledged to provide basic equipment, communications, and regular meetings of the "site directors," selected by the laboratory directors to operate the programme. A Methods Manual was written in 1990, containing standardized protocols for monitoring the structure and function of the Caribbean's principal coastal ecosystems — coral reefs, seagrasses, and mangroves — as well as key physical time-series variables. In 1991, a Data Management Center (DMC) was established at the University of the West Indies in Kingston, Jamaica, and a basic set of monitoring equipment was distributed to all participants. The CARICOMP network presently consists of 21 marine laboratories in 16 countries (figure 2). About half of the participating laboratories began to collect data according to the protocols in 1993 and it is expected that about 18 laboratories will eventually be able to carry out the protocols. Membership in the network will remain open and the sole requirement for participation will be to send data to the DMC. Those laboratories that are presently unable to collect data may participate in the regular meetings and they may join at any time that their capability to carry out the protocol is established.

In addition to monitoring, the CARICOMP network serves as a means for communication, education, and training. Workshops have been held on the operation of automated environmental monitoring equipment. In early 1994, the site directors participated in a workshop on remote-sensing applications of the CARICOMP network, anticipating the regional ground truthing of a new generation of satellite sensors to be placed in orbit in late 1994. Close communications will also warn the network of regional phenomena such as coral bleaching, plankton blooms, and major storms that may require special observations.

In sum, simple protocols for monitoring coastal-marine ecosystems have provided a means to establish the CARICOMP network, but regional investigations of biological diversity and the facilitation of networking will require substantial future financial support over the long-term.

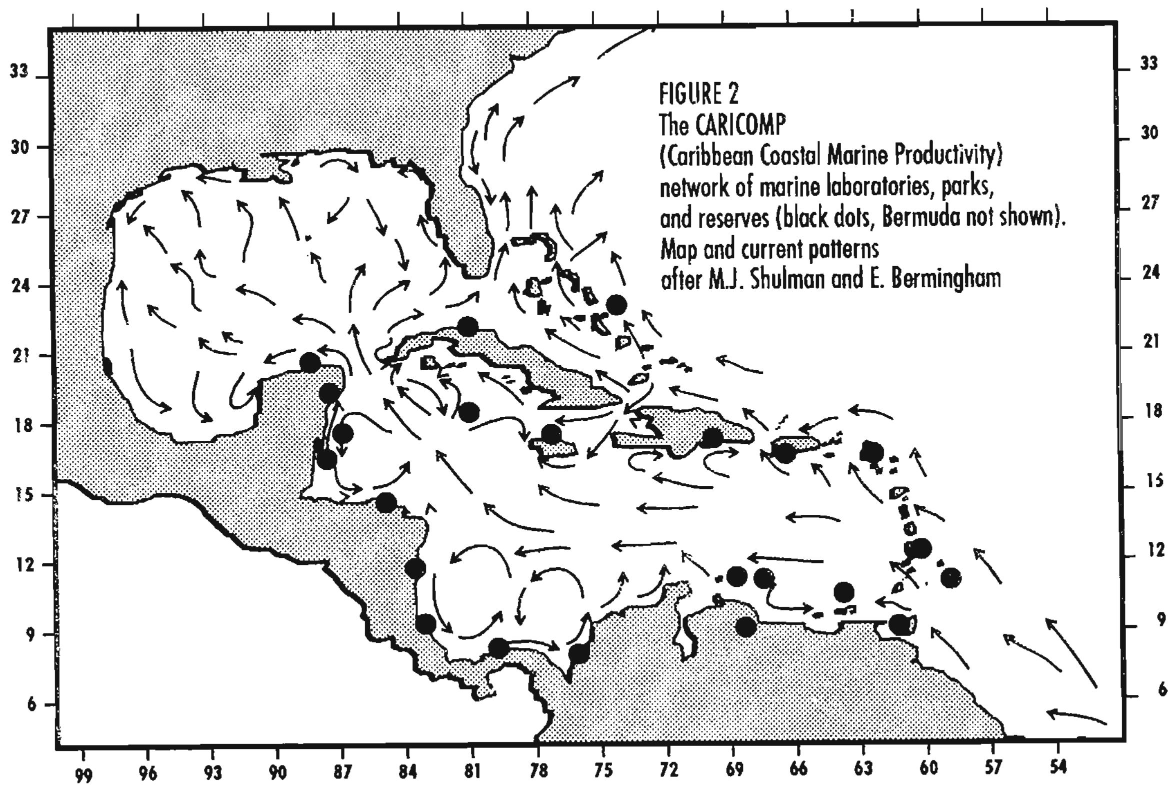

FIGURE 2
The CARICOMP
(Caribbean Coastal Marine Productivity)
network of marine laboratories, parks,
and reserves (black dots, Bermuda not shown).
Map and current patterns
after M.J. Shulman and E. Bermingham

b. *The MARS Example.* Europe has a long tradition in marine biology. In recent decades, many marine stations have celebrated their centenary and have demonstrated that the sense of purpose that led to their creation continues to this day. In 1990, a group of eleven European marine stations, defined as "seaside" laboratories with a traditional involvement in marine biological research and a primary interest in land-sea interactions, set up the Marine Research Stations (MARS) Network. This network is sponsored by the European Community and the European Science Foundation.

A Steering Committee was established and during its October 1992 meeting, it embraced a wider network of coastal-marine laboratories throughout Europe, to identify joint projects and activities that have high priority all over Europe, to put the network on a firmer footing, and to direct the common scientific interest towards biodiversity. A meeting held at UNESCO, Paris, in March 1994, resulted in an enlarged membership of approximately 80 coastal and marine research laboratories. Thus, the fundamental goal of MARS is the development and support of collaborative biodiversity research, which is specifically dependent on the experience and equipment of these laboratories. MARS will focus on the interrelated themes of *Diversitas*. Research is proposed to include observational and experimental studies of ecosystems and extensive studies of diversity along Atlantic latitudinal gradients from Spitzbergen to the Canary Islands and along Mediterranean longitudinal gradients from Gibraltar to Haifa (figure 3).

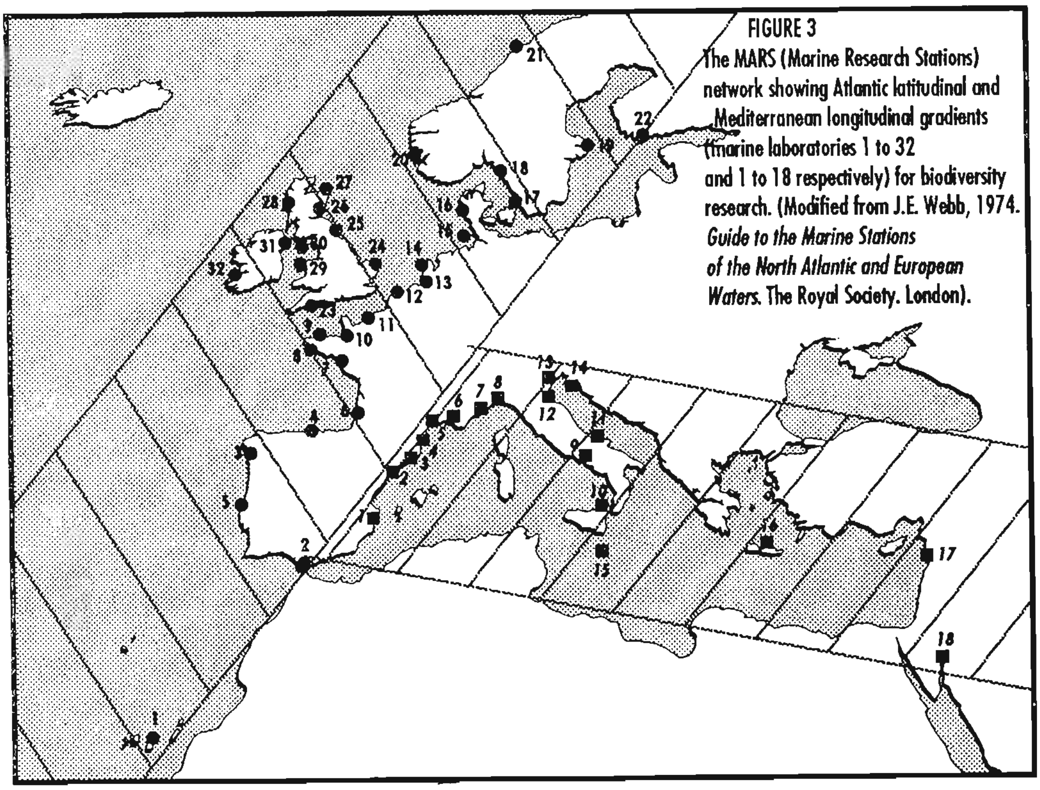

FIGURE 3
The MARS (Marine Research Stations) network showing Atlantic latitudinal and Mediterranean longitudinal gradients (marine laboratories 1 to 32 and 1 to 18 respectively) for biodiversity research. (Modified from J.E. Webb, 1974. *Guide to the Marine Stations of the North Atlantic and European Waters.* The Royal Society. London).

Legend of Figure 3 : MARS network (European Marine Stations of Northern Europe and the East Atlantic Coast)

1. Laboratorio de Canarias, Santa Cruz de Tenerife, Spain
2. Laboratorio del Instituto de Investigaciones Pesqueras, Cadiz, Spain
3. Instituto de Investigaciones Marinas, Vigo, Spain
4. Laboratorio Oceanographico, Santander, Spain
5. Laboratorio Maritimo de Guia, Cascais, Portugal
6. Station de Biologie Marine, Arcachon, France
7. Laboratoire Maritime, Concarneau, France
8. Centre Ifremer, Brest, France
9. Observatoire Océanologique, Station Biologique, Roscoff, France
10. Laboratoire Maritime, Dinard, France
11. Laboratoire Maritime, Luc-sur-Mer, France
12. Station marine, Wimereux, France
13. Nederland Instituut voor Oecologisch Onderzoek, Yerseke, Netherlands
14. Nederland Instituut voor Onderzoek der Zee, Texel, Netherlands
15. Biologische Anstalt Helgoland, Helgoland, Germany
16. Biologische Anstalt Helgoland, List/Sylt, Germany
17. Marine Biological Laboratory, Helsingor, Denmark
18. Kristineberg Marine Biological Station, Fiskebackskil, Sweden
19. Askö Laboratory, Askö, Sweden
20. Biologicaql Station, Espegrend, Norway
21. Institute of Fisheries and Aquatic Sciences, Tromso, Norway
22. Tvarminne Zoological Station, Finland
23. Plymouth Marine Laboratory, UK
24. Fisheries Laboratory, Lowestoft, UK
25. Dove Marine Laboratory, Cullercoats, UK
26. Gatty Marine Laboratory, St. Andrews, UK
27. Marine Laboratory, DAFS, Aberdeen, UK
28. Dunstaffnage Marine Research Laboratory, Oban, UK
29. Marine Science Laboratory, Menai Bridge, UK
30. Department of Marine Biology, Port Erin, UK
31. Marine Biology Station, Portaferry, UK
32. Marine Laboratory, Galway, Ireland

European Marine Stations of the Mediterranean Basin

1. Instituto Marino de Catellón, Spain
2. Instituto de Investigacione Pesqueras, Barcelona, Spain
3. Centre d'Estudis Avançats de Blanes, Spain
4. Observatoire Océanologique, Laboratoire Arago, Banyuls-sur-Mer, France
5. Station de Biologie Marine et Lagunaire, Sète, France
6. Observatoire océanologique, Station marine d'Endoume, Marseille, France
7. Observatoire Océanologique, Villefranche-sur-Mer, France
8. Musée Océanographique, Monaco
9. Stazione Zoologica, Napoli, Italy
10. Stazione di Biologia Marina, Messina, Italy
11. Laboratorio Biologico delle Lagune, Lesina, Italy
12. Stazione Idrobiologica, Chioggia, Italy
13. Istituto di Biologica del Mare, Venezia, Italy
14. Center for Marine Research `Rudjer Boskovic', Rovinj
15. International Ocean Institute, Malta
16. Institute of Marine Biology of Crete, Eraklion, Crete, Greece
17. Israel National Institute for Oceanography, Haifa, Israël
18. Marine Station, Eilat, Israël

European coastal-marine ecosystems have borne the brunt of human exploitation for a very long time. The whole question of how taxonomic and functional diversity relate to each other remains open. The general question regarding biodiversity and ecosystem attributes is what are the impacts on ecosystem function of additions or subtractions of species or system components? In order to address this question, *in situ* experiments, in conjunction with continuous measurements of environmental variation on interannual or decadal time scales, are needed to understand how the pattern of variability translates into marine functional diversity. These are necessary to test hypotheses relating diversity to functional ecosystem attributes, such as the rate and efficiency of transfer of energy between trophic levels and fluxes of materials between the sea bed and water column. In European coastal waters, as in many other regions, interpretation of the causes of change problems are exacerbated by anthropogenic influences such as change in nutrient status through waste discharge and agricultural runoff, which upsets the competitive "balance" among species by removing top predators and which can cause physical disruption of benthic habitats.

Another question to be addressed relates to whether the number of functionally analogous species within functional types has an effect on ecosystem function or stability. There are many examples of striking switches in community structure in marine systems. For example, the Russell cycle has described marked changes in herring and pilchard populations during the last 80 years in the English Channel (Southward, 1980). Similar switches of seaweeds and macrobenthos have been recorded in the western English Channel, over periods of several decades, apparently in conjunction with temperature fluctuations of approximately 0.5°C (Lasserre, 1992). Temperatures in the deep sea at abyssal depths have increased 0.32°C in the last 35 years (Parilla et al 1994). Pollutants from atmospheric sources are also increasing (Lipiatou and Saliot 1991, Simo et al 1991, Takada and Farrington, in press) and these changes may result in reductions in biological diversity over vast areas of deep-sea floor. Unless deep-sea communities are much better studied, these changes may occur without our knowledge.

c. *UNESCO-MAB Coastal Biosphere Reserves.* During the last few years, the UNESCO-MAB Biosphere Reserve principles have received renewed interest from scientists and managers working in the coastal zone as a tool for reconciling conflicts of conservation, research, tourism development, industry, traditional fisheries, pollution monitoring, etc. The value of coastal biosphere reserves, especially those that encompass both land and sea and their interface, lies in integrating conservation, research and development goals in a single, publicly-supported, management scheme. This multi-purpose management can be achieved through the use of zoning, in which core, buffer, and transition areas carry different requirements for biodiversity protection and human use (Batisse, 1990; Price and Humphrey, 1993). A functional, international network for biodiversity research related to management could be developed from the coastal biosphere reserves that have been established during the two-decade existence of the MAB Programme (figure 4).

MAB intends to contribute to a collaborative efforts designated to detect the responses of marine and coastal ecosystems to global change and to contribute to collaborative research projects on sustainable development at the land-sea boundary, and, in general, to link the emerging international biosphere reserve network to other international marine networks. Today there are 324 UNESCO-designated biosphere reserves in 82 countries. Efforts are made to improve local participation and to re-orient regional planning, towards conservation and sustainable use of biodiversity. Recently created regional networks include EuroMAB including 30 countries in Europe plus Canada and the USA. In 1991, EuroMAB launched an initiative to promote Biosphere Reserve Integrated Monitoring (BRIM, see EuroMAB, 1993). Other initiatives are: the Ibero-American Programme for Science and Technology (MAB-CYTED) with activities including synthesis volumes on the biodiversity of Latin America and the reinforcement of the regional network of biosphere reserves.

Activities within the biosphere reserves relate to three functions or 'concerns': in situ conservation of biodiversity; development which allows sustainable use of land and water resources; and the provision of an international network for research and monitoring. Thus, they might provide an important potential basis for global observation systems like GOOS and GTOS. Some of the biosphere reserves are already involved in specific global network programmes including collaboration with sites outside the biosphere reserves system. UNESCO-MAB has identified the need to assess change in biodiversity focused through the *Diversitas* programme, using wherever possible, biosphere reserves. The challenge is in combining the flexible requirements of research with the consistency demanded of monitoring.

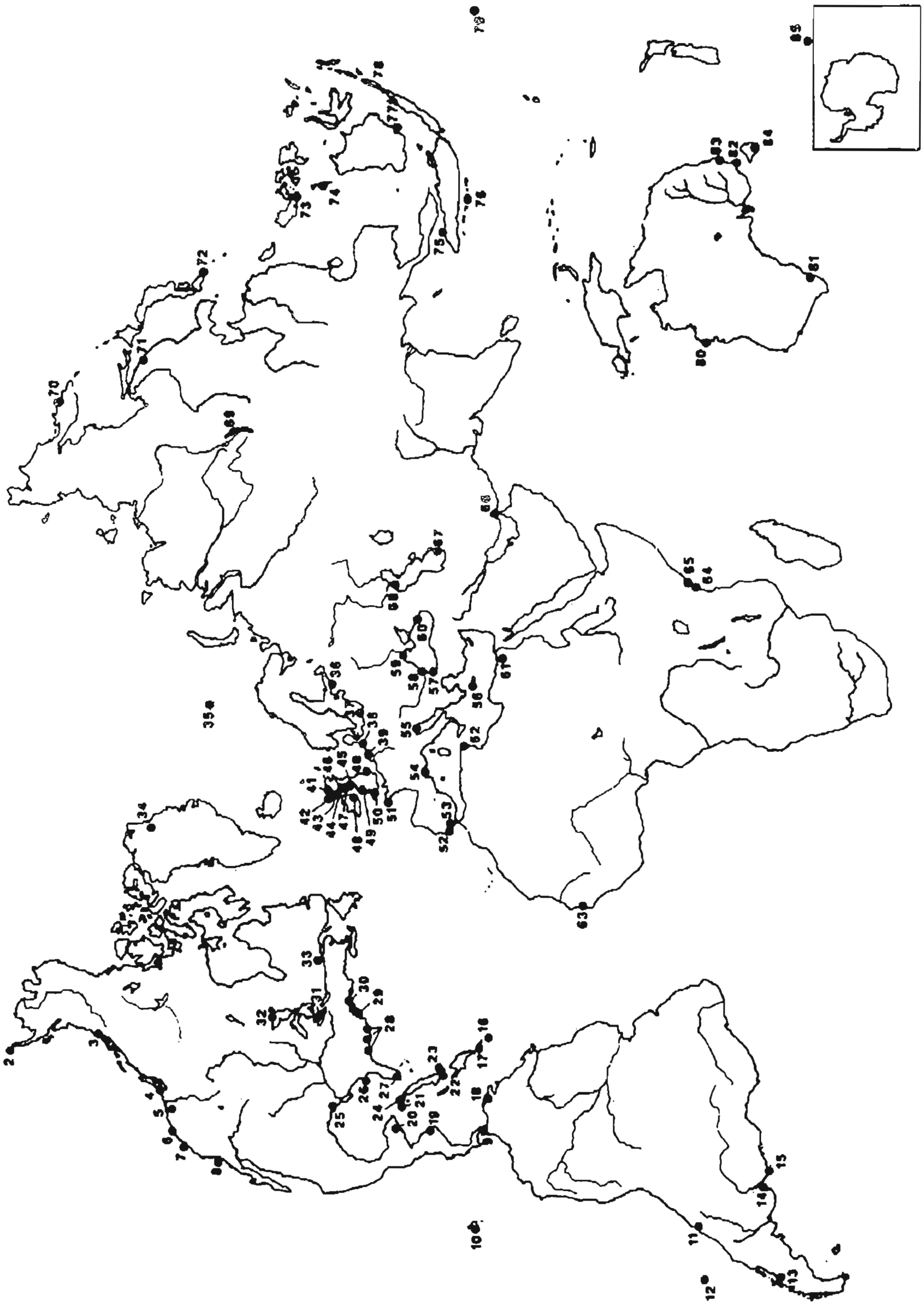

Figure 4: see legend next page.

Figure 4. World Distribution of Coastal-Marine Biosphere Reserves (1991). Biosphere reserves having a shoreline on an ocean, inland sea, or major lake are shown. The sites do not always include coastal barriers. Some do not include open water ecosystems within their boundaries. (Sources: IUCN 1986. MAB Information System: Biosphere Reserves. Compilation 4, October 1986; UNESCO nomination forms for biosphere reserves designated from 1987 through 1990; from Ray and Gregg, 1991).

1. Hawaiian Islands (Hawaii, USA)
2. Aleutian Islands (Alaska, USA)
3. Glacier Bay, Admiralty Island (Alaska, USA)
4. Olympic (Washington, USA)
5. Cascade Head (Oregon, USA)
6. California Coast Ranges (California, USA)
7. Central California Coast (California, USA)
8. Channel Islands (California, USA)
9. Fronterizo Darien (Panama)
10. Archipelago de Colon [Galapagos] (Ecuador)
11. Fray Jorge (Chile)
12. Juan Fernandez (Chile)
13. Laguna San Rafael (Chile)
14. Costero del Sur (Argentina)
15. Banados del Este (Uruguay)
16. Virgin Islands (USA)
17. Guanica (Puerto Rico, USA)
18. Sierra Nevada de Santa Marta (Colombia)
19. Rio Platano (Honduras)
20. Sian Ka'an (Mexico)
21. Peninsula de Guanahacabibes (Cuba)
22. Bacanao (Cuba)
23. Cuchillas del Toa (Cuba)
24. Sierra del Rosario (Cuba)
25. Big Thicket (Texas, USA)
26. Central Gulf Coastal Plain (Florida, USA)
27. Everglades (Florida, USA)
28. Carolinian, South Atlantic (North Carolina, South Carolina and Georgia, USA)
29. Virginia Coast (Virginia, USA)
30. New Jersey Pinelands (New Jersey, USA)
31. Long Point (Canada)
32. Isle Royale (Michigan, USA)
33. Charlevoix (Canada)
34. Northeast Greenland (Denmark)
35. Northeast Svalbard (Norway)
36. West Estonian Archipelago (USSR)
37. Slowinski (Poland)
38. The Wadden Sea of Schleswig-Holstein (Germany)
39. Waddensea (The Netherlands)
40. North Norfolk Coast (United Kingdom)
41. Beinn Eighe (United Kingdom)
42. St. Kilda (United Kingdom)
43. Loch Druidibeg (United Kingdom)
44. Isle of Rhum (United Kingdom)
45. Caerlaverock (United Kingdom)
46. Claish Moss (United Kingdom)
47. Taynish (United Kingdom)
48. North Bull Island (Ireland)
49. Dyfi (United Kingdom
50. Braunton Burrows (United Kingdom)
51. Iroise (France
52. Marismas del Odiel (Spain)
53. Doñana (Spain)
54. Camargue (France)
55. Miramare (Italy)
56. Gorge of Samaria (Greece)
57. Kamtchia (Bulgaria)
58. Rosca-Letea (Romania)
59. Chernomorskiy (USSR)
60. Kavkazskiy (USSR)
61. Omayed (Egypt)
62. Iles Zembra et Zembretta (Tunisia)
63. Delta du Saloum (Senegal)
64. Malindi-Watamu (Kenya)
65. Kiunga (Kenya)
66. Hara (Iran)
67. Golestan (Iran)
68. Astrakhanskiy (USSR)
69. Lake Baikal (USSR)
70. Kronotskiy (USSR)

71. Sikhote-Alin (USSR)
72. Yakushima Island (Japan)
73. Puerto Galera (Philippines)
74. Palawan (Philippines)
75. Gunung Leuser (Indonesia)
76. Siberut (Indonesia)
77. Tanjung Puting (Indonesia)
78. Komodo (Indonesia)
79. Atoll de Taiaro (French Polynesia, France)
80. Prince Regent River (Australia)
81. Fitzgerald River (Australia)
82. Wilson's Promontory (Australia)
83. Croajingalong (Australia)
84. Southwest (Australia [Tasmania])
85. Macquarie Island (Australia)

3. Site selection.

Specific sites for study should be identified according to priorities that reflect both regional characteristics and site capabilities. Ideally, the sites should occupy positions along clearly identifiable gradients, such as those of climate, physical features of water masses (salinity, temperature, etc.), or productivity. Also, initially priority should be given to sites that are fully committed to biodiversity research, with appropriate personnel and logistics. While not at this time suggesting specific locations, we suggest that sites might be of three kinds:

- **reference sites** are selected for the most *intensive* research, located in areas where good background information is available, and where the best prospects for future work are offered. They are chosen, for the most part, by virtue of their biogeographic representativeness and human uses. They would be dedicated to defining aspects of diversity and ecosystem function at differing hierarchical scales from local to regional and along both latitudinal gradients and onshore-offshore corridors. Emphasis would be placed, for example, on the interrelations among species abundance, habitat perturbation, and nutrient availability.

- **comparative sites** are selected for *extensive* research, which would be less ambitious than for reference sites. The research programme would be flexible, allowing those involved to develop their own research and monitoring capacities. The emphasis would be dedicated to comparisons at any appropriate scale to measurements being taken at the reference sites. This would allow, explicitly, for regional networking.

- **network sites** represent the least intensive degree of effort. Research would concentrate, at least initially, on inventory and monitoring procedures.

Suggested regions for initial concentration related to the ecosystem types mentioned above, are:

a. Coral Reefs - Questions concerning the population dynamics of the crown-of-thorns starfish, coral bleaching, effects of storms, spread of diseases and effects of pollutants, and synchronous life history processes require communication among sites and standardisation of methods to answer large spatial scale questions. The best developed coral reefs are in the Indopacific region, Pacific islands and atolls, the Caribbean, -Oceanic-Central Pacific, including Micronesia as well as the Galapagos Islands and Cocos Island to the east; Central Indo-pacific, including the Great Barrier Reef, New Guinea, Philippines, Indonesia, Ryukyus and Taiwan (Kenting National Park), and the Red Sea. Each of these areas might develop into networks that could coalesce into a global coral reef network.

b. Rocky shores - The best developed ecosystems that exemplify this category occur on the eastern sides of ocean basins in the temperate, maritime climates modulated by the influence of western boundary currents. Hemispheric and east-west comparisons would be facilitated by focus on sites in the Northwest or Southwest of continents. Examples are: Northwest coast, USA (Oregon and Washington), Central coast, Chile (Los Cruces), English Channel, Celtic Sea, West Coast, South Africa. The first two regions already have formed an established relationship, involving parallel experiments as well as exchange of data and personnel.

c. Estuaries, Lagoons and associated coastal areas - The CARICOMP network addresses issues in mangrove areas, lagoons and tropical soft-bottom environments. The West African countries close to the equator form a natural cluster of nations and marine facilities that could develop into a network. The Western Pacific region from Colombia to Mexico includes scientists working on mangroves and lagoons who already compare their research and are ready to formalise a network of sites and associated marine stations. Studies in lagoons, estuaries and mangroves could be extended to continental shelf sites along with studies of fish and shellfish populations. Several important individual sites might develop into regional networks. These include the Puget Sound area where there is a long-term data set on soft bottom benthos and a similar area in Chile, the Bay of Concepcion. Tropical, shallow-water, soft sediment environments not subject to very low salinity are among the least known marine environments and most important for consideration of biodiversity. The Danish biologist, Gunnar Thorson, was instrumental in establishing such a site at Phuket, Thailand, approximately four decades ago. Sites in high latitudes such as the White Sea and the Bering Sea, and Antarctica also need to be considered. Examples include: Caribbean, Equatorial West Africa, Tropical Eastern Pacific (e.g. Corcovado), Western Europe (e.g. Wadden Sea), Mediterranean coasts, US. East Coast - Maine to Florida, US./Canada - Northwest Coast (e.g. Puget Sound), Chile/Peru West Coast (e.g. Bay of Concepcion), Southeast Asia (e.g. Phuket, Thailand), Indian Ocean - Bay of Bengal, White Sea, North Pacific from China to S.E. Bering Sea, Antarctica

d. Pelagic and deep-sea benthic systems - Examples of pelagic systems include: Western Boundary Currents ; Kuroshio, Gulf stream, Brazil and Peru current regions; Central Ocean Gyres. North Atlantic, North Pacific, South Pacific, Eastern Tropical Pacific; Bering Sea, Southern Ocean. Some of the highest marine biodiversity measurements have been made in deep-sea environments. The first three sites mentioned below are high diversity deep-sea environments and the remaining sites are hydrothermal or cold seep areas where the fauna and micro-organisms are in most instances unrelated to other marine organisms at highest taxonomic levels. Their adaptations to the unusual vent and seep environments is only beginning to be understood. Examples include Eastern-Atlantic (e.g. Madeira abyssal plain), Mid-Pacific Gyre abyssal plain, Northeast US. Continental Margin, Western Pacific (vents and seeps), Gulf of California - Guaymas Basin, East Pacific Rise (9° - 13° N), Mid-Atlantic Ridge, Jean de Fuca Ridge

IV. PRIORITIES FOR RESEARCH, INVENTORYING AND MONITORING

Much of marine science remains in the discovery-descriptive stage, to which systematics, biogeography, and much of evolutionary ecology are fundamental. So poorly known are coastal-marine systems that this descriptive process is a mandatory initial step for development of a research programme. Therefore, it is the intent of the IMBP to encourage further exploration, while at the same time continuing to develop insights expressed as hypotheses, as well as theoretical models for research orientation and testing.

We suggest that research priorities for coastal-marine systems should encompass, not necessarily in the order given:

- pre-inductive exploration and description;
  hypothesis development;
- the use of: (1) an experimental approach to address these hypotheses, employing manipulative procedures in the field; (2) experimental mesocosms; and/or (3) "natural experiments," e.g. vicariance events, disturbance events (e.g. pollution), storms, etc.;
- targeting of experimental approaches towards the conservation of phyletic richness, the maintenance of diversity in systems under stress, and the sustainable exploitation or restoration of marine communities;
- the development of models to determine the effects of reduced diversity on ecosystem structure and function; and
- iteration, i.e., refinement of hypotheses and models, emphasising systems-level interactions.

It is apparent that some of these "steps" have been underway or covered to various degrees for different systems. The intent here is to emphasize equally the pre-hypothesis, descriptive phase (systematics, biogeography, defining ecosystem parameters, etc.), as well as the need for an integrative and holistic research process. We also wish to emphasize the need for ecosystem-level monitoring, which is necessary to address the many effects of human activities.

1. Hypothesis development.

The first three themes of *Diversitas* (see above) are research-oriented and groups of hypotheses have been developed about them (Solbrig, 1991a,b; Grassle et al 1991). We will not review these, but will give some examples of the sorts of themes that seem particularly relevant to the laboratory network we propose.

a. Theme 1: Ecosystem function of biodiversity. The overall objective of *Diversitas* is to determine the relationship between the biodiversity of the organisms in an ecosystem and the rates and efficiencies of ecosystem processes. At the level of global environmental change, we need to know how sea-level rise, changes in weather patterns, ozone depletion, increased UVB intensity, and global warming affects marine biodiversity and how ecosystem function may be predicted. This is made especially complex by the ecological feedbacks between the biota and ecosystem function, for example, the production of dimethyl sulfides by phytoplankton, which has an influence on climate. Thus, there is an urgent need to understand the extent to which the biota of large marine ecosystems affects the cycling of carbon and the rate and the efficiency of transfer and materials. Such effects may depend on the genetic and species diversity of the organisms which mediate large-scale, regional properties of marine ecosystems and how this affects the sustainability of those systems.

Another key problem reflects the need to be able to predict the effects of the removal of barriers to distribution through introductions, accidental or purposeful, and of large-scale engineering projects on biodiversity. These problems will need to be addressed if biodiversity conservation is to be successful in the long term. For example, it is of central importance for both conservation and management to know how changes in genetic diversity, species diversity within functional groups (e.g., feeding guilds), and the diversity of functional groups affect the rates or efficiencies of such marine ecosystem processes as productivity and nutrient recycling. It is also of fundamental importance to know whether differences in genetic, species, and functional diversity affect the stability (i.e., resilience and persistence) of assemblages of marine organisms.

Where field studies are difficult, a number of laboratory experimental approaches could be envisaged, particularly using functional groups of organisms with fast turnover times, e.g. diatoms or meiobenthos. Experiments could be undertaken with assemblages varying in genetic or species diversity to determine the rate of recovery after a perturbation, or stability in a fluctuating environment. Research will also be facilitated by the development of a new generation of models linking the statistical models of community ecologists to deterministic ecosystem models and models of physical processes. Research can be greatly enhanced through networks of marine laboratories, in cooperation with investigators from universities and natural history museums.

b. Theme 2: Origins and maintenance of marine biodiversity. Debate among terrestrial ecologists about the sources of high diversity has been mirrored by intense research interest among tropical marine ecologists, especially in relation to the high species diversity of coral reefs. A classic view has emphasized increased resource partitioning over geological time and the structuring of communities by competition and predation. This has been questioned by more recent research, which has highlighted semi-random, small-scale community composition, implicating stochastic recruitment processes.

A number of key questions needs to be addressed. For example, many groups of marine organisms have a good fossil record, which enable us to address questions concerning speciation rates, extinction events, and the degree of functional specialization of taxa. In addition, maintenance of biological diversity also involves an understanding of how life history characteristics and dispersal mechanisms may influence gene flow among populations. With respect to both origins and maintenance, we need to know how species influence the establishment and maintenance of patterns of diversity? The utilisation, whenever possible, of cross breeding experiments may reveal - as it has been shown in certain groups - an unexpected range of inter- and intraspecific differentiations affecting a multiplicity of characters such as degree of polymorphism, concealed genetic variation, sex determination, and reproductive strategies.

c. Theme 3: Inventorying and monitoring of biodiversity. It follows from the above that regional collaboration is necessary for inventorying and monitoring marine biodiversity. In compiling and collating existing information, priority should be given to:

- identifying and cataloguing sources of information, where held and for what areas;
- maintaining existing collections, such as those at natural history museums and in marine laboratories;
- collating all appropriate species data, quantified by community and by location;
- providing for use of the data at different geographical and time scales, as well as for different scales of classification (e.g., by habitat, community, species, etc.;
- assessing the variation in quality of the information entered into databases;
- ensuring that databases are easily accessible, "user friendly," and inter-comparable, both nationally and internationally; and
- expanding the networks to cover the whole of the continental shelf, slope and rise regions, and the deep sea.

Especially significant for marine systems, given the very large number of unequally marine taxa, is the erosion of scarce specialist taxonomic skills and expertise. Field work in marine laboratories is invaluable for stimulating student interest and learning and the need for taxonomic identification courses for graduates and undergraduates is urgent. Specialist high-level taxonomic skills should be strengthened by establishing opportunities for collaboration and staff exchange, especially among museums, the universities, and coastal marine laboratories. Given the high levels of genetic variability within some marine species, research at the "within species" level is also called for. Equally, we see a need for a taxonomy of "functional groups" within marine ecosystems; this is an area where traditional taxonomy and research into functional aspects of biodiversity will usefully come together. Of particular importance are time-series records of species distributions for assessing the effects of natural and man-made change. However, several key biological time series in the marine environment have either been ceased (the Plymouth Marine Biological Laboratory's 70-year "Russell cycle" time series in the English Channel) or are running on a year-to-year basis with uncertain funding (the 60-year Continuous Plankton Recorder Survey for North Atlantic and European coastal waters).

2. Perceptions and values of biodiversity.

The Convention on Biological Diversity emphasizes sustainable use of biological resources. This is not only a scientific matter. The reasons and the means to conserve biodiversity are intimately linked with societal perceptions and estimations of "value."

Most societies living along the coastal zone have strong cultural relations with their environments. Each coastal society has its own particular nature, which is a projection of its structures and its values. Thus, understanding of traditional, popular, and specialized knowledge enables us better to understand the links that humans have forged with their environments and the resources that they use. This leads to research that can be integrated into traditional research on natural systems, the goal of which is to devise means to use traditional knowledge to manage marine biodiversity sustainably.

It is widely recognized by many coastal states that interactions between the dynamics of human societies and the dynamics of plant and animal populations is rapidly changing under the joint impact of human population growth and of changes in resource use through fishery practices, aquaculture, and economic valuation. Nevertheless, a glaring gap in our knowledge involves the valuation of marine biodiversity. Placing value on the services provided by marine ecosystems and species is in its infancy as a quantitative discipline. In most cases, discussions of marine biodiversity value revolves around either its future potential for biotechnology innovations, new pharmaceuticals, or food (e.g. seaweeds, molluscs, fish). However, the real value of marine biodiversity, based on actual current use, is far more extensive. For convenience, we may recognize the following categories of marine biodiversity valuation, as follows:

a. ***Global intangibles.*** This encompasses ecological value and geopolitical value. As far ecological value is concerned, marine biodiversity is not a static entity, but a dynamic system of evolutionary innovation and complex, functioning ecosystems. Some of these global values, such as carbon sequestration and coastal protection can be quantified; others, such as the impact of healthy ecosystems on climate change and ozone depletion, are much more difficult to assess. Concerning geopolitical value, maritime nations in developing countries depend on marine biodiversity on an even more immediate basis than do developed nations. The increasing environmental degradation of the coastal zone and small islands, exacerbated by growing populations, economic crises, and social unrest creates a series of vicious circles that become difficult to break. If not dealt with in the near term, this multitude of small, degradation-based crises may coalesce into national and regional conflicts, in which densely populated coastal countries with badly degraded environments may rapidly enter into such vicious circle of political and economic instability, for which signs are already evident. Whatever political solutions may be devised, coastal countries will not be viable over the long term without major restoration of their natural marine resource base.

b. ***Major Ecosystem Functions.*** Certain ecosystem functions such as watershed protection for urban and agricultural use, for coastal wetlands protection, and aquaculture for carbon sequestration and for water purification can be quantified through existing methodologies. However, this is only now starting to be taken into consideration when looking at the value of a given marine ecosystem, and is rarely incorporated into national income-accounting procedures. Nonetheless, and even more than for inland systems, this value is so great that it, by itself, justifies the study and protection of marine ecosystems.

3. The need for social-science research.

This topic deserves special attention because of the overwhelming human population densities in coastal areas and because the primary use of marine areas is economic including the value of recreation and tourism.

Social scientists are an underrepresented minority among scientists who have addressed environmental problems, including loss of biodiversity. This is all the more distressing, since humans are largely primary agents of environmental change. These changes have been most directly observed in terrestrial areas, but the impacts of humans on marine environments and their biodiversity are covert and poorly documented.

It seems clear that the monitoring and management of coastal and marine biodiversity demands the collaboration of natural and social scientists, since social systems and their technologies continue to modify the planet and its levels of biodiversity. In a partnership with ICSU, the International Social Science Council, is developing a programme to address the Human Dimensions of Global Environmental Change (HDP). The HDP programme has recommended the involvement of social scientists in three areas (Jacobson and Price 1991; Stern et al. 1992):

a. The social dimensions of resource use. At present, most of the social-science research has focused on fisheries, especially economic systems. However, other studies are becoming equally important as coastal and marine resource use intensifies. For example, cultural traditions of rights to marine resources have long histories and require involvement of anthropologists and economists to resolve problems of over exploitation. A case in point is the traditional exploitation of sea mammals and birds by Inuit peoples. Heavy exploitation of marine food resources by Asians is a similar problem, but of substantially greater scale and with global political and economic consequences. A third example is seaweed and animal aquaculture, which will certainly intensify in the near future.

b. Perception and assessment of change. There is considerable interest within the social sciences in the concept of the "tragedy of the commons", as first described by Hardin. The controversy centers on common property and whether human social systems are capable of conservation for common use by the social unit. This issue is especially important for marine areas, because perception of the seas as common property is almost a cultural universal, and this perception has contributed to unbridled exploitation.

c. ***Impacts of socio-economic and political structures.*** In all societies, the value of human life and the welfare of humans is considered paramount. Immediate human needs take precedence over long-range, particularly transgenerational, needs. It is within this context that exploitation of and competition for marine resources by humans must be placed and understood. Additionally, socio-economic systems are tightly integrated within the political structures of societies. Increasingly, the world economic and political system has profound effects on smaller scale societies. Therefore, studies of social systems at different scales and complexities are needed in order to understand the scope of biodiversity changes, as well as to manage exploitation patterns so as to predict and to control losses.

Coastal areas and their drainage basins of rivers must be seen as interlinked economic, cultural/societal and ecological systems. LOICZ Focus 4 (Economic and social impacts of global change on coastal systems) recognised that one conceptual starting point for collaboration between natural and socio-economic scientists is retention and recycling of nutrients by natural systems (Holligan and DeBoois 1993). Human activities have opened up these cycles. Some of the key actions may well lie in the areas where marine laboratory networks and biosphere reserves have an important role to play.

Improvements in resource recovery, and the consequent reduction of nutrient and toxic burdens in coastal ecosystems, will require the transfer of knowledge and technology in the broadest sense. This should not only involve the traditional transfer from developed to developing countries, but also exchanges among developing countries and from them to the industrialised world. Many successful traditional nutrient recycling systems exist in developing countries and should be exploited more widely (Strong and Arrhenius, 1993).

One important request of the developing countries is that the Intergovernmental Committee for the Convention on Biological Diversity examine legal and other methods by which the rights of indigenous and local communities may be recognized for insights into implementation options under the Convention. It is clear that along the coastal zones this problem is particularly important. Many indigenous and local communities have harvested and have sustainably used the coastal resources of their surrounding environments for thousands of years. If species and ecosystems are to be conserved and used sustainably, these communities must have a stake and interest in maintaining them. The skills and techniques practised by indigenous and local communities provide valuable information to a global community challenged by a growing population and a shrinking resource base. Traditional knowledge and management of coastal systems may also have high commercial value. For example, in the 1970s, the Mikmaq fisherfolk in Nova Scotia, Canada, applied traditional knowledge to solve the problem of growing oysters on soft muddy bottoms. Unfortunately, their method was copied by non-indigenous businesses who did not share the economic benefit realized with the Milmaq peoples (Daes, 1993). As for terrestrial areas, the coastal indigenous people and their communities may require, in accordance with national legislation, greater control over their coastal ecosystems, self-management of their resources (multispecies fisheries and aquaculture), and participation in the management of protected areas.

V. CONCLUSION - THE PRACTICAL APPLICATION OF SCIENCE TO CONSERVATION AND MANAGEMENT OF MARINE BIODIVERSITY

This paper emphasizes that greatly expanded basic research on coastal-marine biodiversity, applied to solving specific problems, is essential to determine what resources are present, how to protect and manage them properly, and how to detect change over time. In order to comprehend how biodiversity affects ecological function, we need to understand the natural dynamics and processes of populations and ecosystems. We need, also, to become able to assess the effects of specific threats and to devise effective management responses. In addition, managers and decision makers must work hand-in-hand with scientists and better make known their needs, thus making research in phase with the demands of society.

The broad geographical distribution and activities of marine laboratories, all over the world, is a great asset for this purpose. Marine research laboratories provide important opportunities to promote interdisciplinary and intersectoral approaches and activities. From a strictly scientific point of view, this implies both descriptions of ecosystems and their biota and analysis of ecosystem function. However, we presently lack the scientific basis for predicting the long-term consequences of species' extinction and landscape changes at the ecosystem level.

Basic research on natural systems, however, is not enough. By nature, it is oriented towards discovering fundamental mechanisms and to perfecting methodologies. The researchers can only say in general terms: "Here is what we must do and here is how we could do it." But there must be an important focus on the sociological problems associated with maintaining global ecosystem biodiversity, emphasizing the practical application of research for achieving sustainable resource management. This is to say that science, by itself, will not provide solutions. Rather, society as a whole will be the decision-maker. Therefore, an important contribution will be to develop and implement projects linking science with policy. When we examine the institutional mechanisms for decision making (both terrestrial and marine), it can be seen that the true specialists are very much in the minority and the importance of scientific programmes is underrated. With this perspective, we can distinguish three scientific objectives that could have practical applications for improving ecosystem management and that respond to conservation and sustainable use, as expressed in the Convention on Biological Diversity:

- identifying the factors which determine biological diversity and their changes in the short and long-term;
- evaluating, modelling and predicting the impact of human activities on biological diversity and on ecosystem function at the local to regional level; and
- understanding and making the best use of biodiversity for human societies from the economic, ethical, and cultural points of view.

The several new initiatives being taken to address global issues such as biological diversity, of which *Diversitas* and the Biological Diversity in Marine Systems (BioMar, see

Butman and Carlton, in press) are recent initiatives, must be also accompanied by improved institutional capacities for education and training, which we propose as essential ingredients of the IMBP programme. All over the world, a broad range of universities and other institutions have developed education and training programmes in marine biology and oceanography. These courses offer "total immersion" programmes for graduate students and advanced postgraduates. The primary objective is to train research students in the latest concepts, theories and techniques, with emphasis on basic understanding of marine organisms and marine ecosystems, as well as in multidisciplinary approaches to marine ecosystem processes. At present, many marine laboratories are developing new orientations in their graduate and postgraduate programmes directed to the information needs of management. The networks of marine laboratories in association with universities, museums, and UNESCO, can strongly contribute to the training of new generations of students, at an interdisciplinary level, involving expertise in ecology, economics, and appropriate methodologies and technologies.

Marine laboratories have proven, historically, to have been very important in the emergence and development of concepts and new techniques of fundamental biology, ecology, and oceanography. Most of the members of the marine community in the past knew one another, or at least what others were doing, and the contacts were informal and efficient. However, the marine-science community has expanded tremendously in recent decades and, with the emergence of new developments, it is common for researchers to be subdivided into groups that do not effectively communicate. Networks of marine laboratories will, therefore, give new impetus to the examination of one the highest-priority global problems: how biodiversity can be affected by environmental changes, with a view to its conservation and its proper sustainable use. This aspect is one of the central tenets developed in the Convention on Biological Diversity and Agenda 21.

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REFERENCES

Angel, M.V. 1992. Managing biodiversity in the oceans. pp. 23-62 in *Diversity of Oceanic Life: an Evaluative Review* (edited by M.N.A. Peterson). Center for Strategic and International Studies, Washington DC.

Batisse, M. 1990. Development and implementation of the biosphere reserve concept and its applicability to coastal regions. *Environmental Conservation*, 17: 111-116.

Global Change (edited by Solbrig, van Emden & van Oordt). IUBS Press, Paris, France.

Lipiatou, E. and A. Saliot 1991. Fluxes and transport of anthropogenic and natural polycyclic aromatic hydrocarbons in the western Mediterranean Sea. *Marine Chemistry 32*: 51-71.

Lubchenco, J., A.M. Olson, L.B. Brubaker, S.R. Carpenter, M.M. Holland, S.P. Hubbell, S.A. Levin, J.A. MacMahon, P.A. Matson, J.M. Melillo, H.A. Mooney, C.H. Peterson, H.R. Pulliam, L., S.A. Real, P.J. Regal, and P.G. Risser 1991. The sustainable biosphere initiative: An ecological research agenda. *Ecology* 72 (2): 371-412.

May, R.M. 1988. How many species are there on Earth? *Science* 241: 1441-1449.

Norse, E.A. (editor, 1993) *Global Marine Biological Diversity: a Stategy for Building Conservation into Decision Making*. Island Press, Washington DC, USA

Ogden, J. C. 1987. Cooperative coastal ecology at Caribbean marine laboratories. *Oceanus, 30*: 9-15.

Paine, R. T. 1966. Food web complexity and species diversity. *American Naturalist 100*: 65-75.

Paine, R. T. 1980. Food webs: linkage, interaction strength and community insfrastructure. *Journal of Animal Ecology 49*: 667-685.

Parilla, G., A. Lavin, H. Bryden, M. Garcia and R. Millard 1994. Rising temperature in the subtropical North Atlantic Ocean over the past 35 years. *Nature 369*: 48-51.

Perry, J.S., J.W.M. Riviere, and J. Matron-Lefèvre 1993. Understanding our own Planet: An Overview of Major International Scientific Activities. ICSU, Paris.

Price, A.R.G., S.L. Humphrey (efds). 1993. Application of the Biosphere Reserve Concept to Coastal Marine Areas. Papers presented at the UNESCO/IUCN San Francisco Workshop of 14-20 August 1989. IUCN, Gland, 114 pages.

Ray, G.C., 1991. Coastal-zone biodiversity patterns.*BioScience* 41 (7): 490-498.

Ray, G.C., and W. G. Gregg, Jr. 1991. Establishing biosphere reserves for coastal barrier systems. *BioScience*. 41 (5): 301-309.

Rex, M.A., C.T. Stuart, R.R. Hessler, J.A. Allen, H.L. Sanders, and G.D.F. Wilson 1993. Global-scale latitudinal patterns of species diversity in the deep-sea benthos. *Nature* 365: 636-639.

Rohde, K. 1992. Latitudinal gradients in species diversity: the search for the primary cause. *Oikos* 65: 514-527.

Roughgarden, J., S. Gaines, and M. Possigham 1988. Recruitment dynamics in complex life cycles. *Science 241*: 1460-1466.

Sherman, K., L.M. Alexander, and B.D. Gold 1993. Large Marine Ecosystems: Stress, Mitigation, and Sustainability. AAAS Press, Washington, D.C.

Sherr E. B. and B. F. Sherr. 1991. Planktonic microbes: tiny cells at the base of the ocean's food webs. *TREE 6*: 50-54.

Simo, R. M. Colom-Altes, J. O. Grimalt, and J. Albaiges. 1991. Background levels of atmospheric hydrocarbons, sulphate and nitrate over the western Mediterranean. *Atmo. Environ. 25A*: 1463-1471.

Simpson, B.B. 1988. Biological diversity in the context of ecosystem structure and function. *Biol. Int'l* 17: 15-17.

Solbrig, O.T. (editor) 1991b. *From Genes to Ecosystems: A Research Agenda for Biodiversity*. Report of a IUBS-SCOPE-UNESCO workshop, Harvard Forest, June,1991. IUBS Monogr. Ser. No. 7, Paris.

Solbrig, O.T. 1991a. *Biodiversity: Scientific Issues and Collaborative Research Proposals*. MAB Digest 9. UNESCO, Paris.

Briggs, J. C. 1994. Species diversity: land and sea. *Systematic Biology 43*: 130-135.

Butman, C. A. and J. T. Carlton (in press). Biological diversity in marine systems (BioMar): A proposed national research initiative. National Science Foundation, Washington, DC.

Clarke, A. 1992. Is there a latitudinal diversity cline in the sea? *TREE* 7(9): 286-287

Daes E.I., 1993. Study on the protection of the cultural and intellectual property of indigenous peoples. Sub-Commission on Prevention of Discrimination and Protection of Minorities. E/CN.4/Sub.2/1993/28.

DeLong, E. G. 1992. Archaea in coastal marine environments. *Proc. Natl. Acad. Sci. 89*: 5685-5689.

DiCastri, F., and T. Younès 1990. Ecosystem Function of Biological Diversity. *Biology International* Spec. Iss. No. 22: 19 pp.

ESA 1993. Forum: Perspectives on Sustainability. *Ecol. Applic.* Vol. 3, No. 545-589.

EuroMAB, 1993. Access. A Directory of Contacts, Environmental Data Bases, and Scientific Infrastructure on 175 Biosphere Reserves in 32 Countries. Dept of State Publication, Washington DC, and UNESCO-MAB, Paris.

Grassle, J. F. 1986. The ecology of deep-sea hydrothermal vent communities. *Advances in Marine Biology 23*: 301-362.

Grassle, J. F. 1991. Deep-sea benthic biodiversity. *BioScience* 41 (7): 464-469.

Grassle, J. F. and N. J. Maciolek. 1992. Deep-sea species richness: regional and local diversity estimates from quantitative bottom samples. *American Naturalist 139*: 313-341.

Grassle, J. F., and N. J. Maciolek Blake, 1990. Are deep-sea communities resilient? pp. 385-393, in *The Earth in Transition* (edited by G.M. Woodwell). Cambridge University Press, New York.

Grassle, J. F., P. Lasserre, A.D. McIntyre, and G.C. Ray 1991. *Marine Biodiversity and Ecosystem Function. Biol. Int'l.* Spec. Iss. No. 23: 19 pp.

Heal O.W., J.C. Menaut, W.L. Steffen. 1993. Towards a global terrestrial observing system (GTOS): Detecting and monitoring change in terrestrial ecosystems. *MAB-Digest 14 and IGBP Global Change Report 26*. UNESCO, Paris and IGBP, Stockholm.

Holligan P.M. and H. de Boois. 1993. Land-Ocean Interactions in the Coastal Zone (LOICZ): Science Plan. Global Change Report n°25, 50 pages.

Holligan, P., 1990. Coastal Ocean Fluxes and Resources. IGBP Global Change Rept. No. 14. Stockholm.

Huntley, B.J., E. Ezcurra, E.R. Fuentes, K. Fujii, P.J. Grubb, W. Haber, J.R.E. Harger, M.M. Holland, S.A. Levin, J. Lubchenco, H.A. Mooney, V. Neronov, I. Noble, H.R. Pulliam, P.S. Ramakrishnan, P.G. Risser, O. Sala, J. Sarukhan, and W.G. Sombroek 1992. A sustainable biosphere: the global imperative the international sustainable biosphere initiative. *Bull. Ecol. Soc. Amer.* 73(1): 7-14.

IOC (Intergovernmental Oceanographic Commission). 1993. Assessment and monitoring of large marine ecosystems. IOC/INF-942, UNESCO, Paris, 51 pages.

Jacobson, H.K., and M.F. Price 1991. A Framework for Research on the Human Dimensions of Global Environmental Change. ISSC/UNESCO, Paris.

Johannes R., P. Lasserre, S.W. Nixon, K. Ruddle & J. Pliya, 1983. Traditional knowledge and management of marine coastal systems. *Biology International, IUBS/ICSU 4* : 18 pp.

Jumars, P. A. 1993. Microbial Loops. pp. 179-197, In: Concepts in Biological Oceanography, An Interdisciplinary Primer. Oxford University Press, New York and Oxford, 348 pp.

Lasserre P., 1992. The role of biodiversity in marine ecosystems. pp. 105-130 in *Biodiversity and*

Southward, A.J. 1980. The Western English Channel - an inconstant ecosystem. *Nature 285*: 361-366.

Stern P.C., O.R. Young, D. Druckman (eds). 1992. Eglobal Environmental Change: Undertanding the Human Dimensions. National Academy Press, Washington, 308 pages.

Strong M. and E. Arrhenius. 1993. Tropical and subtropical coastal management: a question of carbon flow in a sectoral society. *Ambio, 22*, special issue n°7: 413-496.

Takada, H., J. W. Farrington, M. H. Bothner, C. G. Johnson and B. W. Tripp. In press. Transport of sludge-derived organic pollutants to deep-sea sediments at Deep Water Dump Site 106. *Environmental Science and Technology*.

Tunnicliffe, V. 1991. The biology of hydrothermal vents: ecology and evolution. *Oceanography and Marine Biology Annual Review 29*: 319-407.

UNEP, 1992. Convention on Biological Diversity, 5 June 1992. UNEP, Geneva.

WCED, 1987. Our Common Future. Oxford University Press, 400 pages.

Younès, T., 1992. The IUBS-SCOPE-UNESCO Programme Ecosystem Function of Biodiversity: A Progress Report. *Biol. International* No. 24: 16-21.

Glossary of Acronyms

CARICOMP : Caribbean Coastal Marine Productivity

COMAR : Coastal Marine Project (UNESCO)

GOOS : Global Ocean Observing System (IOC)

GTOS : Global Terrestrial Observing System

HDP : Human Dimension Programme

IABO : International Association for Biological Oceanography (IUBS)

ICSEB : International Conference for Systematics and Evolutionary Biology

ICSU : International Council of Scientific Unions

IGBP : International Geosphere Biosphere Programme (ICSU)

IMBP : International Marine Biodiversity Programme

IOC : Intergovernmental Oceanographic Commission (UNESCO)

IUBS : International Union for Biological Sciences

IUCN : World Conservation Union

LMEs : large marine ecosystems

LOICZ : Land Interaction in the Coastal Zone (IGBP)

MAB : Man and the Biosphere Programme (of UNESCO)

MARS : Marine Research Stations network

SCOPE : Scientific Committee on Problems of the Environment (ICSU)

SCOR : Scientific Committee on Ocean Research (ICSU)

UNCED : United Nations Conference on Environment and Development

UNESCO : United Nations Educational, Scientific and Cultural Organization

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IUBS SECRETARIAT
51, Boulevard de Montmorency, 75016 Paris, France.
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