Marine Board

Towards a European marine research area

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Editors

J. Boissonnas and L. d'Ozouville

Core Drafting Group

J. Boissonnas, O.R. Godø, C. Jeandel, J.W. de Leeuw, K. Lochte, R.F.C. Mantoura
J. Marks, J.F. Minster, G. O'Sullivan, L. d'Ozouville, S. Vallerga, G. Wefer

Other contributors

H. Halvorson , C. Heip, B. B. Jørgensen
and
Delegates of the ESF Marine Board

Contributions

Feasibility Study Group on marine biotechnology, 22 - 24 November 2000
Hanse conference "Ocean margins systems", Delmenhorst, 19 - 23 November 2000
EurOCEAN 2000 conference, Hamburg, 29 August - 2 September 2000

Contact address

European Science Foundation
ESF Marine Board – Secretariat
1 quai Lezay-Marnésia
67080 Strasbourg Cedex . France
Tel: +33 (0)3 88 76 71 41
Fax: +33 (0)3 88 25 19 54
E-mail: marineboard@esf.org

Home Page: http://www.esf.org/marineboard

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"Ocean science will have to become more holistic, more interdisciplinary and more international. If we are to adequately address ocean issues at the local, national, regional and global levels, science cannot operate in isolation but will need to integrate more fully a response from society at large. There must also be changes in the way we regulate marine activities, in our social goals and our attitudes to ocean governance. If we are to make the right decisions, however, we must understand how things 'work' in the oceans and how they interact; and we must recognise the role of the oceans in our life-support system and its value for humankind. This will require excellent science, together with the technology for pursuing it, as well as the support of individuals and governments. Ultimately, it calls for a vision of the planet that embraces land, sea, the atmosphere and human societies in all their interactions."

The Ocean, Our Future
Report of the Independent World Commission of the Oceans
(1998)

Background

To what extent has the European scene in marine science and technology changed during the last decade? In many aspects, quite considerably.

Regarding the **institutional context**, the MAST programme, initiated in 1989, has come to an end after having greatly contributed to the creation of a European community of marine scientists. Partly relaying MAST under the Fifth Framework Programme (FP5), the key action on Sustainable Marine Ecosystems is in principle more focused on problem-oriented research. In the ESF structure, the shift from EMaPS to a Marine Board with updated terms of reference is giving more visibility to European research organisations. We also note the consolidation of EUROGOOS and, more recently, the launch of MEDGOOS. A European Federation of Marine Societies (EFMS) was created to provide a forum for associations and learned societies.

Further evolutions are under way. Preparations for a Sixth Framework Programme (FP6) have started. FP6 will be built around the newly proposed concept of a European Research Area (ERA) and, among other innovations, is expected to give greater focus than past FPs to the support of research infrastructure. Current discussions on the creation of a new cooperative structure for marine research in Europe, initially proposed by Portugal, will hopefully lead to important developments.

The **strategic issues** of today and of the coming decade are no longer quite those of the 1980s and early 1990s. The quest for sustainability – a sustainable environment, the sustainable exploitation of resources – has imposed itself as one of the key drivers of research. Of equal importance is the present call for interdisciplinarity. Years ago physicists and biologists were urged to work together, but there is now a much more comprehensive requirement to involve social scientists, economists and, generally all stakeholders in problem-oriented projects: this holds especially true for the coastal zone. Also new, or expressed in new terms, are present preoccupations with public awareness and ethics. The benefits, and indeed the inevitability, of a regional approach in marine research are being emphasised nowadays, particularly in the context of the emerging ERA. And finally, there is a new insistence on improving the visibility of Europe in global and international programmes.

With regard to **scientific priorities**, we also notice a number of evolutions, some of them dramatic, others more subtle. Most notable perhaps is the reference to the Earth System, in which land, oceans and atmosphere are in constant interaction. Until a few years ago, the priority was to investigate each compartment of the system separately. Now the key word is integration : we need to find out how the oceans, atmosphere and land surface function together as a dynamic system, and our aim is to understand the causes and consequences of interacting environmental changes.

Given the context outlined above, it is both timely and essential to elaborate strategies for European marine research in the next five or ten years. This strategic plan will be complemented by a detailed science plan by mid-2001.

Executive summary

Public awareness of the oceans, of their importance to mankind, of the complex issues raised by their exploitation and protection appears to be increasing in Europe.

At the EurOCEAN 2000 Conference in Hamburg, (29 August-2 September 2000), two sessions organised by the European Science Foundation (ESF) Marine Board were dedicated to discussing the strategic and scientific issues of a marine science plan for Europe. Its concept and the key scientific challenges to be addressed were fully endorsed by the participants.

In this context, the ESF Marine Board is developing a vision of marine science for the next decade, integrating all relevant dimensions of the natural and social sciences and the concerns of all end users of European seas, and taking into account that marine research is a major component in the understanding of the Earth System. Accordingly, the ESF Marine Board has embarked on preparing a marine science plan for Europe. The main objective of this strategic plan is to guide European and national decision-makers in formulating their future priorities, taking into account the recently proposed European Commission initiative of a European Research Area. As a first step, the present report outlines a new strategic context to prioritise and coordinate future European research into the marine environment and the most important RTD issues of relevance to Europe. A full-scale Marine Science Plan will then be produced as a result of a second stage of the work, after extensive consultations of all interested parties.

The main drivers for the elaboration and implementation of marine research programmes today are:

- the pursuit of sustainability for the environment and the exploitation of marine resources;
- the dominant role of the world ocean in the climate system: the need to understand climate changes and minimise their impacts;
- the ocean as the ultimate frontier for research and the prospect of promising technological developments.

Five major scientific challenges have been identified for priority actions:

1. Ocean climate coupling: processes, variability and predictability; greenhouse gases;
2. Sustainable exploitation of living and non-living resources;
3. Health of the coastal zone: management and protection of the coastal zone; biodiversity;
4. New frontiers in marine life: biotechnology and new ecosystems;
5. New frontiers in ocean margin systems: seafloor studies.

In considering these major scientific challenges, we will take into account several strategic issues:

- The interdisciplinarity of marine science, associating natural and socio-economic disciplines, as well as academia and industry.

- The Earth as a “system”, in which oceans, atmosphere and land surface are in constant interaction: this implies an integration of marine science in the larger context of global environment change and sustainable development.

- The need for "focused research areas" in European seas, taking into account the diversity of situations – geographical, climatic and economic – and the implication that relevant disciplines of the natural and social sciences must be coordinated to find integrated solutions.

- The regional dimension of European marine research and its potential for integration in global programmes: this offers the possibility of dealing with a variety of case-study areas and bringing together different disciplines.

- The need to link national and European programmes: this should be considered in the framework of the EUROCORES initiative of the ESF, the emerging European Research Area and the forthcoming EU enlargement.

- The primacy of ethics to guide sustainable exploitation and experimentation in the ocean, and the importance of deontolongy in the professional practice of either.

- The importance to have access to quantitative indicators, socio-economic data and syntheses required for marine science management and policy development.

- The need to define and implement a European strategy for the identification of the requirements and the management of marine research infrastructures.

The Member Organisations of the ESF Marine Board are dedicated to foster the implementation of the Marine Science Plan presently under development but this also requires a special effort at European level in the spirit of the European Research Area for which marine science presents a fertile opportunity as a test case. This also implies that marine research should be an integral element in the Sixth Framework Programme.

General recommendations

A European Marine research plan must:

- provide the scientific background for proper governance of European seas;
- support research to underpin the sustainable development of Europe's marine resources and protection of the marine environment;
- quantify the economic social and environmental benefits accruing from such research;
- support interdisciplinary research at the appropriate spatial and temporal scales;
- recognise the equal importance of both basic and applied research and their contribution to economic and social development;
- facilitate commitments to long-term (decadal) ocean observation systems;
- have a clear regional dimension, recognising that some issues are regional and must be addressed at a regional level;
- incorporate an element of public awareness, creating a sense of wonder and excitement;
- must address ethical issues where they arise;
- be based on an agreed programme harnessing both EU and Member State Marine Research Programmes, expertise and infrastructures;
- promote the participation of industry, including the SME sector, in research projects;
- support the European dimension of international programmes and agreements;
- use the unique opportunities offered by information technology for the development of e-marine science;
- recommend a unified frame for marine research in the Sixth Framework Programme, integrating the research needs of industry, fisheries, science and their socio-economic components.

1. Introduction

Oceans and seas represent a major component of the Earth System[1]. They hold the key to climate. They support a significant proportion of the world's economic activities[2] and a wide range of services and social benefits. And despite major scientific advances in recent years, they still offer exciting perspectives for frontier research on such fundamental issues as, for example, the origin and evolution of life.

> ***"More has been learned about the nature of the oceans in the past 25 years than during all preceding history. Dramatic new insights about the sea floor and life in the oceans...have captured the imagination of both policy-makers and the general public. However, what we know about the oceans is still out-weighed by what we do not know".***
>
> From: "The Ocean, Our Future", Report of the Independent World Commission on the Oceans, 1998.

Europe is the continent with the highest coast/surface ratio, and about 20% of Europeans live along the coast. Moreover, at least 40% of the EU territory is underwater. European seas – Barents and Baltic, North and Irish, the Eastern Atlantic north of the Canaries, Mediterranean – encompass a large range of settings, from the coastal zone through the shelf and shelf-edge into the deep ocean. The sustainable development of marine resources, living and non- living, present in this vast area, the protection of the marine environment and the provision of marine-based services are critical to economic prosperity and to the quality of life of European citizens. Indeed, as a result of expected population growth over the coming decades, especially in coastal areas[3], the economic importance of European seas is likely to increase.

In this context, society – notably in Europe – has to accept the notion that the ocean plays a major role in climate control and is vulnerable to human pressure[4]. Water quality and life in coastal and shelf areas are strongly impacted by activities on land. Policy-makers and informed citizens have by now learnt that living resources, at the present rate of exploitation, are finite. Another point worth stressing is the multiplication of conflicts among competing uses (fisheries, hydrocarbon exploitation, transport, leisure etc.), and the detrimental consequences of poor coordination at the national, European and international level in the quest for solutions.

Decision-makers need advice from scientists. A dedicated research effort is required to understand the natural and anthropogenic processes at work in the marine environment, and their socio-economic impacts. Europe has a rich and diverse marine research infrastructure and a long, distinguished and competitive research tradition in the world ocean. By its very nature, marine science demands a multidisciplinary approach encouraging international cooperation and equipment sharing. The International Year of the Ocean, 1998, was a milestone. As we move into the new millennium and the era of the European Research Area (ERA), marine science stands out as one of the domains where we can truly develop a European research ethos and partnership.

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[1] Half of the photosynthesis on Earth is carried out by phytoplankton in the sea.

[2] In the G7 countries, marine resources and services contribute on average 5% of GNP.

[3] In 1995, Commission Communication COM(95)511 reported that 47 % of the EU population resided permanently within 50 km of the coastal zone.

[4] Uncontrolled discharges of hydrocarbons amount to 2 million tonnes per year in the oceans, of which 600 000 tonnes go into the Mediterranean, this is the equivalent of one *Erika* disaster per week (*Le Monde*, 14 November 2000)

2. Drivers

The main drivers of research on marine science and technology in the current era are the environmental and socio-economic concerns related to sustainable development and the need to minimise the impact of global climate change. A guiding principle of action in these fields is that governance and prediction are keystones to enhancing economic prosperity and quality of life. Additional impetus is provided by emerging technologies (for example nanotechnology) and by the better application of existing technologies (IT, acoustics, biotechnology etc) to the sustainable use of marine resources and the exploration of new frontiers.

These drivers are now embedded in a number of European and international conventions and agreements to which the EU and its member states are bound (Appendix C).

2.1 Sustainable development and the precautionary principle

Concerns about sustainable development and its various components – environmental, economic and societal – have emerged at the forefront during the last twenty years. As stated in the Brundtland report of 1987, "environment and development are not separate challenges; they are inexorably linked. Development cannot subsist upon a deteriorating environmental resource base; the environment cannot be protected when growth leaves out of account the costs of environmental destruction. These problems cannot be treated separately by fragmented institutions and policies…" This focus on integration is central to the concept of sustainable development and has to be taken on board in marine research.

Also of importance is the fact that uncertainty is an intrinsic part of marine research, all the more so because the processes studied operate and evolve on long time-scales: uncertainty is thus the basis for the so-called "precautionary principle", or better perhaps: "precautionary approach", in the management of the marine environment.

> ***"Uncertainty does not necessarily mean low quality in scientific information in policy contexts…High quality does not require the elimination of uncertainty, but rather its effective management".***
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> From: Funtowicz S.O. and Ravetz J.R., *Uncertainty and quality in science policy,* Kluwer Academic.Press, 1990.

Past approaches to the economics of the marine world (Table 1) were based on the notion, now abandoned, that resources from oceans and seas are infinite. The value of the oceans and of the ecological services they provide was consistently underestimated, and consequently there was a failure to take into account the notion of sustainability. European seas are no exception, and the challenge of their sustainable management has still to be met.

Table 1

- 80% of all international trade is carried by sea.
- By the year 2020, 75% of the world's population will live within 60 km of sea coasts and estuaries.
- The world fish catch amounts to about 20% of total human consumption of animal protein.
- In 1995 offshore production of oil and gas accounted for 26% of the world's total.
- Coastal marine environments and wetlands may provide as much as 43% of the estimated value of the world's ecosystem services, and yet, over 50% of such areas have already undergone severe environmental degradation.

Sources: Report of the Independent World Commission on the Oceans, 1998; GOOS Prospectus 1998

For Europe, despite gaps in available statistics, one can estimate that roughly 3-5% of input to the GNP of the European Union is generated directly by marine-based industries and services. The value added by these activities is of the order of 110-190 billion Euro/ annum. European citizens. European maritime regions account for over 40% of the EU GNP.

Of the EU external trade 90% is conducted through shipping; more than 300 000 persons are employed in the maritime and river transport chain in Europe. Depending on the areal definition of the "coastal zone", 20-50% of Europe's population live in the coastal zone and depend on it for their living and their quality of life. The increasing flux of tourists contributes to the anthropogenic pressure on the coast: in the mid-1990s the Mediterranean coastline received annually about 75 million international and 60 million domestic tourists. Fisheries, sea farming and associated processing industries employ more than 600 000 people and generate a turnover of 12 billion Euros.

Half of Europe's needs in gas and oil are met by the exploitation of hydrocarbon resources in the North Sea, which requires more than 200 000 highly skilled jobs. Annual investment in the area varies between 15 and 20 billion Euros and as a consequence of the rapid development of deep sea hydrocarbon exploitation and extraction, these enterprises are exporting their know-how to new and extremely competitive markets in Asia and the South Atlantic.

2.2 The ocean in the Earth System: its role in climate variability and prediction

Our planet is a "system", in which oceans, atmosphere and land surface are in constant interaction. As a result, the 71% of the planet which is covered by sea water plays a key role in shaping the climate at all levels, from global to local. Variations of the pattern of ocean currents, especially in the North Atlantic, will dramatically affect the global climate and even more so that of Europe. The Mediterranean, Black Sea and Baltic ecosystems are strongly linked to North Atlantic climate, as well as to Sahelian rainfall. Climate change (0.6° C average temperature increase since 1900) in turn affects the marine environment in several ways: increased storminess, sea level rise, resuspension of contaminants in the sea, decline or regional shifts in aquaculture and fisheries productivity etc. New research is greatly stimulated by the need to better understand the role of the ocean in climate change, and by current prospects in the operational forecasting of climate trends and of ocean parameters.

2.3 The ocean, a new frontier for science and technology

In the last decade, new technology has tremendously extended the scope of research and is now putting scientists on the threshold of an exciting new era. European seas have been the locus of unexpected discoveries: intriguing ecosystems and life forms, thermal vents and cold seeps, huge accumulations of methane in the form of gas hydrates etc. The implications of these discoveries for our understanding of ecosystem functioning and of the global carbon cycle are still largely unknown. So is the applicability of some of these discoveries to human activities: it is assumed, for example, that micro-organisms of deep sea sediments will offer prospects for biotechnology and that gas hydrates may become a potential energy source.

Other subjects are also now on the agenda for frontier research. For example: (1) the possible consequences of change in the marine environment for human activities and health, the coastal sea being a possible vector of diseases; (2) the ocean as the largest gene pool for biodiversity; (3) the use of extremophile organisms in marine biotechnology; (4) stepping up the use of renewable energies; (5) monitoring Earth processes and hazards by means of seafloor observatories; (6) extending to 2 500 m and beyond, access to a new range of targets for hydrocarbons exploration.

3. Key strategic issues

In formulating a European Marine Science Plan adapted to the context of the coming decade, one has to take into account a number of strategic issues relating to science policy, the European and international scene, and socio-economics.

3.1 Evolving requirements in the implementation of marine research

Interdisciplinarity

As marine science progresses, it becomes increasingly necessary that new research initiatives be formulated with an interdisciplinary framework. For example, one can no longer study the food chain without understanding circulation and mixing processes. Ocean forecasting, the dynamics of eddies and gyres, halieutic models, are topics which require a close interaction with hydrodynamics and the physics of non-linear systems. Fighting the consequences of a ship wreck calls for contributions from experts in hydrodynamics, chemistry, biology, sedimentology and socio-economics, in a constant dialogue with relevant authorities and the public. Strategies to prevent accidents and risks must be developed through the joint efforts of marine scientists, specialists in international maritime law and representatives from the shipping and other industrial sectors.

Interdisciplinary research can best be organised around **"focused research areas"** ("chantiers"), where all relevant disciplines of the natural and social sciences must be made to converge towards an integrated approach for solving problems. The question to be addressed can be an environmental problem, for example, an oil spill, a toxic algal bloom, the risk of a hazard on the sea floor, or a scientific issue at a particular geographic location (straight, canyon, shelf break). As for the spatial scale, there is no a priori definition: a "focused research area" can be an ocean basin, an area of the continental shelf, an estuary or any stretch of coastal zone. Nevertheless, the scientific questions to be addressed and their geographical dimension are interdependent.

By focusing interdisciplinarity in this way, the Marine Science Plan is consistent with the notion of large targeted projects contained in the ERA proposal, keeping in mind that the content and implementation of such large projects must be allowed to adapt over time.

Process versus problem-oriented research

The current economic and political climate favours applied (or problem-oriented) research over basic (or curiosity-driven) research. Yet it is from basic research that the really fundamental discoveries are made and innovative technologies emerge. Contrary to what is happening in Europe, the funding of basic research in the USA is on the rise. The Sixth Framework Programme of the EU should strike an appropriate balance between both approaches.

The importance of long-term commitments

In recent years, marine research has moved away from the traditional expeditionary mode. On subjects such as climate-relevant research, ocean ecology, environmental impacts, and for all purposes of operational forecasting, data have to be collected systematically over long periods, of tenyears or more. In order to cope with this increasingly important trend of science, adequate commitments from policy makers and financing authorities are required (Appendix 2: Current level of support for marine science and technology). Failure so far to develop appropriate funding mechanisms for observation systems and computing power needed to forecast trends, is regarded by many as a major drawback. Coordination and long-term commitments must be addressed by a European marine science policy and will have to be developed between ministries and agencies with responsibilities for marine affairs.

3.2 Geopolitical dimensions

Regional dimension

The seas around Europe display great contrasts in their geographical setting, their degree of exposure to human activities, and their role in the functioning of the marine system. The Baltic and Black seas, the Mediterranean sea – viewed both globally and in some of its elements like the Adriatic – are almost enclosed. By contrast, the Atlantic coast of Europe faces the open ocean and the North Sea is in a intermediate position. A European marine science plan must take these regional differences into account. The implementation of global programmes – in which many European scientists participate – relies on the integrated study of regional causes and effects. Conversely, global forecasts must be downscaled for regional applications.

The existing network of European marine biological stations is an element of regionalisation. These stations are often vulnerable to underfunding. The Marine Science Plan will provide incentives for them to network their activities.

Insisting on a regional dimension of marine research is in line with the ERA concept. It does not contradict the notion of a European scientific community because there are broad common issues across European seas which call for intercomparisons (for example: pollution and human pressure in the Baltic and the Adriatic). Furthermore, the integration of regional studies into world programmes can play a decisive role in emphasising a European identity.

Participation in international programmes

The EU, through its marine science institutions and infrastructures, has a major contribution to make to international programmes, for example: World Climate Research Programme (WCRP), International Geosphere-Biosphere Programme (IGBP), Ocean Drilling Program (ODP) and its continuation after 2003 as the Integrated Ocean Drilling Programme (IODP). In fact, this contribution is very substantial but often lacking European concertation: the need for a higher European profile is clear. The strategic objectives of a Marine Science Plan must address this problem by:

- maximising complementarities of national programmes;
- enabling European marine scientists to interact and share experience with colleagues in other parts of the world;
- putting the science and technology capabilities of Europe at the international community's disposal (including developing countries);
- defining a coherent policy with regard to the use of large European infrastructures;
- maintaining appropriate links with existing European and international bodies such as ICES (the International Council for the Exploration of the Seas), IOC (the Intergovernmental Oceanographic Commission of UNESCO), and the secretariats of various conventions on the protection of the marine environment.

EU enlargement

A major objective for the EU is to bring together the scientific communities of western and eastern Europe. The European Marine Science Plan will help EU candidate countries, especially those with a marine coastline, to assess their strengths and weaknesses. It will create opportunities to integrate their priorities and their scientists.

The Plan will also extend the scope for cooperation to other European and non-European countries bordering the Mediterranean basin, the Black Sea and the Baltic. In these seas, or at least in their coastal waters, the overriding issue is that of human pressure, and the challenge of governance across national boundaries is especially pressing. Special attention should be paid to developing cooperation with the Russian Federation regarding the involvement of their scientists in EU projects and reciprocal access to research facilities.

Co-operation with developing countries

Cooperation in marine science with developing countries should be engaged through partnership programmes. These must be relevant to the development of the host country and strengthen its capacity. Joint projects should include training in research and results can only be obtained through long-term partnership. The time is ripe for a comprehensive approach involving the European Commission, individual countries, the developing world, and the UN organisations. Building regional centres of excellence and establishing Internet networks are important elements in such an approach.

3.3 Socio-economic strategic issues

Making academia and industry work together

In contrast to the current belief that industry has no interests in the marine environment other than those related to the exploitation of resources, the Marine Science Plan acknowledges that industry is also a potential actor in strategies to monitor and forecast the marine environment. In fact the notion of sustainable development, which includes risk assessment, implies a shared responsibility of all parties concerned in marine-based activities. There is a problem of lack of mutual awareness between academia and industry both for the formulation of research needs and the transfer of results. Cooperation on projects of mutual interest, and with clearly defined terms – as is the case at present in an FP5 "cluster" on the European continental margin – can be extremely rewarding: the best expertise, the best technology, the most effective procedures of data collection, are made to converge in a very cost-effective manner. Areas for possible synergy include offshore energies (renewable or non-renewable), biotechnology, new materials, sensors, remote-sensing products, services and products for monitoring and forecasting, etc. Because SMEs, despite their dispersion, influence large segments of the market (fishing, offshore, shipping), they must be part of the dialogue between industry and science and they must be allowed to participate in joint research initiatives.

Public awareness and training

Public awareness and education on the scientific challenges of the sea is of paramount importance to secure, at all levels of society, the acceptance of management policies arising from research results. Judging from the success of aquaria in Europe and elsewhere the general public, especially the young, is only too happy to respond to messages about the wonders of the marine world. Novel technologies – for example video cameras coupled to Internet – can bring the public into virtually direct contact with the life and events in the sea. What is needed above all, however, is *a* fundamental shift in perception of marine science from curiosity about charismatic species to understanding the challenges of ecosystem management.

Ethics in marine research

Promoting an ethical dimension in marine research is central to the concept of human stewardship of nature, sustainability and the precautionary principle. It may help to resolve conflicting opinions about the acceptability of particular research initiatives, for example, those that might involve future large-scale experiments in the water column, on the sea-floor and below the sea floor; or those that might seek to introduce controversial new methods of exploitation (for example in aquaculture). The ethical concerns in biotechnology have considerably increased in the recent years and the public needs to be convinced, through communication efforts, of the clear benefits of research in this domain. Ethics in marine research are a requisite for the governance of the ocean and can go a long way towards safeguarding public trust in science and in scientists.

3.4 Information and indicators

Europe is presently without relevant quantitative indicators, socio-economic data and syntheses required for policy development and marine science management such as:

- indicators of status and evolution of marine science, funds and manpower devoted to marine research and technological development; scientific publications and their impact (citations); European patents by marine science and technology sectors;

- information on the objectives, current status and results of various research and technological development initiatives and programmes, both at the national and European level;
- socio-economic indicators describing status and evolution of sectoral ocean-related activities: economic added value and employment generated by various branches of marine research and technology;
- biological, geological, chemical and physical indicators characterising the health of coastal waters, the nature of pollutants and their relation to human activities and urban concentration.

Many such indicators and information may exist on a national basis but less frequently at European level (they exist for example for fisheries and coastal environments). Synthesis and further development of indices would need to:

- define and analyse the policy value of relevant quantitative indicators;
- identify existing primary science and technology indicators and socio-economic data on a sectoral and national basis;
- analyse the validity and relevance of such indicators and data for policy development such as demonstration of sustainable development options adapted to regions;
- make syntheses of existing indicators with a view to developing European indicators, including benchmarking of indicators and practice;
- provide information rapidly so as to respond to crises in European seas (oil spills, algal blooms, outbreaks of toxic algae, coastal pollution, etc.).
- publish and disseminate regular reports on the state of European seas and marine activities based on these indicators, in relation to the European Environment Agency and other relevant organisations.

These objectives will contribute to the establishment of a comprehensive database on existing scientific, technical, and socio-economic competence relevant to policy making and should be implemented through active and innovative cooperation with relevant European and national organisations. The information will be at the disposal of public and private users. It will also serve as a vehicle to increase public understanding of marine issues and to develop a common consciousness in Europe concerning the challenge of the seas and the necessity of improving their governance.

4. Overview of the scientific challenges

The concept of challenges, as formulated in this strategic marine science plan, has a history that can be traced back to the early 1990s. In September 1994, after a series of meetings and preparatory workshops, the European Committee on Ocean and Polar Sciences (ECOPS)[5,6] presented to European policy-makers and scientists four Grand Challenges for future long-term cooperation in Europe. These were: operational forecasting of the oceans and coastal seas; variability of the deep sea floor; the Arctic ocean; and, in the field of climate related research, the European Programme on Ice Coring in Antarctica (EPICA).

The Grand Challenges were seen as representing some of the strongest scientific priorities of the time. Since then, our perception has changed to a certain extent. We have become aware that Nature tends to respond in a non-linear manner to gradual and continuous environmental change. This awareness should help us in our attempts to predict future ecosystem behaviour in a changing context.

New focus on the Earth System has been highlighted in the Background section of this report. Operational forecasting was, and still is, a challenge, but matters have progressed to the point where it is an established strategy, not only an objective to be lobbied for and pursued. Benefits will be felt in most sectors of marine activity and services, particularly those relating to the sustainable exploitation of resources and to coastal zone management. Polar research is more than ever a priority, less for its marine aspects alone than as an interdisciplinary effort to address climate change.

Although biogeochemical cycling was already very much on the science agenda five or ten years ago, the urgency, complexities and implications of quantifying the planet's carbon budget had not yet been fully expressed[7]. Concern with greenhouse gases has increased, and we need more than ever to clarify our ideas on sources and sinks of carbon dioxide and other gases.

In the early 1990s, deep sea research was advancing rapidly. Since then, it has produced a new stream of exciting results on fluid flow at the continental margin, on the occurrence and significance of gas hydrates, carbonate mounds and cold water reefs along the European margin, and on the micro-organisms in ocean floor sediments. It is important to stress here the driving role of the hydrocarbon industry in its march towards exploitation at increasing water depths.

European scientists have by now developed a clear vision of what should be a research plan on marine biodiversity. This has been set out in two position papers of the ESF Marine Board; activity in this field is taking place under the umbrella of the MARS network. The ocean is the largest gene pool for biodiversity. Modern developments in molecular biology and genetics provide us with the concepts to explore this new frontier for possible applications in biomedicine, pharmacy, food production and environmental remediation.

[5] ECOPS was jointly set up by ESF and DG XII (Research) of the Commission of European Communities. Its members were designated in their personal capacities. Ref : *The Ocean and the Poles, Grand Challenges for European Cooperation*, ed. G.Hempel, Gustav Fisher Verlag, 1995.

[6] During its lifetime ECOPS also initiated consultations on biodiversity, coastal zone management, various aspects of technology (in particular for deep sea instrumentation), and sponsored the preparation of a marine science plan for the Baltic, thus paving the way for extended cooperation with eastern Europe.

[7] See *Our Changing Planet, the U.S.Global Change research program*, NSTC report, 1999.

Being heavily impacted by human activities, the coastal zone poses a formidable challenge for its sustainable management and protection. Some progress has been made on the concept of Integrated Coastal Zone Management, its requirements, the technical and sociological obstacles to be overcome. On the dark side however, pollution of all sorts remain a problem. New threats to human health and economy may occur particularly in coastal environments due to the release of alien species, viral infections or the spread of toxic algae. One of the major challenges lies in the recognition of the causes of species changes and their impact on ecosystem functions.

Given the pace of technological progress in the past decade, many new instruments are now available to investigate, survey and exploit the seas. The main advances have been in robotics, miniaturisation and nanotechnology, information technologies and data transmission. These recent developments, and others that will no doubt follow, are the key to our ability to meet the main challenges of the future.

The ESF Marine Board has now identified five major thematic challenges for future research: 1) ocean climate coupling; 2) sustainable exploitation of resources; 3) health of the coastal zone; 4) new frontiers in marine life; 5) new frontiers in ocean margin systems: seafloor studies. The main objectives of research under each challenge and its sub-challenges are listed below. Explanations are provided in Appendix A of this report.

Challenge 1: Ocean climate coupling

1.1 Processes, variability and predictability

- **understand processes governing ocean currents, air-sea exchange and sea-air-ice interactions;**
- **for short-term warning and forecasting: improve predictions of sea state and currents, develop weather service operations;**
- **for seasonal to interannual forecasts: enhance global observing and data systems, develop modelling, assess climate variability on human activity;**
- **for decadal to centennial forecasts: investigate forcing factors, paleoclimatology, modelling.**

1.2 Greenhouse gases

- **reduce current uncertainties in ocean carbon fluxes within the global carbon budget;**
- **investigate ocean to atmosphere fluxes of other greenhouse gases;**
- **evaluate the feasibility, sustainability and impacts of carbon sequestration options (deep disposal of CO_2, surface fertilisation experiments).**

Challenge 2: Sustainable exploitation of resources

2.1 Living resources: fisheries and aquaculture

- for the operational monitoring and forecasting of living resources: integrate biological and environmental dynamics on different time scales;
- for the sustainability of resource management : integrate relevant knowledge of ecosystem functioning and climate fluctuations;
- develop the biological basis for aquaculture;
- prevent, assess and mitigate negative impacts of fisheries and aquaculture on the environment.

2.2 Non-living resources: hydrocarbons, renewable energies and minerals

- investigate hydrodynamics, sedimentation and slope stability in areas open to hydrocarbon exploration;
- assess the possible significance of gas hydrates as a new energy source;
- determine the behaviour, transport and biodegradability of pollutants from oil and related substances;
- investigate the use of aggregates for coastal protection and the environmental consequences of extraction.

Challenge 3: Health of the coastal zone

3.1 Management and protection of the coastal zone

- protect coastal marine biodiversity and ecosystems from damage caused by human activity;
- promote water quality in catchment and coastal areas;
- prevent the occurrence or mitigate adverse effects of virus, bacteria and toxic algae;
- meet public concerns over the discharge and dispersion of waste;
- protect sensitive stretches of the coast line against erosion, excess sedimentation and extreme events;
- promote the preservation of a large part of the European cultural heritage.

3.2 Marine biodiversity

- undertake targeted inventories of biodiversity in European seas;
- understand the functional role of biodiversity;

- predict the consequences of a potential loss of biodiversity resulting from environmental changes.

Challenge 4: New frontiers in marine life

4.1 Biotechnology

- bioprospect for novel compounds in selected organisms and habitats;
- establish new fundamental bioprocesses for bioproduction;
- develop products and processes in marine environmental biotechnology;
- utilise molecular approaches to assess biodiversity and exploit marine genetic resources;
- establish advanced cultivation methods for marine organisms and cell lines.

4.2 New ecosystems

- explore the limits of the sub-surface biosphere;
- study unique habitats (cold seeps, gas hydrates, oil reservoirs, deep brines, mud volcanoes, carbonate mounds);
- identify the dominant organisms and their biomass, diversity and ecophysiology;
- study microbe interactions with minerals and other interfaces;
- search for novel types of prokaryotes with unique properties.

Challenge 5: New frontiers in ocean margin systems: seafloor studies

- reconstruct the geometry and evolution of sediments on active and passive margins;
- assess the role of canyons in focusing and enhancing processes;
- assess hazards associated with European margins;
- investigate the distribution, volume and role of fluid vents and seeps at margins;
- address detrimental impacts of the hydrocarbon industry on the sea floor;
- monitor seismic activity at active margins.

5. Overview of forward-looking technology

Marine science and technology are becoming increasingly interdependent. New cutting-edge knowledge is often directly related to technological breakthroughs. It may be less obvious for the scientific community that technological innovation is closely linked to high level basic research. Until recently, science was driven by the need to **describe the past** and to **understand the present** by gathering isolated snapshots of the oceans. Today the main challenge faced by marine science and technology is to **predict the future** for the purposes of sustainable marine management, ocean forecasting and coping with climate change. The need is now for global 3D and 4D datasets of the oceans to understand the dynamics of the processes, hence a significant strategic change in the way we conduct our science.

Progress in robotic, computer, miniaturised technology and data transmission offers unique new opportunities, which have to be fully exploited to address the needs of marine science. The development of e-marine science, which requires the pooling of large resources, is a prerequisite to progress beyond the current stage of marine research and has a high European added value. The deployment of fibre-optic cables on the sea floor, providing two-way real time high bandwidth communication including video, offers new visions for marine science.

5.1 Scientific requirements

The management of oceans and coastal zones necessitates the continuous monitoring of oceanic and atmospheric conditions. The foremost requirement here is for networks of land-based and sea-based observatories. Monitoring the dynamics of deep water masses, especially in the North Atlantic source region thermohaline circulation, will provide data for early warning of climate change consequences: this task requires the deployment of autonomous deep drifters. To map and survey the sea floor, the requirements are for high performance sub-bottom profilers, ultrasound spectroscopy and deep sea observatories. New impetus for ocean drilling, especially in the context of ODP/ IODP, is conditioned by the development of riser technology and down hole logging tools. Specific instrumentation is needed for short and long-term measurements to give, in real time, a complete picture of the dynamics of the most sensitive parts of the sea floor where geological hazards may occur. With regard to measuring marine life, relative estimation methods to estimate abundance and composition have to be replaced by technological solutions reflecting links or competition between organisms as well as relationships between marine life and the physical environment.

Innovative technology has to meet the following specific needs:

- to record short-term environmental consequences of normal fluctuations and catastrophic events;
- to enable data acquisition over long periods;
- to increase the accuracy of the data needed by models and enable the measurement of new parameters, in particular in the biological field;
- to access data in real-time and enable the standardisation, calibration and validation of data for purposes of integration and intercomparison;

- to guarantee the reliability of data acquisition, processing and rapid delivery, which will be increasingly needed for socio-economic assessments, decision-making and public awareness.

5.2 Measurements and constraints

In the marine environment, there are three main modes of data acquisition: moored platforms (seafloor observatories, buoys), autonomous platforms (drifting buoys, actively propelled systems), air- and ship-borne and towed instrument packages. All systems have to meet severe technical constraints. The design of autonomous data acquisition systems must take into account the needs of interdisciplinarity, energy supply, bi-directional data transfer in real time over long distances. For sensors, modern requirements are the ability to measure nutrients and pollutants *in situ*, long-term autonomy between sessions of maintenance, standardisation of interfaces with host system. The design of new sensors will take advantage of recent innovations in nanotechnology, medicine and molecular biotechnology. Data transfer and management have their specific requirements of the utmost importance and have to be considered at the earliest stage in the development of any scientific equipment.

5.3 Models and limits

Understanding the complexities of ocean currents and their role in the transport of physical, chemical and biological components is impossible without resorting to computer simulations. 3D models integrating all these parameters represent the only possibility of creating a quantitative and complete picture of active processes in the sea. To be effective, these models and their outputs should be in a format which easily facilitates their integration in decision-making systems. The present standard of modelling requires access to the highest performance computers available.

The need is for a hierarchy of models starting from the deep ocean models (Global/Atlantic/Mediterranean), providing boundary conditions for shelf-wide models, which in turn provide boundary conditions to high-resolution local models (for example the southern North Sea or the English Channel). Given models and observations, data assimilation (being the interface between them) is the third essential component of information systems.

To summarise, the main objectives for a forward-looking technology should be to:

- integrate the most advanced progress in the domains of communication, computers, medicine, optics, biomolecular technology, new materials and nanotechnology;
- assess carefully how existing technology might fulfil the scientific requirements;
- tune up technology developments with the involvement of SMEs and promote a European market;
- identify gaps in technology which are problematic and the time scale to fill them;
- improve cooperation between research institutes, the industrial sector and the defence sector for technological transfers and developments necessary to the implementation of European and international programmes.

6. Research infrastructures

From its long maritime history, Europe has inherited many assets in marine research infrastructures: (1) an active and diverse network of scientific institutions: academic laboratories, mission-oriented national institutes, marine stations which have developed throughout the last century with a well trained workforce; (2) important national research facilities: fifty oceanographic vessels longer than 50 m., two scientific submarines, remotely and automated operated vehicles, ocean observation satellites (ERS 1 and 2, SPOT, Topex Poseidon); (3) industrial successes in developing high performance infrastructures equipment for offshore exploration and exploitation and for seafloor surveys.

Research infrastructures are taken to include research vessels, *in situ* buoys, landers, satellite and aerial reconnaissance systems, pressure and test chambers, calibration facilities, data processing and management facilities, research centres and the specialist staff necessary to operate them.

Several aspects need to be considered when developing a European strategy for the management of these facilities:

- the costs: 50% of the overall national European budgets of marine research are dedicated to developing and running the infrastructures.
- organisational and attitudinal changes raised by the development, the management and the use of new research infrastructures;
- the international dimension;
- the impact of monitoring and evaluation.

Ways and means to improve the fabric of European research infrastructures were given high consideration by the European countries at two conferences: EurOCEAN 2000, in Hamburg (29 August-2 September 2000), and the Research Infrastructures Conference in Strasbourg (18-20 September 2000). These were also the subject of a temporary working group of six European countries, which was established at the initiative of France.

At these conferences, the participants confirmed that the provision of first class research infrastructure is of prime importance for the success of marine science, both in Europe and internationally, and recommended **that an overall European strategy on marine research infrastructure be defined and implemented**. These objectives imply the development of appropriate mechanisms to fund, share and access such facilities, bearing in mind the increasing cost of running large-scale and highly specialised infrastructures. New information technologies, such as the Internet and World Wide Web, should be used to provide virtual inventories and pools of the available marine research equipment.

More specifically, the recommendations from these discussions were as follows:

1. promote, as soon as possible, coordination in Europe on the identification of the needs and the building of new dedicated research vessels and large-scale facilities. This should prevent gaps and duplications in marine infrastructure capabilities.

2. Promote European concerted approaches in the requirements of internationally agreed science programmes for infrastructures.

3. Develop appropriate long-term funding mechanisms to provide ocean observation systems, such as the Continuous Plankton Recorder, a European Network of Ocean Data Buoys, a facility to operate satellites for operational oceanography, a network of European flagship sites for marine biodiversity.

4. Evolve common standards for evaluating scientific proposals and for operations, performances as well as safety procedures.

5. Improve the coordination of existing and new data collection; assemble the data into European common databases (sediment cores, seismic and high level bathymetric data, etc.) and make them available to researchers for value added processing and new analysis.

6. Establish and support networks of regional marine research facilities, and networks of competence and expertise, with EU Framework Programme and Structural Funds support.

7. Review the role of industry in collaborative projects, particularly in the context of industry, especially SMEs, providing cost-efficient services/equipment to these projects.

8. Develop highly skilled human resources required by the use of new technology: promotion of training, mobility of scientists and technicians, in order to share experience and best practice in the operation of large scale facilities at European level.

These initiatives, driven by the European added-value principle, should contribute to the building of a European network of marine research infrastructures although most of them would still remain nationally organised. In this context, robust electronic networking through the interconnection of national structures, and a political will at European level, are absolute prerequisites.

7. A new era for European marine research

European marine science presents a fertile opportunity as test case to validate the European Research Area (ERA), recently proposed by the European Commission to strengthen the coherence of research activities and policies conducted in Europe. The ERA will require the full application of the principles of European added value and complementarity between the research activities of the EU and its member states.

7.1 Research activities

The implementation of the five scientific challenges identified by the ESF Marine Board will require as appropriate:

- Networking and coordination of national programmes: making full use of the national and regional potential and taking into account their specificities.
- Evolving large-scale targeted projects of a European dimension through:
  - clusters of regional projects;
  - integrated European research programmes;
  - focused research projects of multidisciplinary and regional dimensions;
  - networks of European scientists and laboratories from the public and private sectors.
- Leading/participating in large-scale programmes of an international dimension for enhancing European complementarities and competitiveness.
- Stepping up innovation with industry, including SMEs, as an essential component of research projects from the design phase to the dissemination and the exploitation of the results.

Appropriate mechanisms of cooperation for the overall coherence of these research activities being implemented at different levels will have to be developed.

7.2 Research infrastructures

Research infrastructures are taken to include the facilities required to carry out research projects ranging from research vessels to satellites, data processing and management facilities, and the specialist staff necessary to operate them.

A European strategy for marine research infrastructures is missing. This hampers the optimal use of the existing facilities and limits the development of new equipment such as ocean observing-systems and seafloor observatories.

7.3 Human resources

A sound policy of human resources is an essential component of a European marine research area. Some of the issues are to:

- attract young people, in particular women, to embark on careers in marine research;
- facilitate the mobility of scientists within Europe, and outside Europe including developing countries;
- bring together communities from industry and academia with potential common interests;

[8] *Making a reality of the European Research Area: guidelines for EU research activities (2002-2006)*; Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions, COM (2000) 612 final.

7.4 Science, society and citizens

Public awareness of the oceans, of their importance to mankind, of the complex issues raised by their exploitation and protection appears to be increasing in Europe.

Support of policy making

- expert panels to provide strategic science-based advice;
- schemes for advance warning (geological hazards, climate extremes);
- indicators characterising the health of coastal waters.

Science and society

- public awareness, appreciation and education on the scientific challenges of the ocean;
- ethics for the governance of the ocean (assessing the ethics of research projects) and deontology in professional practices such as aquaculture and biotechnology);
- marine science information system.

The recent EC communication[8] recognises that ***"Making a reality of the European Research Area will necessarily be the product of a joint effort by the EU, its Member States and research stakeholders".***

Appendix A
Scientific challenges

1. Ocean climate coupling

1.1 Processes, variability and predictability

Each year, human lives and billions of Euro are lost because of severe storms, floods and other natural hazards that could have been predicted a few weeks ahead. It is estimated that Electricité de France would save 150 million Euros annually if short-term forecasts were 50% reliable. On longer time scales, seasonal to interannual, natural phenomena such as El Niño or, closer to European coasts, the North Atlantic Oscillation (NAO) in conjunction with the North Thermohaline Current (THC), have a great impact on the frequency of storms and the distribution of rainfall. In countries influenced by such interannual variations, droughts and floods can have disastrous effects on agriculture and the economy in general. And finally, on a decadal to centennial scale, greenhouse-induced warming will increasingly impact our societal systems and natural environments, possibly provoking human migrations during the 21st century. These facts challenge researchers, in Europe and in the world, to improve assessment and prediction capabilities.

It is clearly understood now that climate depends on the coupling of atmosphere and ocean and, in polar areas, on interactions of these with ice. One of the main challenges is to understand present-day and past responses of the North Atlantic Ocean to external driving forces. This sector of the world ocean largely determines the climate of Europe, because of the intensity of ocean-atmosphere exchanges that take place in the area. It is the starting zone of the so-called "ocean conveyor belt" that transports energy and heat all over the globe. It is also one of the most complex oceanic areas in the world, due to the different temporal and spatial scales on which the different climate drivers (Gulf Stream, NAO,.etc.) interact with each other. As for the European seas, they too are influenced by variations in climate forcing, either directly or through their link with the North Atlantic.

Bearing in mind the ocean-atmosphere linkage, the objectives of research are:

- **to understand the processes governing ocean currents, air-sea exchanges and sea-air-ice interactions;**
- **to advance short-term warning and forecasting services, through reliable predictions of sea state and oceanic currents and the development of modernised weather service operations;**
- **to implement seasonal to interannual climate forecasts, through the enhancement of global observing and data systems, progress in modelling and the assessment of climate variability on human activity;**
- **to assess and predict decadal to centennial changes, by characterising processes that force climate change on these time scales, obtaining long-term climate records (including past climates) and developing models.**

Meeting these objectives will strongly depend on the existence of suitable networks of observation systems (including satellite-based) and researchers: transatlantic and international cooperation is therefore crucial for the implementation of research programmes. It also requires taking advantage of the latest technological developments, particularly in information technology, that are needed for data acquisition, handling and exchange, and in computers for modelling. Equally important will be the promise of long-term commitments from decision-makers.

Table 3

Climate change: warming estimates revised upwards		
Rise in average temperatures in 2100 in comparison with 1990		
↑	1995 forecast	2000 forecast
	1 to 3.5 °C	**1.5 to 6° C**
Level of CO_2 concentration in the atmosphere in 2100		
↑	1995 forecast	2000 forecast
	500 ppm	**540 to 970 ppm**
Rise in global temperature between 1860 and 2000		
↑	1995 analysis	2000 analysis
	0.3 to 0.6 °C	**0.4 to 0.8° C**
Rise in sea level in 2100 in comparison with 1990		
↓	1995 forecast	2000 forecast
	0.15 to 0.95 m	**0.14 to 0.80 m**

Source: International Panel on Climate Change Report, in *Le Monde* 03.11.00

1.2 Greenhouse gases and the role of the oceans

The need to understand how carbon is cycled through the Earth System – ocean, land and atmosphere - is critically important to the ability to predict future climate change. It has deep implications for the debate about emission controls. Carbon cycle science is at a threshold of new understanding, with the prospects of developing in the next ten years integrated and robust estimates of carbon sources, sinks and fluxes. The reservoir of carbon in the ocean is approximately 500 times larger than that of the atmosphere, and thus the ocean plays a profoundly important role in carbon storage, exchange and burial.

Over the last decade, European marine science has contributed in a major way to the discovery and quantification of new biogeochemical and physical drawdown processes that export anthropogenic carbon to the deep sea.

The new objectives for European research on ocean carbon dynamics should fall under three broad strategies:

- **to reduce current uncertainties in ocean carbon fluxes within the global carbon budget, by focusing on the continental margin (river inputs, carbon cycling in estuaries and shelf seas), upwelling systems as sources or sinks of CO_2, the role of nano-nutrients;**
- **to investigate ocean to atmosphere fluxes of other greenhouse and climate-reactive biogases (methane, nitrous oxide, dimethyl suphide,etc.);**
- **to evaluate, in a manner compatible with environmental and ethical concerns, the feasibility, sustainability and impacts of carbon sequestration options (deep disposal of CO_2, surface fertilisation experiments) being proposed by some industrial nations.**

There is an urgent need for European ocean time series stations to track and distinguish natural from climate/ anthropogenic-driven climate variability in the fluxes of ocean carbon. Novel technologies are available for a renewed research effort (molecular probes, sensors, ROVs, benthic observatories).

2. Sustainable exploitation of resources

2.1 Living resources: fisheries and aquaculture

Resources of the ocean have been exploited commercially for centuries, but harvesting beyond sustainability to the brink of extinction is a feature of our time. Production from aquaculture is growing and still has a large potential for expansion. The requirement to feed a rising world population creates an incentive for overexploitation and uncontrolled cultivation and hence raises the demand for improving the science base of management. The shallow coastal and nearshore marine environments are those which support the greater proportion of renewable resources production. According to FAO, 95% of all fisheries harvests worldwide are from coastal waters.

At present, the management of commercially exploited stocks in European waters is based on scientific advice. The uncertainties inherent in this advice are generally large and the costs to industry and environment are substantial. Obvious limitations in current approaches are due to a variety of causes: imprecise survey methods, the neglect of ecosystem constraints and climatic effects in final resource assessment, erroneous reporting from industry itself.

Aquaculture has in recent decades expanded to become a viable industry, important on a regional scale. It still has a large potential for development, but the risk of negative impacts on the coastal zone is growing. The problems to be faced in developing this industry are complex: they involve several disciplines (ecology, biology, oceanography, technology, economy) and their solution requires European-wide interdisciplinary cooperation.

The objectives of research are:

- **to improve the operational monitoring and forecasting of marine resources through better understanding of the relationship between biological and environmental dynamics on different time scales;**
- **to ensure the sustainability of operational resource management by improving survey assessment and by integrating relevant knowledge of ecosystem functioning and climate fluctuations;**
- **to assess and mitigate the detrimental effects of commercial exploitation of marine habitats;**
- **to develop the biological basis for aquaculture production, including the knowledge of pathologies and the application of genetic engineering;**
- **to counteract negative impacts of industrial aquaculture on the environment.**

Despite substantial achievements of earlier research programmes, the direct application of ecosystem and climate science in order to improve sustainability has been very limited up to now. Future models must enable an ecosystem approach, that is the system from plankton to sea mammals must be considered a unity. Since commercial exploitation can seriously damage the marine habitat and its biological diversity, there is an urgent need for methods to detect and quantify the impacts of harvest and to develop environment-friendly harvesting technology.

With regard to aquaculture, methods to detect and monitor ecological impacts must exist alongside the provision of new technological solutions for industry. Furthermore, industrial development must be made part of a coastal management plan to secure long-term sustainability.

2.2 Non-living resources: hydrocarbons, renewable energies and minerals

Energy

Mankind's ever increasing demand for energy requires that oil and gas exploitation proceeds further into the ocean, beyond continental shelves and well into deep waters. Today water depths of more than 2 500 metres are reached at some locations. In such extreme environments, safety must be the priority, and the risk of undesired environmental impacts is enhanced. In order to meet these concerns, we need research on hydrodynamics to understand the regime of surface and bottom currents, on sedimentology and geophysics to assess continental slope stability, on methods to prevent or fight pollution from oil spills and accidents on platforms.

Furthermore, the possibility of new energy resources in the marine domain must be investigated. Such a potential resource is the huge amounts of methane stored as gas hydrate in the sediments of continental margins. There are other reasons to investigate these hydrates: rapid climate changes in the past have been partly attributed to the release of methane from the destabilisation of gas hydrates; it is also assumed that large-scale submarine slope slides can be triggered by their decay, and *vice versa*.

In parallel with research related to hydrocarbon exploitation, a renovated approach to energy production follows from the demands of the Kyoto Agreement to significantly reduce CO_2 production. Renewable energies (with zero CO_2 production) such as offshore wind and wave, and to a lesser extent geothermal and tidal energy, represent an alternative source capable of contributing to Europe's energy needs in the twenty-first century. The western margin of Europe has one of the highest wind and wave energy climates in the world. The development of renewable energies from the sea represents not only a scientific and technological challenge for the EU but also a valuable technological niche market.

Minerals

Twenty or thirty ago, a number of scientists and industrial consortia were actively engaged in research on the potential of deep sea minerals (mainly the so-called manganese nodules, also cobalt crusts and various deposits of base metals). Although the economic and political context makes the exploitation of most of these deposits unlikely in the medium term, interest may be revived at some point in the future.

In contrast with deep sea minerals, there is a growing demand for sand and gravel from the near offshore for use in construction, road building, beach nourishment and infill. Large-scale aggregate extraction commonly alters the dynamic system of seafloor sedimentation and poses a threat to the marine ecosystem.

In this wide-ranging and diversified area of non-living marine resources, research will focus on:

- **hydrodynamics, sedimentation and slope stability on continental margins, in areas explored by the hydrocarbons industry; (see also Challenge No. 5);**
- **the possible significance of gas hydrates as a new energy source;**
- **the behaviour, transport and biodegradability of pollutants from oil and related substances;**
- **renewable ocean energy technologies, their economic and environmental contributions to society, their environmental interactions;**
- **in the context of near shore minerals extraction: the mechanisms of transport of sand and clay, the use of aggregates for coastal protection, the environmental interactions and consequences of exploitation.**

In anticipation of possible activities on the deep sea floor (mining of minerals and the possible future re-emergence of a disposal option in the ocean), serious consideration would have to be given first to the environmental impact of operations. Carefully designed experiments, requiring the development of observing systems, are mandatory.

Current concerns about conventional energy sources and emissions should provide an incentive for stepping up research on renewable ocean energies.

3. Health of the coastal zone

3.1 Management and protection of the coastal zone

The European continent has 89 000 km of coastline and its economy is increasingly dependent on resources in the coastal zone[9]. For example, tourism in coastal areas represents about half of the activities of the sector in the EU, and marine aquaculture relies on the availability of feeding grounds in estuaries. A healthy environment is required for these industries to survive.

The coastal zone is constantly exposed to natural forces of change (waves, currents, sedimentation etc.) Especially in areas of low topography, the consequences of Global Climate Change (sea level rise, storms, wave height) are likely to be increasingly felt. However, it might be the build up of social and economic pressure that will most affect coastal areas in the years ahead. The rapid growth of populations, multiple uses of resources and competing interests provoke habitat destruction, water pollution and significant alterations in the biology and chemistry of coastal areas. Coastal seas are increasingly invaded by toxic algal blooms and by proliferation of harmful bacteria and virus, largely as a consequence of excess input from farming and industry in catchment areas. Fisheries can have a detrimental impact on fragile and even robust marine environments.

When the coastal zone and its ecosystems are degraded as the result of unplanned or poor management, there are two options for rehabilitation: to restore the original ecosystem or to modify the remaining ecosystem in order to sustain an alternative use.

The ultimate result of conflict between Man and Nature is to "freeze" the coastline in a state that excludes natural fluctuations and its capacity to adapt to evolving socio-economic pressures.

There is also a cultural dimension to the coastal zone: it is important to remember here that European coasts and the adjacent sea floor display a rich heritage of archaeological and historical sites.

The central objective of research is to provide a scientific background for Integrated Coastal Zone Management. The main topics should be:

- **to protect coastal marine biodiversity and ecosystems from damage arising from human activity;**

[9] According to the European Environment Agency (EEA), of the 25 least economically developed countries in the EU in 1983, 23 were coastal areas; 19 remained so in 1996.

- **to promote water quality in catchment and coastal areas, and control the impact of fisheries, in order to ensure the sustainability of resources including tourism and the dynamism of economy. More particularly, in the interest of public health, it is important to prevent the occurrence, or mitigate the adverse effects, of virus, bacteria and toxic algae in coastal waters;**
- **to meet public concerns over the discharge and dispersion of various kinds of waste (effluents, oil spills, residues and pollution arising from the exploitation of sands and gravel);**
- **to protect sensitive stretches of the coastline against erosion, excess sedimentation and the consequences of extreme events;**
- **to promote the preservation and valorisation of a large part of the European cultural heritage.**

Coastal authorities are in need, above all, of forecasts of events such as pollution peaks and algal blooms. Data sets of hydrological, biological and chemical variables will be integrated in large-scale forecasting systems. Applications of forecasts and of research results must be based on rigorous boundary conditions and end users should be encouraged to focus on their specific needs: this can be approached through the study of test cases.

Maintaining the integrity of the coastline and the health of coastal ecosystems, ensuring the sustainability of coastal resources, are challenges requiring that decision-makers and the public be made aware of the issues at stake and of possible solutions. Keys to improved decision-making in the coastal zone are: forecasts, interdisciplinarity, the ability to manage risks, and the formation of partnerships with representatives of land-based activities.

3.2 Marine biodiversity

Biodiversity is the sum total of genes, species and habitats in the environment. Genes exist within species, species exist within habitats and landscapes, and the evolution, maintenance and change of biodiversity is therefore an extremely complicated set of interactive processes occurring at different levels of biological organisation, from the gene to the ecosystem.

Because life originated in the sea and more than half the animal phyla are restricted to the oceans, the genetic patrimonium of the oceans is far greater than that of land. The new tools of genomics will allow the better description and use of this genetic patrimonium in the decades to come. The search for new genes and their products is just beginning and this area will see an enormous expansion, with many important applications for industry, medicine, food and industrial production through genetic engineering and biotechnology. For the ecologist the challenge will be to link genes (and species) to ecological functions such as photosynthesis, nitrogen fixation, de-nitrification, sulphate reduction etc.

Appendix A
Scientific challenges

The discovery of new life forms goes on at an unrelenting pace. For some years it has been known that viruses are extremely abundant in sea water and probably regulate bacterial populations and therefore an important part of the carbon cycle in the oceans. The application of modern molecular and analytical tools has allowed the discovery of many new species and even entirely new groups of photosynthetic organisms less than 3 ìm in size. Molecular biological analysis has required a complete revision of the phylogeny of bacteria and new bacterial groups are discovered nearly every day with as yet undescribed and unknown functions, in special habitats such as the deep biosphere, cold seeps, coastal muds, or as symbionts and pathogens of higher organisms. But also among plants and animals our knowledge of existing species is far from complete. European waters are among the best studied in the world and a long-standing tradition of taxonomic expertise exists, but cautious estimates are that even in Europe perhaps half of the marine animals are yet to be described. Most of those are from the deep ocean floor, but also an incredible variety of transparent, bioluminiscent animals exist in mid-depth waters of the open ocean; these have been observed from submersibles, have been seen on television screens worldwide but have yet to be caught and examined by scientists.

One of the great challenges posed to European marine science is therefore to make an inventory of what biodiversity exists, where it exists and why it exists. Without such a baseline against which changes have to be judged it will be extremely difficult to develop sound management of marine ecosystems and sustained exploitation of marine resources. A lot of information often already exists but the problem is to bring this together and to establish the spatial and temporal patterns of marine biodiversity in Europe, including genes, species and habitats. This baseline information has existed in geology and terrestrial ecology for more than a hundred years but is still unavailable for the marine environment.

Unravelling the functional role of biodiversity will be the next great challenge. Marine organisms play a crucial role in almost all biogeochemical processes that sustain the biosphere, and provide a variety of products and functions that are essential to mankind's well-being, including the production of food and natural substances, the assimilation of waste, the remineralisation of organic matter and the regulation of the world's climate. The rate and efficiency of any of the processes that marine organisms mediate, as well as the range of goods and services that they provide, are determined by interactions, between organisms, and between organisms and their environment, and therefore by biodiversity. These relationships have not yet been quantified, and we are at present unable to predict the consequences of a potential loss of biodiversity resulting from environmental change in ecological, economic or social terms. Any investigation will have to include a assessment of the potential of species to adapt and evolve, and of the potential of species communities to be robust and stable. This requires addressing biodiversity at different levels of biological organisation.

To summarise, the main objectives for research on marine biodiversity should be to:

- **undertake targeted inventories of biodiversity in European seas;**
- **understand the functional role of biodiversity;**
- **predict the consequences of a potential loss of biodiversity resulting from environmental changes.**

4. New frontiers in marine life

4.1 Biotechnology

Life originated in the sea, and has sustained itself to the present time. Today the world's oceans comprise the largest habitats on earth and contain the most ancient forms of life. Marine biotopes contain an unmatched metabolic and organismal diversity. Over billions of years marine microbes have molded the global climate and structured the atmosphere, overcoming the obstacles posed by vastly different environments. Knowledge of these successful processes allows today the advent of technologies needed as life in the sea now faces unprecedented threats from environmental changes of natural and anthropogenic sources. We are beginning to understand in molecular terms the continuity of life through time and species. Yet the success or failure of species depends on their unique specialisations, and the large and unexplored diversity of living species is today to a great extent found in the oceans. Only with the tools of modern science can these specific adaptations be understood in detail and thereafter be applied for the benefit of biomedical and industrial innovation, environmental remediation, food production and fundamental scientific progress.

For the last two decades, all the international fora considering strategic challenges in science have identified the marine biotope as the largest untapped area for exploration. Yet to this day no concerted and focused initiative to realise this vision has materialised in Europe. The urgency of the problems in terms of human health, nutrition and environmental impact, and also the new capacity to understand biodiversity and balanced reproduction, add to the attraction and potential of a European programme. Current events and needs suggest that now is the time for such action.

The combined expertise of many fields, from biology to chemical and physical oceanography, will be needed in order to understand how life and its reproduction are shaped by the parameters of the marine biotopes. A European initiative will integrate these activities, achieve clear synergies, and exert wide appeal on industry, biomedicine and society at large. A common European endeavour in marine biotechnology will challenge a new generation of young scientists, now dispersed in different countries, to contribute their talents and energy to the field and thus ensure its success.

Key objectives of a science plan to be developed for a programme are to:

- **bioprospect for novel compounds in selected marine organisms and habitats;**
- **develop knowledge to establish new fundamental bioprocesses for bioproduction;**
- **develop products and processes in marine environmental biotechnology;**
- **utilise molecular approaches to assess biodiversity and exploit marine genetic resources;**
- **establish advanced cultivation methods for marine organisms and cell lines.**

4.2 New ecosystems

Interest in the origin of life on Earth and the prospects of life on other planets has accelerated in recent years and has gained great public awareness. Some hypotheses[10] consider that the conditions of high pressure and temperature at the origin of life still exist today on Earth, implying that it should be to observe the processes of creation of life in the Ocean. Whereas life has been explored and found everywhere on the surface of our own planet, the deep sub-surface was until recently considered to be influenced only by abiotic processes. The discovery of micro-organisms in several million-year-old sedimentary deposits and even in basement rock has profoundly changed our perspective of the limits of living organisms. It is now clear that processes in the geosphere may provide the driving force for life and that, *vice versa*, the sub-surface biosphere has a large impact on present geological processes.

The emerging fluids of cold seeps in subduction zones along continental margins are chemically modified by deep bacteria just as the fluids of hydrothermal vents along mid-oceanic ridges are modified by geothermal processes. Both fluid flows have a major influence on modern ocean chemistry. The slow biological degradation of organic carbon in the deep sub-surface and the formation of huge quantities of methane have a large-scale impact on seafloor processes, such as the accumulation of gas hydrates or the formation of carbonate mounds along the European Atlantic margin. There is an intriguing association between a large province of carbonate mounds, actively explored hydrocarbons basins and surface expressions of fluid flow.

The current database on the distribution and abundance of bacteria in sediment cores obtained from the Ocean Drilling Program (ODP) indicates that this newly discovered biosphere may comprise 10% of all living biomass on Earth. The population densities (10^5-10^7 cells per cm^3 down to >750 sediment depth) are of similar magnitude as those found in ocean water. The organisms in this deep and extreme environment have applied significance, for example, for the formation and exploitation of fossil fuels (oil, gas, gas hydrates), deep burial of toxic wastes, and as source of unique bacteria for biotechnology.

European scientists were in the forefront in the early exciting discoveries which are now the basis for

[10] Günter Wächtershäuser, La Recherche, 336, November 2000, pp. 109 - 111

international initiatives. Future research will require a multidisciplinary cooperation in order to use and further develop advanced technological facilities, for example mapping, coring and sampling of the sea floor. Novel concepts and new analytical and experimental methods are required for the study of these microscopic prokaryotes, as we do not even know which are the dominant organisms, how they maintain basic life processes, or what are the relevant physical-chemical properties of their habitat.

Among the main objectives of a European research effort should be:

- **to explore the limits of the sub-surface biosphere with respect to depth, temperature, energy availability and other properties of the habitat;**
- **to study unique habitats such as cold seeps, gas hydrates, oil reservoirs, deep brines, mud vulcanoes and carbonate mounds;**
- **to identify the dominant organisms and their biomass, diversity and ecophysiology;**
- **to study microbe interactions with minerals and other potentially energy-providing interfaces;**
- **to search for novel types of prokaryotes with unique properties.**

In order to fulfill these objectives, new strategies must be promoted:

- **identification of targeted areas and habitats for international cooperation;**
- **development of new facilities for sampling, experimentation, and observation;**
- **development of *in situ* technologies and undecompressed laboratory incubation systems;**
- **initiation of interdisciplinary research programmes which include biogeochemistry, microbial physiology and environmental genomics.**

5. New frontiers in ocean margin systems: seafloor studies

The continental margin is a critical environmental interface – a fundamental Earth discontinuity – where terrestrial, marine and atmospheric processes converge and mutually influence one another across a number of spatial and temporal scales. In a broad sense, the margin comprises the coastal zone, the continental shelf and, on its seaward fringe, the continental slope, leading down to the deep abyssal plains. Compared with the open ocean, the margin is the site of greatly enhanced marine processes: biological productivity, cycling of carbon and nutrients, sediment transport and deposition.

This challenge on new frontiers in ocean margin systems is focused on a number of geological and geochemical processes at work on the sea floor. The coastal zone is the subject of Challenge No.3-1. The role of the continental margin in the global carbon cycle and in biological productivity is addressed in Challenges No.1-2 and No.2-1, while novel aspects of seafloor macro- and microbiology are mentioned under Challenge No.4-2.

There exist two types of continental margin: active (or convergent) and passive (or rifted). Both types occur around the European continent. In the Northeast Atlantic, the margin is passive, resulting from the break up and drifting apart of Europe and North America. In the Mediterranean, although the pattern is complex, one should at least mention the active margin of Greece and Turkey, where sediments are caught and compressed in the northwards subduction of the African plate; this region is particularly exposed to seismic risks.

Continental margins are the most significant areas on earth for sediment transport and deposition. Sediments originating on land and on the shelf are deposited on the slope and accumulate as fans on the deep sea floor. The NE Atlantic and Mediterranean margins are deeply incised by a series of canyons, which tend to channel the transfer of sediments and of water masses. There is abundant evidence of slope failure and submarine landslides, sometimes on a huge scale. For example, the Storegga slide, off the coast of Norway, affected an area of 52 000 km^2 and displaced a volume of 5 600 km^3 over 800 km.

Oil companies exploring those areas are confronted with a wide range of geohazards: slides, earthquakes, sudden releases of gases or methane from hydrates. Geohazards on margins have an impact on many other activities as well, such as cable laying, underwater communication, and fishing.

Evidence for widespread occurrence of fluid flow from continental margin systems has accumulated during the last decade. These fluids influence water quality in the coastal zone and are a potential resource for human needs (aquaculture, water desalination, irrigation); they control the release of methane into the ocean, the formation of gas hydrates and the development of unique macro- and microbiological communities at discharge sites. Not enough is known about their size and composition, their role in redistributing chemical elements and how they affect slope stability.

The main objectives of research are:

- **to reconstruct the geometry and evolution of sediments on active and passive margins by applying the modern concepts and technologies of earth sciences (stratigraphy and geophysics);**
- **to assess the role of canyons in focusing and enhancing processes: (upwellings, turbidity currents and mass wasting);**
- **to assess hazards associated with European margins: location, triggering factors (earthquakes, gas hydrate releases), prediction;**
- **to investigate the distribution and volume of fluid vents and seeps at margins, and assess their role in marine processes;**
- **to prevent, investigate and counteract detrimental effects of hydrocarbon exploration/ extraction on the sea floor;**
- **to monitor seismic activity at active margins.**

Forward-looking technology

Marine science and technology are becoming increasingly interdependent. New cutting-edge knowledge is often directly related to technological breakthroughs. It may be less obvious for the scientific community that technological innovation is closely linked to high level basic research. Until recently, science was driven by the need to **describe the past** and to **understand the present** by gathering isolated snapshots of the oceans. Today the main challenge faced by marine science and technology is to **predict the future**, for the purposes of sustainable marine management, ocean forecasting and coping with climate change. The need is now for global 3D and 4D data sets of the oceans to understand the dynamics of the processes, hence a significant strategic change in the way we conduct our science.

Progress in robotics, computers, miniaturised technology and data transmission offers unique new opportunities which have to be fully exploited to address the needs of marine science.

1. Scientific requirements

Some specific needs which have to be fulfilled by new technology are the following:

- **to record the effects of short-term environmental events resulting from normal fluctuations and catastrophic events;**
- **to acquire long time-series of data;**
- **to increase the accuracy of the data needed for the models and measure new parameters, in particular in the biological field;**
- **to access data in real time and enable standardisation, calibration and validation of data for purposes of integration and intercomparison;**
- **to guarantee the reliability of data acquisition, processing and rapid delivery, which will be increasingly needed for resource management and decision-making processes and public awareness.**

1.1 Oceans and coastal zone management

"In the marine environment, some phenomena such as tidal cycles have been predicted on the basis of scientific understanding for many years. Increasing skill is being shown in predicting short-term variations resulting from some classes of interaction between the ocean and atmosphere. On the other hand, many features of the actual oceanic circulation are not easily measured and, as a result, neither well understood nor fully predictable. The possibility of creating operational oceanographic information services that lessen uncertainty, improve the efficiency of management and minimise the cost of damage, is appealing, provided that the benefits achievable in practice

exceed the cost of those services. There is no hope of creating such services unless they are based on a sound, numerate scientific understanding of the phenomena concerned. Such understanding demands data."

Citation from the GOOS Prospectus, 1998

Due to the increasing socio-economic pressure on the oceans and the coastal zone, special attention should be paid to the technologies required for their sustainable management. We know that the coast is routinely affected by adverse events damaging property and natural habitats, harming fisheries, tourism and local economies. Land-based and sea-based networked observatories should be deployed to continuously monitor oceanic and atmospheric conditions.

Dissemination and interpretation of measurements of the seas, oceans and atmosphere is needed to: (1) assemble long-term data sets (climatic, physical and biological) which will provide data for description of past states, and time series showing trends and changes – hindcasting; (2) provide the most useful accurate description of the present state of the sea including living resources – nowcasting; (3) provide continuous forecasts of the future condition of the sea as far ahead as possible – forecasting.

1.2 The Ocean interior

The dynamics of deep water masses are critical factors controlling climatic changes and should be monitored. Key regions for routine measurements include the Strait of Gibraltar, the Mediterranean and the source regions for the thermohaline circulation in the North Atlantic. In particular, the deployment of measurement networks in the North Atlantic could be of significant importance for setting up an early warning procedure with respect to climate changes.

Quantitative measurements of temperature and salinity profiles as well as current fields can be obtained by deployment of different kinds of autonomous platforms, for instance floats, gliders and fixed profiling instrument carriers.

1.3 Mapping the seafloor and investigating the sub-seafloor

Multiparametric and high resolution sub-bottom profilers are the most modern instruments for measuring the structures and layers of ocean sediments from a moving ship. The location of methane hydrates trapped in the ocean floor and of the gases released from sediments, can also be recorded echographically with ultrasound spectroscopy.

Drilling into the ocean floor for close to thirty years has considerably accelerated our understanding of the dynamics of the Earth. High resolution drilling to track climate change in the sediments and deep oceanic drilling require new technology including down hole logging tools, risers for deep drilling, recovery of high resolution stratigraphic sequences.

Specific instrumentation is needed for short- and long-term measurements to give, in real time, a complete picture of the dynamics of the most sensitive parts of the sea floor where geological hazards may occur.

1.4 Measuring marine life

Due to the difficulties in measuring marine life directly, scientists have traditionally been happy to track changes through time. For better understanding and modelling of the ecosystem, relative estimation methods of abundance and composition have to be replaced by technological solutions reflecting links and competition between organisms as well as relationships between marine life and the physical environment. Special challenges are to extend observation methodologies to greater ocean depths where our present knowledge is very limited, to develop efficient technological solutions for observing marine bottom habitats and distribution, and to estimate the abundance of bottom dwelling/digging organisms.

Miniaturisation of technology opens the way for putting together advanced sensors systems, installing them on adequate platforms (including using the organisms themselves as a platform) that can observe marine life and their surrounding environment in much more detail than before. Such approaches are far from being fully exploited today.

2. Measurements and constraints

Generally, data acquisition from the marine environment is achieved in three main ways: moored platforms (seafloor observatories, buoys); autonomous platforms (drifting buoys, actively propelled systems); air- and ship-borne and towed instrument packages. The development and use of these facilities are facing several technical constraints.

2.1 Autonomous data acquisition systems

The scope of these systems is global and multidisciplinary, including those that span the air-sea interface, the entire water column, and the solid earth below. The development of autonomous data acquisition systems to be remote controlled by scientists or operated automatically, and able to carry out increasingly sophisticated tasks, is still constrained by several problems:

- Observatories need to be designed taking into account the requirements of multidisciplinarity, so as to enable scientists to deploy different instruments on the same infrastructure.
- The long-term deployment of autonomous systems is limited at present by the insufficient capacities of available energy systems. The mean time between maintenance should be increased by using energy management systems and sub-systems requiring low-energy demands.
- Bi-directional data transfer over long distances in real time is needed

to control, pilot and evaluate the measuring instruments, and is therefore a requisite for ocean forecasting. In the case of imaging equipment, wide-band data telemetry is needed to accommodate the required picture transfer. To achieve this purpose further development in the field of acoustic and optical methods has to be undertaken.

2.2 Sensors

Sensors are the basic components of all instrumentation systems and sensor development has to comply with scientific strategies. Long-term, high quality measurements will be needed by the future permanent monitoring networks foreseen in various disciplines.

Sensing the environment is of great concern. Emphasis should be put on new sensors to measure *in situ* nutrients and main pollutant concentrations. Recent progress in genetic research should be applied to the development of new biological sensors for the detection of harmful algal species, taking advantage of recent innovations obtained in sectors and disciplines such as medicine and biomolecular technology.

Observation of marine life is characterised by under-utilisation of advanced acoustic and optic systems. Multifrequency and broad band acoustic systems (calibrated multibeam systems, parametric sonars) can potentially give quantitative information about density, size and species of marine life from the smallest plankton to the largest fish.

Special care should be paid to sensor integration in order to minimise their vulnerability to biofouling and to improve the quality and the reliability of the delivered data.

Combining acoustic and visual observation systems with physical sensors might create new powerful instrumentation that will improve reliability, temporal and spatial resolution, and not least, reduce the demand for expensive biological sampling.

Standardisation of interfaces (physical, electrical and communication) between sensors and host systems should be strongly encouraged to improve the flexibility and the adaptability of sensor systems.

2.3 Satellites

Major progress has been achieved during the last twenty years in using satellites to remotely sense the Earth and the ocean. Satellites now play an essential role in monitoring and detecting changes, and ocean forecasting would not be possible without the extensive use of satellites. Satellite data are also used to feed numerical models in order to understand and predict possible changes, and for independent verification of model performance.

The design of new satellite missions is often so large and of such broad interest that it has to be managed in the framework of European and international programmes. Due to the large timescale and high cost of developing a new mission, efforts should be made to promote concerted actions between all interested parties, in particular when there are possible overlaps between the interests of several European research programmes.

2.4 Data management technology

Data management has to be considered at the earliest stage in the development of any scientific equipment in order to:

- **define the scientific criteria for data management and delivery (specifying quality assurance, quality control standards and comparability);**
- **organise the fastest data transmission to data centres and end users;**
- **ensure reliable data archives;**
- **advise on all aspects of numerical modelling, data assimilation, and model validation.**

3. Forecasts: models and limits

Understanding the complexities of ocean currents and their role in the transport of physical, chemical and biological components is impossible without resorting to computer simulations. Three-dimensional models integrating all these parameters represent the only possibility for creating a quantitative and complete picture of active processes in the sea. To be effective, the outcomes of these models should be in a format which easily facilitates their integration in decision-making systems. The present standard of modelling requires access to the highest performance computers available.

The need is for a hierarchy of models starting from the deep ocean models (Global/Atlantic/Mediterranean), providing boundary conditions for shelf-wide models, which in turn provide boundary conditions to high-resolution local models (for example the southern North Sea or the English Channel). Given models and observations, data assimilation is the third essential component of information systems.

For physical models we currently lack: (1) “open boundary” conditions needed for limited-area numerical models; (2) appropriate forcing data fields (winds, air pressure, etc.); (3) geographical coverage of measured data on the global scale, but also regionally, and in sub-surface in particular. Realistic modelling of the biological systems needs an upgrade of observations on temporal and spatial dynamics, covering biological characteristics (density, growth, sex, maturation etc.) as well as behavioural and migration dynamics. Interaction between physical and biological models is essential for reliable biological forecasting. Precise forecasting of marine ecosystems is particularly needed for management of harvested resources but it is still in its infancy.

To address the major objective of forecasting the ocean and the marine ecosystem, Europe lacks:

- computer power and high speed access systems enabling a network of computing services and models;

- deployment of European large-scale arrays of measuring systems throughout the Atlantic and Mediterranean;
- funding mechanisms for a series of operational ocean observing systems in the next ten to fifteen years.

4. E-marine science: a new dimension

Information technology in marine science, the so-called "e-marine science", is beginning to play a major role in the way of thinking ahead and carrying out research. In a number of circumstances, the impact of e-marine science would be extremely beneficial: monitoring and observing systems over large geographic areas; pooling computing capacities for climate modelling; bringing together distributed databases; remote operation of sensors.

The development of e-marine science, which requires the pooling of large resources, is a prerequisite to go beyond the current state of art in marine research and has a high European added value.

The deployment of fibre-optic cables on the sea floor offers new visions for marine science. Cables provide two-way real time high bandwidth communication including video. Linked to the Internet, the system gives the scientists the ability to monitor experiments and vehicles from any laboratory in the world. Real-time distribution via the World Wide Web also offers the public and educators a direct link to seafloor observatories. Such cables could be deployed in the European seas or between America and Europe.

5. Links with industry

One of the most critical features influencing any industrial strategy is the perspective of a clear market. For scientific equipment, the market is greatly fragmented and there is a lack of long-term commitment needed in all industrial activities. As a result, there is the problem that industry never reaches the threshold level necessary to start the economic engine. The Sixth Framework Programme should be organised in such a way that marine technology and science could be closely associated and not separated as is presently the case in the Fifth Framework Programme. Initiatives should be taken to link existing European organisations involved in industrial and scientific research. Common research interests could be identified in domains such as renewable energies, new materials, corrosion, biofouling, hydrodynamics and structures.

6. Requirements for human resources

Careful attention should be paid to human resources from the early stages of the development of new equipment to its operation. Sharing experience is essential at a time when technology is becoming increasingly sophisticated. At present there is little opportunity for technical staff and managers to share their experiences in handling existing and new equipment. Scientists should be aware of the limits of the data obtained by new technology and be proactive in developing appropriate methods to process these data, and then be willing to transfer proven successful methods to the community at large.

The successful establishment of new technologies strongly depends on the efficient interplay between all partners involved in the innovative process, the initiating group, industry and future scientific users.

To summarise, the main objectives for a forward-looking technology should be to:

- **integrate the most advanced progress in the domains of communication, computers, medicine, optics, biomolecular technology, new materials and nanotechnology.**
- **assess how existing technology might fulfil the scientific requirements;**
- **tune up the technology with the involvement of SMEs and promote a European market;**
- **identify gaps in technology which are problematic and the times needed to fill them in;**
- **improve cooperation between research institutes, the industrial sector and the defence sector for technological transfers and developments for the implementation of European and international programmes.**

Appendix C

International and regional conventions, and EC directives

International Conventions	Year	Area covered	Objective
Rio (UNCED)	1992	Global	
1. Biodiversity	1992	Global	Conservation and sustainable use of biodiversity
2. Climage change	1992	Global	Climate change
3. Kyoto Protocol	1997	Global	Regulation on CO_2 emission
Vienna	1985	Global	Protection of the ozone layer
Montreal Protocol	1987, 1995		
FAO	1995	Global	Code of conduct of fisheries
UNCLOS (UN Convention on the Law of the Sea)	1982	Global	Law of the Sea
New York	1995	Global	Management of migrating species

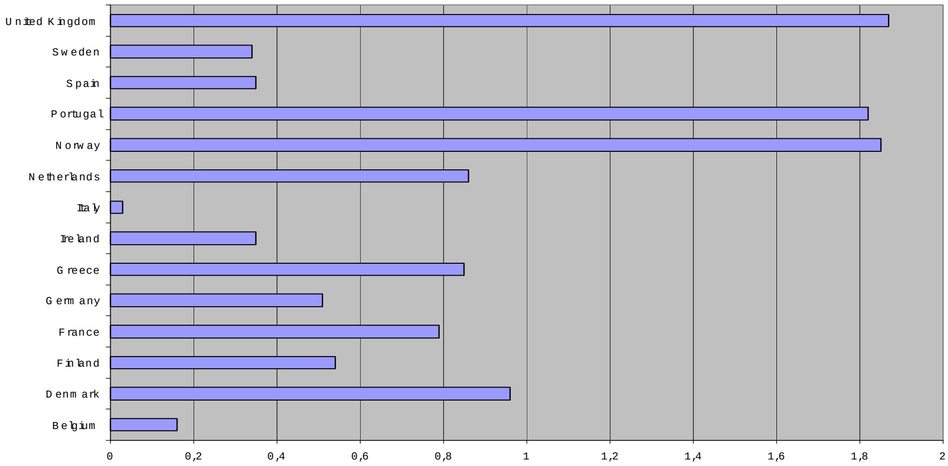
Regional Conventions	Year	Area covered	Objective
Barcelona	1975, 2000	Mediterranean Sea	Protection of the marine environment
HELCOM	1974, 1992	Baltic Sea and Baltic catchment area	Protection of the marine environment
OSPARCOM	1972, 1974, 1992	Northeast Atlantic	Protection of the marine environment
Bucharest	1992	Black Sea	Protection against pollution
Warsaw	1982	Baltic	Fishing and conservation of living resources
Lisbon	1990	Northeast Atlantic	Protection of the coasts and waters against accident pollution

EC Directives	Year	Area covered	Objective
Bathing water	1976	European Union	Good quality of bathing water
Fish and shellfish waters	1978, 1979	European Union	Water quality for fish and shellfish
Habitat and species	1988	European Union	Special areas of conservation, Natura 2000
Water Framework Directive	2000	European Union	
Integrated coastal zone management	Under preparation	European Union	A European strategy for integrated coastal management

Appendix D

Current level of support for marine science and technology

The percentage of European research spending as a proportion of GDP is 1.8%, compared with 2.7% in the USA and 3.1% in Japan. Funding for marine science in Europe is estimated to be of the order of 0.8% of the EU RTD expenses.



Percentage of money spent on marine R&D compared to total investment on all R&D in EU Member States plus Norway

(Source: Spanish Ministry for Education and Culture, EU CREST Committee and OECD)

Appendix E
ESF Marine Board

The European Science Foundation (ESF), in concert with the European Commission has, for some time, recognised the need for improved co-ordination between European marine science organisation and for the development of a strategy for marine science in Europe.

To address these issues, a co-ordinating structure –European Marine and Polar Science (EMaPS)–, was created in October 1995. EMaPS has now evolved into the European Polar Board and the ESF Marine Board.
The principal achievements of the Marine Board have been to:
- facilitate the development of scientific strategies (organising and sponsoring workshops and conferences; publishing position papers);
- improve the shared use of equipment;
- advise on strategic and science policy issues at the European level.

Presently, with its membership of 24 marine research organisations from 16 European countries, the Marine Board has the appropriate representation to be a unique forum for marine science in Europe and world-wide.

Objectives

In developing its activities, the Marine Board is addressing four main objectives:

Forum: bringing together member organisations to share information, to identify common problems and, as appropriate, find solutions, to develop common positions, and to co-operate on scientific issues.

Strategy: identifying and prioritising emergent disciplinary and interdisciplinary marine scientific issues of strategic European importance, initiating analysis and studies (where relevant, in close association with the European Commission) in order to develop a European strategy for marine research.

Voice: expressing a collective vision of the future for European marine science in relation to developments in Europe and world-wide, and improving the public understanding of science in these fields.

Synergy: fostering European added value to component national programmes, facilitating access and shared use of national marine research facilities, and promoting synergy with international programmes and organisations.
Whilst the emphasis is on science, the Marine Board fully recognises the increasing interdependence between science and technology and, as a result, will promote the appropriate technological developments for the achievement of its scientific objectives. In the development of its objectives, the Marine Board shall not be involved in any operational activities.

Structure

The Marine Board operating within ESF is a non-governmental body. Its institutional membership is composed of organisations which are major national marine scientific institutes and funding organisations within their country in Europe. No more than two organisations per country can be members of the ESF Marine Board. It has an Executive Committee, consisting of a Chairperson and four Vice-Chairpersons.

Executive Secretariat

A permanent Executive Secretariat, in ESF and based in Strasbourg, France, supports the activities decided by the Marine Board and its Executive Committee.

Funding

The Member Organisations of the Marine Board contribute annually the funds for the financing of its activities and the running costs of the Executive Secretariat. As appropriate, the Marine Board explores access to other sources of funding.

Activities

The Marine Board has prepared a three-year Science Work Plan, 2000-2002, in order to successfully address its objectives as follows:

- promote the new course of the Marine Board: forum, strategy, voice, and synergy;
- be recognised as the multidisciplinary European science forum;
- identify the need for research in different fields;
- maintain and further develop close links with the European Polar Board, and other groups within the European Science Foundation and other European institutions;
- develop a European consensus on marine research.
- Recognising the value of continuing to produce position papers on science policies and science strategic plans, the Marine Board will focus its unique strategic role on a number of topics.

Membership (As of November 1999)

Austria

- Fonds zur Förderung der wissenschaftlichen Forschung
- Österreichische Akademie der Wissenschaften

Belgium

- Fonds National de la Recherche Scientifique
- Fonds voor Wetenschappelijk Onderzoek - Vlaanderen

Finland

- Suomen Akatemia / Finlands Akademi

France

- Centre National de la Recherche Scientifique
- Institut Français de Recherche pour l'Exploitation de la Mer

Germany

- Deutsche Forschungsgemeinschaft
- Hermann-von-Helmholtz-Gemeinschaft Deutscher Forschungszentren

Greece

- National Centre for Marine Research

Appendix E

ESF Marine Board – membership

Ireland

- Marine Institute

Italy

- Consiglio Nazionale delle Ricerche
- Ente per le Nuove Tecnologie, l'Energia e l'Ambiente

Netherlands

- Koninklijke Nederlandse Akademie van Wetenschappen
- Nederlandse Organisatie voor Wetenschappelijk Onderzoek

Norway

- Havforskningsinstituttet
- Norges Forskningsråd

Poland

- Polska Akademia Nauk

Portugal

- Instituto de Cooperação Científica e Tecnológica Internacional

Spain

- Consejo Superior de Investigaciones Cientificas
- Oficina de Ciencia y Tecnología

Sweden

- Naturvetenskapliga Forskningsrådet

Turkey

- Türkiye Bilimsel ve Teknik Arastirma Kurumu (TÜBITAK)

United Kingdom

- Natural Environment Research Council