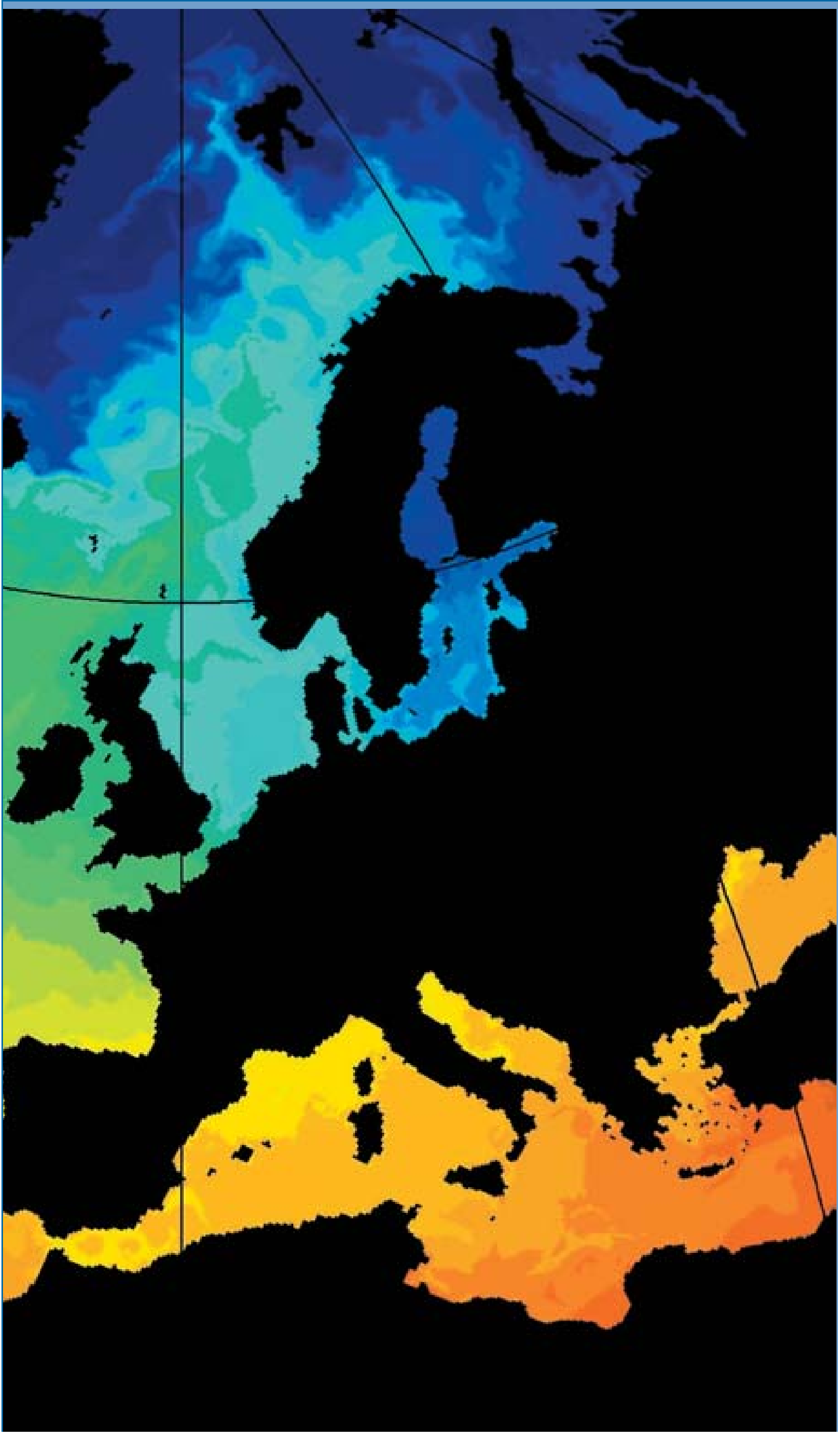
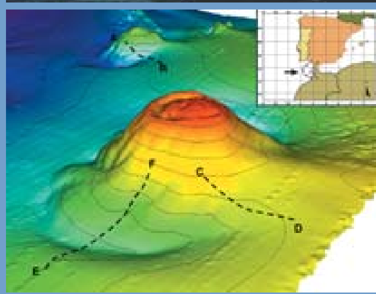
ESF Marine Board Position Paper 5

Integrating Marine Science in Europe





Marine Board

November 2002

The European Science Foundation (ESF) acts as a catalyst for the development of science by bringing together leading scientists and funding agencies to debate, plan and implement pan-European scientific and science policy initiatives.

ESF is the European association of 70 major national funding agencies devoted to scientific research in 27 countries. It represents all scientific disciplines: physical and engineering sciences, life and environmental sciences, medical sciences, humanities and social sciences. The Foundation assists its Member Organisations in two main ways. It brings scientists together in its EUROCORES (ESF Collaborative Research Programmes), Scientific Forward Looks, Programmes, Networks, Exploratory Workshops and European Research Conferences to work on topics of common concern including Research Infrastructures. It also conducts the joint studies of issues of strategic importance in European science policy.

It maintains close relations with other scientific institutions within and outside Europe. By its activities, the ESF adds value by cooperation and coordination across national frontiers and endeavours, offers expert scientific advice on strategic issues, and provides the European forum for science.

ESF Marine Board

The Marine Board operating within ESF is a non-governmental body created in October 1995. Its institutional membership is composed of organisations which are major national marine scientific institutes and funding organisations within their country in Europe. The ESF Marine Board was formed in order to improve co-ordination between European marine science organisations and to develop strategies for marine science in Europe.

Presently, with its membership of 24 marine research organisations from 17 European countries, the Marine Board has the appropriate representation to be a unique forum for marine science in Europe and world-wide.

In developing its activities, the Marine Board is addressing four main objectives: creating a forum for its member organisations; identifying scientific strategic issues; providing a voice for European marine science; and promoting synergy among national programmes and research facilities.

Cover pictures: Map of Europe showing sea surface temperature, © Southampton Oceanography Centre (SOC); AUTOSUB AUV, © Southampton Oceanography Centre (SOC); Mud volcano cluster, © J P Henriet, Ghent University; *Strongylocentrotus droebachiensis* and the cnidarians *Gersemia rubiformis* and *Urticina eques*, © B Gulliksen; Common dolphins, © M Mackey, CMRC-UCC; The French trawler 'Drake' off the north-west of Scotland, © O Barbaroux, Ifremer

Integrating Marine Science in Europe

Editors and Contributors (in alphabetical order)

Jean Boissonnas, Niamh Connolly, Fauzi Mantoura, Laurent d'Ozouville

Editors of the ESF Marine Board Executive Committee

John Marks, Jean-François Minster, Mario Ruivo, Silvana Vallerga

Other Contributors

Avan Antia, Laura Castellucci, Juanjo Dañobeitia, Jens Degett, Bob Dickson, Graham Edgar, Paul Galvin, David Griffith, Gwyn Griffiths, Harlyn Halvorson, Carlo Heip, Jean-Pierre Henriet, Catherine Jeandel, Frank Lamy, Jacques Legrand, Han Lindeboom, Karin Lochte, Jens Meincke, Geoffrey O'Sullivan, Nadia Pinardi, Gérard Riou, Douglas Wallace, Gerold Wefer, John Woods.

"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)

Acknowledgements

The ESF Marine Board is grateful to those member organisations that financially supported the preparatory workshops and working groups, and the publication of the IMS-E Position Paper. Particular thanks are due to the European Commission, EurOcean and the Hanse Institute for Advanced Study and all those involved in the following workshops and working groups, which contributed to this Position Paper:

Preparatory workshops

- Feasibility Study Group on Marine Biotechnology, Galway (Ireland), 25-27 July 2001
- Euroconference *Biodiversity of Coastal Marine Ecosystems: Pattern and Process*, Corinth (Greece), 6-10 May 2001
- Workshop on *Marine Technology Frontiers for Europe*, Brest (France), 26-28 April 2001
- Marine Socio-Economic Working Group, Strasbourg (France), 26-27 March 2001
- Hanse conference *Marine Science Frontiers for Europe*, Bremen (Germany), 18-21 February 2001
- Network on Public Awareness of Marine Science, Strasbourg (France), 5-6 February 2001
- Feasibility Study Group on Marine Biotechnology, Oristano (Italy), 22-24 November 2000
- Hanse conference *Ocean Margins Systems*, Delmenhorst (Germany), 19-23 November 2000
- EurOCEAN 2000 Conference, Hamburg (Germany), 29 August - 2 September 2000

Working groups

- Core Drafting Group of the Position Paper
- Feasibility Study Group on Marine Biotechnology
- Network on Public Awareness of Marine Science
- Socio-Economic Working Group
- Marine Technology Working Group

Sincere thanks are expressed to DG Research of the European Commission for its encouragement to the ESF Marine Board to produce the Position Paper.

Acknowledgement is especially due to all scientists and other experts who have been involved in the preparation and validation processes of the Position Paper.

The skills of the Secretariat of the ESF and the Marine Board were essential during all stages of the preparation and publication of this report and are gratefully acknowledged.

Contents

Appendices

Foreword

The Oceans have always been of major strategic importance for the economic and social development of Europe. Nowadays, it is clear that living resources are finite, and that scientists have an ethical responsibility to disseminate their knowledge towards the effective management of these resources. Coastal seas, adjacent to which two thirds of the world's major cities are located, are heavily impacted by anthropogenic developments, with increasing conflicts between competing uses. The Oceans, which cover 71% of planet Earth, also provide the inspiration for curiosity driven research, with exciting discoveries in domains such as the origin of life and new deep sea ecosystems.

With its present membership of 24 marine research organisations from 17 European countries, the European Science Foundation (ESF) Marine Board provides a unique forum to express a vision for integrating marine science in Europe. This Position Paper *Integrating Marine Science in Europe* (IMS-E) represents an initiative to establish a Europe wide summation of marine research, prioritise recommendations and identify where future scientific challenges lie, while incorporating European societal needs. Its production is the result of in-depth consultation by the ESF Marine Board with all marine science stakeholders, including aspects of socio-economics, technology and research infrastructures. It represents the first summation of the status and priorities of marine research in Europe.

I welcome this original initiative of the ESF Marine Board, stressing the vital importance for Europe to play an active role in global ocean affairs. I particularly welcome the development of, and commitment to, an implementation process, which demands immediate action. The unique validation process adopted, which involved the scientific community, the ESF Marine Board and the ESF itself, strengthens the relevance of the recommendations and insights, ensuring a commitment to implementation.

The Position Paper was developed not as a blue print, but rather as a compass for navigating a common course for individual national and European research programmes. This common course will strengthen Europe's scientific research capacity and competition globally. It will also facilitate an integrated underpinning of European policies in fisheries, sustainable exploitation of natural marine resources, and the management of coastal and oceanic regions.

I want to emphasise two recommendations in this report which are of great relevance to the ESF's initiatives in European research, namely: coordination of research infrastructure, and the improvement in the use of existing research instruments at national and European levels. By addressing European and national research programmes, the Position Paper provides a tool for scientists to interconnect with and influence both. The ESF has offered to play a role in coordination of infrastructure needs throughout European research, and the proposals for implementation detailed in this Position Paper provide a process for furthering this in the marine field.

This Position Paper, which is complementary to the ESF Scientific Forward Looks and EUROCORES instruments, and the strategy papers of the ESF expert committees, represents another contribution by the ESF to the establishment of the European Research Area (ERA).

I consider this well-researched and cogently argued Position Paper to be a major contribution towards the implementation of a Marine European Research Area, from concept to reality, a process in which the ESF Marine Board expects to play a leading role.

Enric Banda, *ESF Secretary General*

Summary of Recommendations and Actions for Implementation

The Position Paper on Integrating Marine Science in Europe is a milestone in the process of integrating and developing a strong, fully European profile for marine science as a key component of the European Research Area.

The European Science Foundation's (ESF) Marine Board convened a series of workshops and specialist groups during 2000-2001 to identify scientifically challenging and socio-economically important research themes in marine science and technology that are expected to contribute to a sustainable future for the ocean's ecosystems. During this process, two reports were produced: *Towards a European Marine Research Area* in December 2000, and *Navigating the Future* in February 2001, both serving as contributions to the preparation of the European Commission's 6th Framework Programme (EC FP6). Following a wide ranging and in depth consultation with many leading European scientists and policy makers *(see Appendix I),* a draft of the current report was announced in June 2001 on the ESF Marine Board website; comments subsequently received contributed towards finalising this ESF Marine Board Position Paper on *Integrating Marine Science in Europe* (IMS-Europe). Thus, this Position Paper provides a summary of a Europe-wide reflection on marine science, and details specific research actions considered to be of fundamental importance, as a result of this multifaceted consultation process.

During this process, three major strategic drivers were identified and used as the cornerstones for developing the rationale for integrating marine science in Europe.

1. **Understanding and predicting the impacts and feedbacks of ocean climate change.**
2. **Scientific and socio-economic bases for sustainable development of European seas and their resources.**
3. **The ocean as an ultimate frontier for marine research.**

Within the context of these drivers, the aim of the IMS-Europe Position Paper is to provide a profile of the status and priorities in marine research to:

- Marine research teams in Europe, detailing a strategic synopsis of research themes that will assist them in integrating their expertise and contribute to new collaborations.
- National institutes and agencies, to facilitate optimal development of strategic options, which would help in formulating their marine research priorities in a synergistic mode, and so link them within European opportunities such as the European Commission's 6th Framework Programme (2003-2008), and the ESF's EUROCORES and Forward Looks programmes.

The Position Paper is not presented as prescriptive or definitive, rather it is intended to inform and contribute to reflection on marine research issues.

The Position Paper will be widely distributed among the marine scientific community in Europe and beyond, and among policy makers and other stakeholders. This will stimulate ideas and initiatives for effective implementation of integrated marine research, leading to actions and opportunities. The existing role of the ESF Marine Board, as a facilitator in marine research, creating synergy, developing capacities and capabilities, promoting the integration between initiatives and assisting in mobilising the approach to the management and funding structures in Europe, will ensure the effective implementation of the recommendations from the Position Paper. The ESF Marine Board has the commitment, capacity and willingness to play an active role in promoting the implementation of integrated marine research, as documented in this Position Paper; it will not only provide leadership, but will also monitor the implementation process. The ensuing observations, disseminated to the research community and policy makers on a regular basis, will allow readjustments, where appropriate, of the implementation strategy.

In addition to promoting the scientific recommendations, the ESF Marine Board will pay special attention to the implementation of the European and societal dimensions of issues identified in the Position Paper.

Main recommendations

The scientific, infrastructural and strategic recommendations that emerged from the IMS-Europe Position Paper are summarised below, according to the seven thematic categories by which the Position Paper is organised, namely:

1. **European and societal dimensions**
2. **Natural marine resources**
3. **Europe's coastal zones and shelf seas**
4. **Ocean climate interactions and feedback**
5. **New frontiers in marine science**
6. **Critical technologies**
7. **Research infrastructures**

1. European and societal dimensions

Science, society and citizens

1.1 **M**arine research and its discoveries are of strategic significance to Europe and of importance to its citizens. In addition, effective governance requires the participation of informed citizens. The European marine scientific community is encouraged to become more proactive in public debates concerning the marine environment, and in disseminating scientific information and analysis in issues of societal concern such as biodiversity loss, waste disposal, deep sea fishing, genetically modified marine organisms, CO_2 sequestration, climate change etc. *(see also 3.20, 4.9).* Marine scientists should be encouraged to develop an ethical dimension to their research, central to the concept of human stewardship of nature, sustainability and the precautionary principle. The ESF Marine Board network of national experts on scientific public awareness should take an active role in disseminating the latest marine scientific undertakings, discoveries and issues to educational and political institutions, and to the media. The newly created European Centre for Information in Marine Science and Technology (EurOcean), through the development of its Internet Portal, should be in a position to take a proactive role in this area.

Maritime regions, ultraperipheral regions and EU enlargement

1.2 **E**nhanced national and European investment in regional marine research and infrastructures could significantly contribute to the policy of reducing regional disparity in scientific knowledge, innovation, RTD (research and technology development) and competitiveness *(see also 7.2, 7.5, 7.6, 7.7).* Special attention should be afforded to developing cooperation with Newly Associated States, the Russian Federation, Eastern European countries and ultraperipheral regions.

Cooperation at the global level and with developing countries

1.3 **E**urope should actively support marine science and technology towards developing international collaboration on research issues. Europe has a history as an initiator of, and active partner in, international treaties dealing with the sea. It should continue to be proactively associated with research to support resolution of international issues including threats to fisheries resources, marine biodiversity, regulation of wastes and disposal of structures, deep ocean resources, and climate change. Development of scientific capacity, both at the national and collective levels of the European Union (EU), is necessary to support compliance with statutory obligations resulting from international conventions.

1.4 **C**ooperation with other countries, particularly developing countries with insufficient finances and expertise to adequately resource their marine science capability, should be central and prominent rather than peripheral to the integration of marine science in Europe. Europe should provide expertise for sustainability issues in developing countries, in particular where European Union Member States are actively involved in resource exploitation. Negotiation over resource exploitation (e.g. fishing, hydrocarbons) should involve the same precautionary approach to sustainability that would apply if the resources were located within EU waters. Within this context, the identification and establishment of coastal and marine protected areas (MPAs) in developing countries should also be a priority for Europe.

1.5 **E**urope should engage in partnerships to develop training programmes and research in developing countries. A comprehensive approach would involve coordination between European Union Member States, the European Commission (EC), the UN and host countries.

Human resources

1.6 **A**ttracting and retaining young people into marine research, facilitating mobility of researchers and technologists, and networking partnerships with industry *(see also 6.3, 7.2)* is a priority for developing and maintaining Europe's capacity as a leader in global marine research and technology.

Marine European Research Area

1.7 **O**ver 90% of European marine science is supported by national RTD agencies; considerable benefits would be gained from networking thematically similar national marine research programmes. ESF's EUROCORES and similar mechanisms such as the new instruments of the European Research Area (ERA) and the EC 6th Framework Programme (FP6) (e.g. Networks of Excellence, Large Integrated Projects, infrastructure support, ERA-Net, and the network of managers of Member States' national marine science programmes) should be fully exploited in this context.

2. Natural marine resources

Towards ecologically sustainable fisheries and aquaculture

2.1 **M**any commercial fish stocks have been depleted to critical levels and the associated environment degraded by overfishing and pollution. To achieve sustainable and ecologically viable fisheries and protect fisheries resources, research design should be based on the behaviour of the ecosystem. An enhanced strategic alliance and collaboration between fisheries, oceanography, marine ecology and socio-economic researchers, institutes and associations in Europe would facilitate further progression from species-specific research to ecosystem studies and models. Future fisheries research should endeavour to: (i) integrate fish stock studies with oceanographic, biogeochemical and biodiversity studies in an ecological perspective; and (ii) evaluate the ecological and socio-economic driving forces, implications and effects of different management regimes on fish stocks and the marine environment *(see also 2.5, 2.6, 2.12, 2.13)*.

2.2 **L**ong-term observations of fish stocks and environmental variability are essential to detect climatic drivers for predicting how greenhouse and other natural climate change scenarios might affect fisheries *(see also 4.4)*. Application of genetic techniques (*see also 2.4*) to stock assessment will assist in detecting population changes, and possible sources for re-establishment of depleted stocks. At the European level, commitment to decadal funding (beyond the current three to five-year funding cycle of national and EC Framework RTD) is essential for tracking climate variability and its impact on fisheries.

2.3 **R**esearch on technologies for selective and targeted fishing, and reduction of bycatch of other species, including birds and mammals, is essential to ensure that the fishing industry becomes more sustainable and impacts less on the marine ecosystem, by adopting a more ethical approach and taking responsibility for marine stewardship *(see also 2.6).*

2.4 **A**quaculture production is rapidly increasing to support Europe's demands for consumption of fish. Research is required to: (i) identify new aquaculture techniques for improved husbandry, species diversification and genetic selection; (ii) ensure compatibility with environmental constraints and reduce environmental impacts (e.g. polyculture systems, sustainable feeds, combining ranching with wind farms); (iii) improve the vigour and diversity of stocks (e.g. genetic selection, vaccines, new species); and (iv) ensure compatibility with other coastal and maritime activities *(see also 2.5, 2.6, 3.1).* State-of-the-art genomics techniques such as quantitative trait loci (QTL) and amplified fragment length polymorphism (AFLP), which have the potential to rapidly identify species-specific genetic markers for species identification, diagnostics etc. should be adopted by aquaculturists. These techniques, in combination with family selection by pedigree analysis, can enable very rapid improvement in strain characteristics, and so facilitate competitive advantage in the aquaculture industry *(see also 3.14).*

2.5 **M**ethodologies should be developed to evaluate the economic impacts of: (i) implementing new policies; (ii) effects of ecosystem changes on resource characteristics; and (iii) the determinants of fisheries and aquaculture activities *(see also 2.12, 2.13).*

2.6 **T**he conflicting requirement of sustainable fisheries and aquaculture, environmental protection and other competing human uses (e.g. shipping, recreation and coastal development) in the coastal zone should be a primary focus for marine socio-economic research and modelling *(see also 2.3, 3.1).* The development of common indicators and indices of ecological status of habitat types, in particular geographical areas, would be of great benefit to fisheries management *(see also 2.12, 2.13).*

New energies and wealth from the sea

2.7 **T**he ocean holds a vast reservoir of energy in the form of hydrocarbons (oil, gas, gas hydrates etc.), renewables (wind, wave, tides, geo-thermal and ocean-thermal etc.) and materials (aggregates, minerals, sea water chemicals etc.) of strategic or technological value to society. With appropriate incentives, European marine industries and science should forge new partnerships for a better understanding of the origin, location, and responsible sustainable exploitation of these resources. This will contribute to minimisation of environmental impacts and long-term risks from geological and climatic hazards, so that Europe can meet its increasing energy demands, while addressing concerns about greenhouse gas emissions and adherence to the Kyoto Protocol.

2.8 **T**here should be a concerted effort to improve cooperation between marine research groups and petroleum companies to: (i) explore new hydrocarbon reservoirs, especially in deep and ultra deep offshore areas; (ii) study the stability of the sediment layers of the continental margins *(see also 3.10)*; (iii) help understand and reduce the potential impact of hydrocarbon exploitation on the marine ecosystem; and (iv) develop the necessary technology. Research is also necessary to develop adequate observation and prediction systems to monitor oil spills and assess their potential impact *(see also 6.4).*

Gas hydrates

2.9 The occurrence of global quantities of gas hydrates at continental margins is a potentially important new and relatively clean source of energy for Europe. Research on gas hydrates should afford special attention to: (i) their biogeochemical origins; (ii) their occurrence in association with carbonate mounds; (iii) their stability; and (iv) novel mapping and exploitation technologies. The environmental impacts of exploration and exploitation of gas hydrates should also be assessed *(see also 3.10, 3.12, 5.3, 5.4, 5.5).*

Renewable energy

2.10 Research on requirements for effective location, operation and harnessing of renewable energy sites, and optimal integration into domestic energy grids, is vital so that Europe can meet its increasing energy demands, while addressing concerns about greenhouse gas emissions and adherence to the Kyoto Protocol. Research is also required to estimate the impacts of new offshore structures and their hardground and turbulence effects on local sedimentation, marine benthic and pelagic life, seabirds, marine mammals and navigation *(see also 3.1).*

Aggregates and ore deposits

2.11 Research should be carried out in association with dredging and dumping of sediments to avoid effects of coastal erosion, to maintain the functioning of natural marine systems, and other activities such as fisheries. Enhanced procedures for effective environmental impact studies on coastal marine ecosystems are required before exploitation of ore deposits takes place *(see also 3.1).*

Socio-economics and marine resource sustainability

2.12 The economic and social values of the marine environment contribute to the GDP (Gross Domestic Product) and quality of life in Europe. Economic evaluations of the intrinsic resources of coastal and marine areas and the impacts of pollution damage, biodiversity change and improper management of these resources should be assessed. The conflicting requirements of sustainable coastal and marine resource management and its competing human uses with environmental protection in the coastal and marine area should receive special attention by socio-economic modellers *(see also 2.5, 2.6, 3.1, 3.15).*

2.13 Three categories of indicators should be prioritised for development: (i) indicators of marine science and technology;
(ii) socio-economic indicators;
(iii) environmental indicators to contribute to the implementation of effective resource management and protection protocols *(see also 2.6)*. These environmental indicators would encompass biological, geological, chemical and physical factors characterising the health of coastal and oceanic ecosystems. In addition, indicators should be developed with regard to the nature of pollutants and their relation to human activities and urban concentration *(see also 3.4)*. Such indicators would provide input to the reports on the marine environment produced by European organisations and conventions such as the International Council for the Exploration of the Seas (ICES), the European Environment Agency (EEA), the Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) etc.

3. Europe's coastal zones and shelf seas

Coastal zone

3.1 To meet the challenge of progressing integrated coastal zone management (ICZM) and governance, baseline interdisciplinary research is required. The strategies for ICZM should be based on integrating oceanographic, fisheries, geological and biological research with the requirements of sustainable resource use, maritime transport and offshore industries, and environmental protection *(see also 3.21).* This will enhance resolution of the conflicting requirements of multi-user needs *(see also 2.6, 2.12).*

3.2 Across Europe and its ultraperipheral regions, coastal developments and management actions are impacting on regional biodiversity. Within ICZM research, prioritisation should be given to investigating the environmental impacts and biodiversity consequences of increasing tourism and leisure in the littoral zone, port developments, intense aquaculture in inshore locations, selective fishing of top predators, and deep ocean disposal of domestic and industrial wastes including CO_2 *(see also 3.11, 4.9).*

3.3 Estuaries, shelf seas and ocean margins are reactive highways for the transfer and transformation of terrestrial and anthropogenic products into the ocean. The transformation of these fluxes is generally poorly understood. Systematic research on biogeochemical budgets of nutrients (carbon, nitrogen, phosphorous) and their ecological effects are required for contrasting estuaries and shelf systems. Research should also focus on the fate of terrestrial carbon and pollutants in the ocean, and on the climatically important role of ocean margins as net sources or sinks of carbon *(see also 4.8, 4.9)*.

3.4 Europe faces dramatic increases in the numbers of organic and biotechnological compounds and pathogens discharged into the marine environment. These pollution mixtures exceed the monitoring capabilities of Europe's environmental agencies and there is a risk that major impacts on ecosystems will not be detected. Europe should rapidly adapt new array-biotechnological chips to provide non-invasive, affordable, and high-throughput systems for ecotoxicological screening of water quality *(see also 6.3).* This would allow ecologically more meaningful toxicity-based discharge consents and toxicity-directed chemical monitoring strategies that can cope with the multitude of new chemicals discharged annually into European coastal waters. It would ultimately contribute to the development of reliable ecotoxicological indices of the status of oceanic and coastal waters *(see also 2.13).*

3.5 Natural and anthropogenic causes of ecosystem variability should be characterised and distinguished, particularly in the coastal seas. Long-term, high-quality observations of climatic drivers, oceanographic, biogeochemical and anthropogenic parameters should be synchronised at critical points in the European coastal and marine areas *(see also 3.6).*

Strategic observing and monitoring systems

3.6 Coastal areas are predicted to become increasingly vulnerable to the effects of global warming. Effects include sea level rise, increased frequency and intensity of storms, increased wave height, flooding of lowlands, inundation of installations and settlements (urban and tourist), changing erosion patterns, salt intrusion into groundwaters, littoral zone exposure to extreme winds, and increased river flows due to wetter seasons. A European long-term coastal observing network is required to contribute to monitoring and forecasting extreme events predicted to occur more frequently under greenhouse scenarios *(see also 3.5).*

3.7 There is an overall requirement within operational oceanography for long-term climate simulations, models of climate predictions *(see also 4.2)*, models of monthly ocean currents, weekly meteorological predictions, and coastal current predictions of several days in advance. Few systems are currently in an operational state, and effort is required to improve observing and modelling methods and technologies *(see also 6.3),* capacity building and global collaboration. Updating European bathymetric charts is necessary to contribute to the development of more accurate models for operational oceanography *(see also 3.8, 3.9, 7.6).*

3.8 Research is required for the development of systematic means of acquisition (and production) of information from satellite and other sensor data delivered in a timely manner. There is a requirement for research to look beyond the oceanographic problem per se and include the processes required for data processing, data merging, and for data and product delivery *(see also 3.7, 3.9, 7.6).*

3.9 The marine element of GMES (Global Monitoring for Environment and Security), as devised by the European Space Agency (ESA), Directorate General (DG) Research and DG Environment of the European Commission (EC), provides a mechanism to coordinate and optimise research efforts with monitoring efforts and improved information systems for operational service providers, which will lead to enhanced product development. There are intrinsic research and technological challenges associated with both the effective implementation of GMES, and the maximisation of the results and ensuing products. The scientific, technical, socio-economic and institutional elements of the marine research community should be supported and coordinated to ensure effective involvement in GMES. The ESF Marine Board is ideally placed to enhance connections between the scientific community and ESA, the EC's DG Research and DG Environment, contributing to effective and optimal implementation and application of the marine element of GMES *(see also 3.7, 3.8, 7.6).*

Ocean margin processes and geohazards

3.10 Seabed operations such as oil production and communication cables are vulnerable to geohazards, including gravity slides, earthquakes, and sudden releases of methane from gas hydrates. Deep ocean observation tools and systems fitted with advanced geotechnical sensors are required to supply data on sediment dynamics and stability at ocean margins *(see also 2.9, 3.12, 5.3, 5.5).* This will allow assessment of the scale and frequency of mass sediment flows along ocean margins, and contribute to risk assessment for submarine cables and hydrocarbon exploration structures.

3.11 There is a requirement to investigate the sources, properties, transport and budgets of terrestrial and marine sediments in contrasting European coasts, emphasising the biological influence (stabilisation, cohesion, irrigation, storage) of the global carbon cycle. Evaluation of the carbon depocentre role of different ocean margins and an assessment of the potential for atmospheric CO_2 sequestration at the European continental margins is also necessary *(see also 4.8).*

3.12 **R**esearch is required to analyse the role of gas hydrate reservoirs as dynamic components of the global carbon cycle, recharge and discharge fluxes and their controlling factors *(see also 5.4).* There is a requirement to investigate the mechanism of gas hydrate destabilisation and potential geoclimatic hazards and to evaluate the impact of gas hydrates on slope destabilisation. Geotechnical and sedimentological research in association with the hydrocarbon industry is needed to mitigate against these risks *(see also 2.9, 3.10).*

Marine biodiversity: the blueprint for ecosystem regulation

3.13 **M**arine biodiversity is increasingly impacted by dredging, pollution, overfishing, hydrocarbon exploration and drilling, coastal development, climate change etc. For large-scale monitoring of biodiversity changes in Europe, marine biologists should focus on identifying and agreeing a set of key species (at different taxonomic levels), their niches and functional role. Large-scale biogeographic distribution and biodiversity gradients should be GIS-mapped spatially and temporally in association with oceanographic and geological parameters. Areas identified as of high species and genetic diversity should be the focus for conservation and management efforts, such as the designation of marine protected areas (MPAs) and exclusion zones in shallow and deep waters *(see also 3.14, 3.15, 5.5).* Particular attention should be afforded to establishing the functional biodiversity associated with cold water corals and gas hydrates *(see also 5.3, 5.4).*

3.14 **A**s retiring taxonomists are not being replaced, and yet are vital to research on all aspects of marine biology, there is a requirement to invest in taxonomic education and establish effective career paths *(see also 1.6).* Europe's marine taxonomists should integrate their national research and monitoring activities within large-scale European initiatives in marine biodiversity, and with both population biologists and geneticists. Taxonomic keys require updating, and future taxonomic work should link numerical taxonomy with genomics techniques. Rapid transfer of QTL and AFLP techniques *(see also 2.4)* to a range of marine organisms will greatly improve the ability to resolve population structures and provide estimates of population sizes, and thus status. Europe's classical taxonomic archives, specimen collections and genetic databases are scattered and require integration, and inclusion in the Global Biodiversity Information Facility (GBIF). Further integration of genetic databases with predictive modelling will provide an understanding of the potential impacts of environmental risks, climate change and exploitation.

3.15 **I**mproved understanding of complex marine populations and genomics will yield more robust biodiversity indices required to underpin conservation and socio-economic valuation *(see also 2.12, 3.13, 3.14, 3.16).*

Functional role of biodiversity

3.16 **R**esearch by fisheries biologists, ornithologists, mammologists and marine conservation scientists should be coupled to a more general ecological knowledge of the seas and marine food webs to better understand the relative importance of top-down regulation of marine food webs versus the traditional approach in which bottom-up control (nutrients and primary production) is emphasised. A concerted European action should be developed to understand the role of the relatively few key marine vertebrates, as an efficient method of studying how species impact on ecosystem functioning. Efforts should be made to improve the involvement of vertebrate biologists and ecologists in marine biodiversity networks.

Microbial biodiversity

3.17 **R**esearch is required into the role of microniches and microscale dynamics in sustaining symbiotic consortia of microorganisms. The role of infochemicals, toxins, attractants, biopolymers etc. in shaping pelagic microbial communities and in biotechnological products requires further investigation in order to be understood *(see also 5.1).* There is a requirement for the development of gene probes for *in situ* detection of the abundance and activity of biogeochemically important processes *(see also 3.19, 4.12),* and for classification and detection of viral particles and their infective impacts on bacterial and phytoplankton blooms.

Effects of climate and anthropogenic changes on marine biodiversity

3.18 **R**esearch on the impacts of climate change on marine biodiversity is necessary. Particular attention should be directed towards an agreed set of key organisms, which could act as indicators of ecosystem functioning *(see also 3.16).* Such information will provide a functional understanding of biodiversity and species composition of communities, which can then be used to model and predict the response to global environmental change.

3.19 **R**esearch on the impacts of climate change on microorganisms should include assessment of those that: (i) are important in shaping the marine food web; (ii) control ocean biogeochemistry; (iii) have potential for bioprospecting and biotechnology; and (iv) have a potential human health impact (e.g. harmful algal blooms) *(see also 3.17, 4.4, 4.12, 5.1).*

Integrated governance of European oceans and seas

3.20 **E**urope needs to rapidly move towards a sound and true governance of its oceans and seas, integrating all components for a comprehensive and responsible management of its marine assets. While the development of effective governance requires as its basis sound scientific knowledge, the European Commission (EC) and the European Parliament should be instrumental in developing this issue. This will lead to an effective assessment and management of the resources within the Exclusive Economic Zone (EEZ) of each maritime Member State. A forum of marine scientists and policy makers should be convened to ensure effective communication and synergy between both parties for timely deliverance of relevant and sound scientific knowledge to policy makers.

3.21 **T**o meet the challenge of progressing integrated ocean management and governance, baseline interdisciplinary research is required. The strategies for ocean governance should be based on integrating oceanographic, fisheries, geological and biological research with the requirements of sustainable resource use, maritime transport and offshore industries, and environmental protection *(see also 3.1).*

4. Ocean climate interactions and feedback

Climate change in Europe

4.1 Research is required to improve the temporal resolution in the reconstruction of climate history in oceanographic relationships in scales from ten to one hundred years. Numerical ocean and climate models of the climatic events of the past should be improved. Continuous development of organic geochemical proxies is required for reconstructions of past surface CO_2 content, temperature, pH values and nutrients. Improvement of proxies for the reconstruction of palaeosalinity, an important variable for modelling, is required. Documenting climate variations of the Holocene epoch will also be an important area for future research.

4.2 There are extensive requirements for long-term climate simulation models of climate variability and seasonal climate predictions, essential for forecasting. Efforts should also be directed towards research on regional modelling (e.g. in the Mediterranean). There is a requirement for validated methods to turn data into information, in the form of integrated assessments and indicators, and for improved methods to assimilate data into models. There is a strong case for the European Commission to invest in a computing centre and a high-speed network for ocean and climate modelling.

4.3 There is a research priority to gather the vast amount of palaeoclimate records into databases and to analyse them spatially and temporally. The combined use of palaeoclimate data and palaeoclimate models would advance the understanding of mechanisms of climate change.

4.4 Predicting the response and feedbacks of marine biota to climate change is required *(see also 3.18, 3.19).* Experimental and numerical studies using climate-simulating mesocosms (climatrons) could unravel the basic biogeochemical links and responses of climate-critical planktonic species (e.g. diatoms, coccolithophorids, N_2 fixers, bacteria, viruses, Archaea) to physical drivers of climate change (e.g. temperature, pH, CO_2, solar radiation) and their biogeographic consequences *(see also 4.11, 4.12).*

Ocean thermohaline circulation – Europe's heat engine

4.5 The Atlantic thermohaline circulation (THC) is the regional heat engine responsible for the temperate climate of Northern Europe. Preliminary observations and models suggest that the THC is weakening in response to greenhouse forcing. Multidisciplinary long-term observational networks are required to monitor the evolving dynamics of the THC. Research effort should focus on key deep Arctic or sub-Arctic gateways for outflowing cold dense water, and the return flows of warm surface currents in the world ocean.

4.6 Global models of ocean-climate coupling and the THC should be downscaled to faithfully incorporate: (i) flux-critical processes of convection, overflows and boundary currents; (ii) teleconnections between the Pacific El Niño and North Atlantic Oscillations (NAO), and between the NAO-IO (North Atlantic-Indian Ocean) dipole and Mediterranean climate; and (iii) local and regional impacts on, and responses of vulnerable European seas to greenhouse forcing. The impact of outflow of Mediterranean waters into the Atlantic and their behaviour in the Atlantic Iberian region also requires further attention.

4.7 With observation networks in place, there will be a requirement for new methods to assimilate data into Atlantic and Mediterranean circulation models *(see also 4.2)*, including the NAO and its regional climate and ecological consequences.

Ocean biogeochemical impacts and feedbacks in a greenhouse ocean

4.8 All future greenhouse scenarios predict a globally warmer, more stratified and acidic upper ocean that could significantly reduce both convective and biogeochemical export sinks of atmospheric CO_2 into the deep ocean. This would accelerate accumulation of CO_2 in the atmosphere, with associated risk of accelerated greenhouse warming. To reliably predict future CO_2 levels, research is essential to further elucidate the drawdown mechanisms, absorption limits and oceanic budget for anthropogenic CO_2 under greenhouse scenarios *(see also 3.3)*.

4.9 The United States and Japan are presently undertaking extensive trials in the Pacific Ocean to assess whether deep ocean disposal of liquified CO_2, or iron fertilisation, can be used for large scale removal of CO_2 into the deep ocean. Europe should conduct independent studies and evaluations to objectively debate the environmental feasibility, usefulness, ethics and impacts of ocean carbon sequestration options. Interactions between decision makers, scientists, environmental NGOs and the public should be promoted to avoid any misunderstanding about such sensitive issues, and to ensure effective stewardship of ocean resources *(see also 1.1, 3.20)*.

Ventilation of marine biogases and fertilisation feedbacks

4.10 Research on present-day air-sea fluxes of climate critical biogases (CO_2, DMS, N_2O, CH_4), particularly their regional and seasonal variability, is needed for global assessment of their role in climate change. The biogenic sources, distributions and pathways responsible for production, transformation and efflux of climatically reactive marine biogas compounds should be investigated and modelled under present and future climate conditions.

4.11 There is a requirement to develop coupled physical biogeochemical ocean climate models (*see also 4.2*) that incorporate carbon speciation and nutrient dynamics in order to predict changes and feedbacks in global and regional ocean productivity under greenhouse scenarios *(see also 4.4, 4.12)*.

4.12 Single-celled marine microorganisms (bacteria, Archaea, protozoa, phytoplankton etc.) are abundant, diverse and productive and are the principal drivers of marine and global biogeochemistry. Support should be directed towards adapting biogeochemical gene probes, coupled with phylogenetic probes, to enable the application of high-throughput bioanalytic technologies (e.g. analytical flow cytometry, microarrays) (*see also 6.3*) for shipboard use in large-scale oceanographic exploration of microbial biodiversity, food web dynamics and biogeochemical feedbacks in diverse oceanic environments *(see also 3.17, 3.19, 4.11, 5.1)*.

5. New frontiers in marine science

Marine biotechnology: bioprospecting the planet's largest biotope

5.1 **M**arine biotechnology has the potential to bioprospect the vast genetic richness of the ocean to discover new materials, including pharmaceuticals, agrochemicals and cosmetics. A European flagship project in marine biotechnology is required to bring together the excellent but sub-critical RTD groups in Europe into a common endeavour with industrial biotechnology partners. Enhanced research efforts in marine genetics would also contribute to improved competitiveness in biotechnology *(see also 2.4, 3.14, 3.17, 4.12).* In addition, bioprospecting should be integrated into future oceanographic expeditions.

5.2 **A** European network promoting dissemination of marine biotechnology discoveries, and collaboration between marine biologists, biotechnologists and industrialists should be established to screen biotechnology compounds from marine organisms, and encourage sustainable exploitation of new biotechnology discoveries in Europe and to limit associated environmental impacts.

New ecosystems at oceanic extremes

5.3 **N**ew organisms, evolutionary lines and geochemical processes are continually being discovered at deep seafloor, sub-seafloor and extreme environments (e.g. hydrothermal vents, cold seeps, sub-seafloor bacteria, cold water corals). It is necessary to develop new technologies for observation, sampling and experimentation in the largely unknown ecosystems of the deep ocean as well as techniques for cultivation of organisms from extreme habitats. Deep ocean vehicles and observatories should be upgraded with smart sensors *(see also 6.1), in situ* experimental capabilities and two-way telemetry for remote exploration, experimentation and monitoring of extreme ecosystems and their response to climatic and episodic events, and to integrate these with historic data for decadal to centennial scale analysis. Such observatories are required to establish baseline studies that adopt an ecosystem approach, a priority in advance of management of deep ocean resources *(see also 2.9, 3.21, 6.2).* Improved long-term observation of key terrestrial biomarkers and xenobiotics at specific deep oceanic locations will increase understanding of how the flux of material from land, or the alteration of surface ocean processes, ultimately affect the deep sea ecosystems. Marine protected areas (MPAs) will be needed to safeguard the recruitment of species and the biodiversity of the associated ecosystems (*see also 3.13*). The choice of such areas has to be guided by scientific insight and not solely by the requirements of the fisheries industry.

5.4 **A**n assessment of the role of oceanic gas hydrate reservoirs as hosts of deep biosphere ecosystems is also required. Major consideration should be given to developing a European research programme on gas hydrates to facilitate an integrated implementation of the various recommendations related to gas hydrates in this Position Paper *(see also 2.9, 3.13, 5.3, 5.5).*

5.5 **R**esearch on the specific adaptations of organisms to a range of extreme conditions found in habitats of the deep ocean is required. Research on the vertebrate populations supported by these extreme habitats should also be initiated, and can largely be done in an interdisciplinary manner concurrent with geological and oceanographic surveys. The results of such baseline studies will contribute to effective management and governance of ocean resources *(see also 3.13, 3.16, 3.21, 5.3, 5.4).*

Vents and seeps

5.6 **T**his area of research requires quantification of the transport of material and energy in hydrothermal systems and improved modelling of fluid convection systems. Distinction between fluids originating from heated sea water and those released by fractional crystallisation of underlying magma is required. There is also a requirement to understand and quantify the influence of fluids on sea water composition. Understanding primary generation of hydrocarbons at mid-ocean ridges and considering the volumetric importance of oceanic serpentines, the associated catalytic reactions and the resulting fluxes, requires attention.

5.7 **T**he thermal structure and fluid regimes in areas of colliding plates should be investigated. Quantification of the contribution of cold vents to the geochemical balance of various elements with fluids is also required (i.e. how much carbon, sulphur, water and halogens are introduced into the ocean). Research is required to determine transport paths in mass transfer and the respective contributions of focused and diffuse dewatering. There is a requirement for research on: (i) biological mediation of precipitations at fluid flow sites; (ii) periodicity and transient effects; (iii) integrating early diagenetic material fluxes in models of ocean circulation; and (iv) the relationship between flow, tectonics and earthquakes.

6. Critical technologies

6.1 **M**arine science and oceanography are critically dependent on advanced technologies to observe and understand ocean ecosystem dynamics and processes. Marine technologists should be encouraged to: (i) assess, convert and apply novel miniature sensors arising from bioanalytics, nanotechnology and advanced materials science (*see also 3.4*); (ii) standardise interfaces of system components, and components of novel technologies; and (iii) network national calibration facilities.

6.2 **T**o understand and predict ocean-climate coupling and the sustainable use of marine resources, and to describe the European component of global systems, long-term baseline funding for the development and operation of ocean observatories is required *(see also 5.3).* These are European responsibilities of profound significance to its citizens, and also to the world, transcending the responsibilities and resources of most national programmes. Therefore, a special effort should be made to ensure a visible and effective research contribution by Europe to this domain.

6.3 **D**evelopment of effective industrial partnerships would accelerate development, sales and use of sensors by marine scientists *(see also 1.6, 7.2)*. Particular priorities for sensor development include: (i) development of new sensors for biological and chemical parameters; (ii) development of new systems: multiparameter, networking architecture; (iii) ensuring cost effectiveness: long-term components and high spatial density deployments; and (iv) appropriate infrastructure: two-way data communication and control.

6.4 **C**ollaboration with offshore oil and gas platforms, with their own network of telecommunication cables and infrastructure that could be efficiently adapted for shelf ecosystem and pollution observation, would clearly benefit European marine science, technology and industry *(see also 2.8).*

7. Research infrastructures

7.1 **A**vailability of an oceanographic fleet, and associated equipment including underwater vehicles, will continue to be essential for research at sea. There are strategic requirements for a set of European policies and arrangements to maximise the use of these infrastructures on a pan-European scale and to advise the European Commission and national agencies on new specifications, improved access and cost sharing for these infrastructural investments. The strategic vision exists and the tools for collaboration and coordination are already available, and should be consolidated within the timeframe of the European Commission's FP6.

7.2 **E**urope should widen its support for integrated marine science by incentives for scientific and industrial partnerships and enhanced mobility. Researchers must be encouraged and facilitated in developing industrial links, including Public Private Partnerships (PPPs), to maximise the manufacture and exchange of novel technologies within Europe and to maximise European industrial competitiveness, for the benefit of both marine science and society *(see also 2.8, 5.2, 6.3).* Attracting and retaining young researchers into marine science is particularly important to ensure continued development of European capacity and capability *(see also 1.6).*

7.3 **A** revised effective European data policy should be rapidly elaborated and put into action to ensure: (i) secure storage of appropriate data; (ii) quality control; and (iii) interoperability and open access for science in a timely manner to the petabytes of data and products expected from the next generation of ocean observatories and operational forecasts.

7.4 **A** forum should be established to address the issues of data standards, indexing, transfer and storage. This forum would provide a focus for increased coordination and cooperation between researchers, agencies and authorities.

7.5 **A**s part of the European enlargement process, investment in regional marine research and infrastructures should be enhanced so as to reduce regional disparity in scientific knowledge, innovation, RTD and competitiveness *(see also 1.2).*

7.6 **E**urope's capacity for oceanographic monitoring from space should be enhanced, in particular with regard to research satellites for observing new parameters such as thickness of sea ice, surface salinity etc. In addition, there should be further investment in periodic satellites for observing oceanic evidence of climate change *(see also 3.8, 3.9).*

7.7 **I**nvestment priorities for marine research should be agreed across Europe, and should be designed so that they are not constrained by the limited lifecycles of national and European Union funding programmes. This will ensure not only long-term viability of observation networks, but also retention of capacity and capability within Europe.

Actions for Implementation

The focus for implementing the recommendations from the IMS-Europe Position Paper will be on the use of the existing instruments, primarily national, ESF and European Commission instruments. Through an iterative process of consultation, barriers to the use of the existing instruments will be identified and brought to the attention of the responsible bodies. The following steps will be taken to put the recommendations of the Position Paper into action.

National level

1. The ESF Marine Board Member Organisations will take initiatives at the national level in their own country to disseminate information and promote the implementation of the recommendations among the scientific community and the decisions makers. This in turn should contribute to national marine science programmes and the outcomes should be brought back to the ESF Marine Board as part of an ongoing process. This process should ideally lead to initiatives by national scientific communities and national funding agencies for a European-scale cooperation, possibly through bilateral and multilateral programmes.

European Science Foundation (ESF) and other European organisations

2. The ESF Marine Board will initiate internal consultations with the other ESF bodies with regard to joint European initiatives to promote the implementation of the recommendations in the Position Paper. It will promote activities towards the further development of such initiatives in the scientific and technological communities. Within the ESF, useful instruments include Networks, Programmes, Scientific Forward Looks and Conferences. For the development of collaborative research programmes with broad participation of the scientific community, instruments such as the new ESF EUROCORES scheme offer promising opportunities.
3. The recommendations from the *ESF Forward Look on Earth System Science: Global Change Research* will be considered for initiatives in the area of monitoring and technology development, as well as for research into the role of the oceans and seas in the climate system.
4. The ESF Marine Board will actively participate in discussions in the development of the European Research Council (ERC) concept. This Position Paper will be instrumental in ensuring the inclusion of marine science within the ERC and facilitating the use of marine science as a pilot case.
5. The ESF Marine Board will develop cooperation with existing European organisations with interests in marine science and technology in order to promote synergies and to avoid duplication of activities, in particular through improved exchange of information. To achieve this objective, the ESF Marine Board will work in association with the European Centre for Information in Marine Science Technology (EurOcean) and other relevant European organisations.

European Union

6. The European Commission has, within FP6, a range of instruments that are highly relevant to the implementation of the goals of this IMS-Europe Position Paper. As a result:
   - The ESF Marine Board will support the European Union Member States' initia-

tive to create a network of managers of national marine science programmes.

- The ERA-Net instrument of EC FP6 will, if possible, be used to help support the cost of coordination of collaborative programmes.
- The ESF Marine Board will observe the development of Networks of Excellence and Large Integrated Projects under FP6, and if necessary take steps to stimulate the development of such initiatives in specific areas, as defined in the Position Paper, which are not yet covered.
- Comprehensive research infrastructure is an important prerequisite for the success of a European marine research strategy. The ESF Marine Board will play an active role, through, among other things, discussion with the European Commission and networks established by European Union Member States, in contributing to the long-term strategy for marine infrastructure investment, including progress towards coordination of infrastructural management, and facilitating European-wide access to existing national infrastructures. If necessary, the ESF Marine Board will take additional initiatives in line with the role outlined for the ESF in the European debate about research infrastructure in general.

7. The motivation for the ESF Marine Board in producing the IMS-Europe Position Paper was to provide an integrated marine science vision for input to national RTD, and to the European Research Area (ERA). Thus, this Position Paper has a specific role in elaborating and promoting the European Research Area (ERA). Achieving the goals of the IMS-Europe Position Paper go beyond DG Research to other relevant Directorates General of the European Commission (e.g. DG Fisheries, DG Environment, DG Regions, DG International Cooperation). Specific actions for collaboration with these Directorates General and other appropriate European bodies (e.g. the European Parliament, Council of Europe, Committee of the Regions, Committee for the Ultraperipheral Regions) will be developed by the ESF Marine Board.

International level

8. Progress in marine science requires global cooperation. Europe itself has strong global interests as a consequence of its links with overseas areas. The responsibility for capacity building in developing countries requires a global perspective. A strong, well-articulated and integrated European marine science effort is also a prerequisite for effective partnerships with the United States and Japan. The ESF Marine Board has the commitment, willingness and capacity to play a leading role in the development of research links between Europe and its partners on a global scale and with international organisations (particularly the UN International Oceanographic Commission, IOC, and the International Council of Science, ICSU).

> ***"More has been learned about the nature of the oceans in the past 25 years than during all preceding history…. However, what we know about the oceans is still far outweighed by what we do not know".***
>
> "The Ocean, Our Future", Report of the Independent World Commission on the Oceans (1998)

1. Introduction

1. Introduction

The ESF Marine Board has considered it to be both timely and essential to develop a synopsis profiling marine science in Europe, integrating all relevant dimensions of the natural and social sciences and the concerns of stakeholders and end users of European seas.

This Position Paper of the ESF Marine Board brings together the scientific and strategic analyses and recommendations from key research areas in marine science and technology arising from wide ranging and in depth workshops, specialist groups and Web-based public comments during 2000 and 2001 **(see Appendix I).** ***As part of this process, the ESF Marine Board produced several publications to support the development of the 6th Framework Programme (FP6), including:*** **Towards a European Marine Research Area,** ***in December 2000, and*** **Navigating the Future,** ***in February 2001. The motivation for the ESF Marine Board in producing this Position Paper was to provide an integrated marine science vision for input to national RTD, and to the European Research Area (ERA). The Position Paper will be a tool for scientists, managers and policy makers to aid progress towards interdisciplinarity and integration at the national, European and international level.***

The main objectives of this report are to:

- ***Promote awareness and inclusion of marine science and technology in the European Research Area, under development within the European Union.***
- ***Contribute to the development of national marine science strategies and the networking and integration of national programmes within and between European Union Member States.***
- ***Facilitate the involvement of Europe in international programmes and identify research issues of international dimension.***
- ***Maximise the use of existing research infrastructures and identify future needs, including the development of new technologies.***

1.1 Drivers for integrating marine science in Europe

Research requirements in marine science and technology can be distilled into three strategic drivers:

- Understanding and predicting the impacts and feedbacks of ocean climate change.
- Scientific and socio-economic bases for the sustainable development of European seas and their resources.
- The ocean as an ultimate frontier for marine research.

A guiding principle for action in these fields is that governance and prediction are cornerstones to enhancing economic prosperity and quality of life. Additional impetus is provided by emerging technologies (e.g. nanotechnology, genomics, proteomics) and by the better application of existing technologies (information technology, acoustics, biotechnology etc.) to the exploration of new frontiers and to the sustainable use of marine resources.

These drivers are embedded in a number of European and international conventions and agreements *(Appendix II)* to which the European Union and its Member States are bound.

1.1.1 The ocean in the Earth's system

Our planet is a system, in which oceans, atmosphere and the terrestrial domain 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. There is now compelling evidence that the relentless emissions and atmospheric accumulation of anthropogenic greenhouse gases since the early 19th century are quantitatively responsible for the global warming trends, sea level rises and climate extremes recorded since the 1980s. Even if emissions are stabilised, anthropogenic climate change will continue for several centuries because of the long time scales required for oceanic feedback.

At the start of this new era for planet Earth, Europe, with its wide range of oceanic and climatic regimes and terrestrial habitats, is particularly vulnerable to climate change. Variations in 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 systems, as well as to Sahelian rainfall. Climate change in turn affects the marine environment in several ways, including: increased storminess, sea level rise, resuspension of contaminants in the sea, global shifts in oceanic productivity, biogas feedbacks, oceanic drawdown of CO_2, and decreasing yields in aquaculture and fisheries etc. *(see also Section 4.1: Climate change in Europe).*

In the 21st century, environmental and marine scientists in Europe will have a central role in addressing the issues surrounding climate change, and will be challenged to use the best tools, concepts, observations and models to better understand ocean-climate coupling processes. The resultant understanding is essential to provide Europe with the basis to: (i) make reliable predictions of long-term climate change and short-term operational forecasting; and (ii) make informed and sustainable decisions on socio-economic adaptation and mitigation strategies needed to address and manage climate change.

1.1.2 Sustainable development and the precautionary principle

Marine and coastal resources play a major role in sustaining the economic and social development of European society. However, the links between marine and coastal ecosystem functions and a wide range of different economic activities and benefits are not always clear to policy makers, planners and coastal zone managers. There is a resultant underestimation and ignorance of the value of these ecosystems and their economic functions.

Seabed boulders caught in benthic trawls. © J De Leeuw, Netherland Institute for Sea Research

Europe has approximately 89,000km of coastline and is the continent with the highest coast to surface ratio. Moreover, at least 40% of the EU territory is underwater. European seas, including the Barents and Baltic Seas, North and Irish Seas, the Eastern Atlantic north of the Canaries, the Mediterranean and the Black Sea, encompass a range of marine ecosystems from the coastal zone through the shelf and shelf-edge into the deep ocean.

Europe's economy is increasingly dependent on resources in the coastal marine area *(see boxed text next page)*. A study undertaken for the European Commission estimated that the value of the benefits derived directly from marine and coastal ecosystem services exceeds 18 billion euros annually. Despite gaps in available statistics, it is estimated that approximately 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 euros a year. European maritime regions account for over 40% of the EU GNP (*see also Section 2.3: Socio-economics and marine resource sustainability*).

Data from reports by the Independent World Commission on the Oceans (1998) and the GOOS Prospectus (1998) showed that:

- 80% of all international trade is carried by sea;
- by the year 2020, 75% of the world's population will live within 60km of sea coasts and estuaries;
- the world fish catch amounts to about 20% of total human consumption of animal protein;
- in 1995, the 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.

It is evident that coastal and marine regions of Europe support intense urban, industrial, commercial and tourism activities. Ninety per cent of the EU's external trade is conducted through shipping; more than 300,000 persons are employed in the maritime and river transport chain in Europe. In the mid 1990s the Mediterranean coastline received an estimated 75 million international and 60 million domestic tourists annually. Fisheries, mariculture 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 provides more than 200,000 highly skilled jobs. Annual investment in the area varies between 15 and 20 billion euros.

Harvesting of red seaweed *Kappoficus* in the Bohol lagoon, the Philippines. © O Barbaroux, Ifremer, France

As the value of the oceans and of the ecological services they provide has traditionally been underestimated, there has been a failure to take into account the concept of sustainability. European seas are no exception, and the challenge of their sustainable management has to be met. Future population growth and increasing trends in tourism, leisure, agriculture, fisheries, port activities, shipping, residential housing, waste disposal etc. are planned on the presumption that coastal ecosystem functions can accommodate these increasing demands and pressures. Concerns about sustainable development and its various components – environmental, economic and societal – came to the fore during the last twenty years of the 20th century. 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 effectively addressed by the marine research community.

1.1.3 The ocean, a new frontier for science, technology and society

In the last decade, new technology has tremendously extended the scope of research and is now putting scientists on the threshold of exciting discoveries. European seas have already been the loci of recent exciting discoveries revealing intriguing ecosystems and life forms including cold water corals, thermal vents and cold seeps, huge accumulations of methane in the form of gas hydrates, potential for increasing ocean fertility, renewable energies etc. *(see also Section 5.2: New ecosystems at oceanic extremes; Section 5.3: Vents and seeps)*. The implications of these discoveries for enhanced understanding of ecosystem functioning and of the global carbon cycle are still largely unknown. The applicability of some of these discoveries to human activities is also unknown; it is considered, for example, that microorganisms of deep sea sediments may offer interesting prospects for biotechnology and that gas hydrates may become a potential energy source *(see also Section 5.1: Marine biotechnology: bioprospecting the planet's largest biotope; Section 5.3: Vents and seeps)*.

Subjects now on the agenda for frontier research include: the possible consequences of change in the marine environment for human activities and health; the coastal zone as a possible vector of disease; the ocean as the largest gene pool for biodiversity; the use of extremophile organisms in marine biotechnology; increasing the use of renewable energies; monitoring Earth processes and hazards by means of seafloor observatories; and exploration and recovery of new hydrocarbons from the deep ocean.

European marine science and technology has pioneered and successfully applied the concept of large regional multidisciplinary problem-driven projects in past European Commission framework programmes. The EC has advanced the concept of delivering its 6th Framework Programme by using large targeted integrated projects as one mode of implementation of the European Research Area (ERA). By focusing on major large-scale marine interdisciplinary challenges *(see following sections)*, including supporting technology and socio-economics, this ESF Marine Board Position Paper provides a summary in scientific, operational and societal terms for future marine science activity within the European Research Area.

1.2 European and societal dimensions

1.2.1 Science, society and citizens

Public understanding of marine science

European coastal seas and the bordering open Atlantic Ocean play an important role in the everyday life of Europeans *(see also Section 2: Natural marine resources; Section 3: Europe's coastal zones and shelf seas)*. The coastal zone as the transitional area between land and sea is becoming increasingly important, including: as recreation areas, evident throughout the Mediterranean; as fishing and oil-rich areas such as the North Sea and the Baltic Sea; and as important waterways such as the straits of Gibraltar and Dover. Open ocean areas are equally important. The Gulf Stream and the North Atlantic Oscillation (NAO, an atmospheric pressure swing between Iceland and the Azores) determine, more than other processes, both the weather and, on a longer time scale, Europe's regional climate.

Marine scientists throughout Europe work in laboratories and on research vessels to find out more about the important processes that take place in European seas. The results and information derived contribute to instruments for regulation of the marine environment and resources. Within and beyond the marine sector a large number of stakeholders are dependent on the ensuing advice from marine scientists.

Adult harbour porpoise stranded on rocky shore, Co. Sligo, Ireland. © M Mackey, Coastal and Marine Resources Centre, University College Cork, Ireland

As the marine environment has such an important influence on our daily lives, and information derived from marine science has incalculable value for mankind, the marine scientific community should look upon enhancement of public understanding and public awareness of their science as a vital task. Marine science has many fascinating aspects, which can be easily communicated to the general public. In this way, raising public awareness would build credibility and secure acceptance both of the scientific challenges lying ahead and of the management policies arising from research results.

Effective governance requires at its foundation the participation of informed citizens. Though public awareness of the marine environment and its resources appears to be increasing, this is in tandem with increasing anthropogenic impacts on and demands for marine resource use. Much remains to be done to promote public knowledge and understanding of the issues in this area. In some European countries there is a highly developed programme for communication and education on marine science, managed by public relations and education professionals (known as PREPs). In countries without PREPs, communication and extra curricular education on marine science issues and achievements are mainly ad hoc and not integrated.

European collaboration on marine science communication

To improve the quality and integration of communication between marine scientists and the public, the ESF Marine Board convened a forum of marine PREPs. The aims of the forum included:

- creation of a European network for the exchange of information and cooperation between national marine PREPs;
- making marine scientists and administrators aware of the effectiveness of integrated communication strategies on specific target groups of society;
- assisting ESF and other European funding agencies associated with marine science in developing communication strategies and collaborative initiatives;
- improving communication between scientists and the media, educational programmes, and politicians by creating better information tools.

The consolidation and expansion of this initiative is strongly recommended.

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. There are many controversial issues relating to the proposed use of resources, development and research in the marine environment that science and society should debate openly. Among other things, these include:

- climate engineering: e.g. large-scale ocean CO_2 sequestration either by CO_2 disposal or by iron fertilisation;
- biotechnology benefits and risks of using genetically modified species in marine aquaculture;
- deep sea fishing, mining and waste disposal.

Ethics in marine research are a prerequisite for the governance of the ocean and can contribute towards safeguarding public trust in science and in scientists *(see also Section 3.5: Integrated governance of European oceans and seas).*

1.2.2 Maritime regions, ultraperipheral regions and European Union enlargement

The seas around Europe display great diversity in their geographical setting, their degree of exposure to human activities, and their role in the functioning of the marine system. The Baltic Sea, Black Sea and Mediterranean Sea (viewed both globally and in some of its elements such as the Adriatic) are almost enclosed. By contrast, the Atlantic coast of Europe faces the open ocean, while the North Sea is in an intermediate position. Most of the ultraperipheral regions are located in tropical and polar environments.

One of the major challenges for Europe and its enlargement is its economic, social and territorial cohesion. Among the most important criteria for regional competitiveness identified by the European Commission are: the capacity for innovation, and the activities of research and technological development (RTD). According to EUROSTAT, there are large differences between the regions with regard to RTD. On a scale of 1 to 10, these range from 1 to 7 with regard to the expenditures expressed in terms of percentage of gross domestic product (GDP), and 1 to 10 with regard to employment. The differences apparent between the regions of the EU and the regions of the EU-candidate countries are even more important.

A major readjustment through standardisation of EU policies for innovation and RTD is necessary to reduce these regional differences. This must be taken into account in the integration of marine science in Europe; to achieve effective integration, the European marine research community has to consider the development of a regional dimension for marine research.

Such a regional dimension does not contradict the concept of a European scientific community, as there are broad common issues across European seas that call for intercomparisons (e.g. pollution and human pressure in the Baltic and the Adriatic). Furthermore, the integration of regional studies into world programmes will ensure a decisive role in emphasising a European identity and global responsibility.

The scope for regional cooperation should include the ultraperipheral regions and should be extended 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 *(see also Section 3.5: Integrated governance of European oceans and seas).* Special attention should be paid to developing cooperation with the Russian Federation, eastern European countries and Newly Associated States regarding the involvement of their scientists in EU projects and reciprocal access to research facilities.

Priority issues for marine research at regional level include the requirement to:

- develop strategic and organisational recommendations and plans;
- promote regional research centres of excellence;
- facilitate access to research infrastructures *(see also Section 7.2: Marine infrastructure: status and trends)*;
- encourage training and mobility of researchers *(see also Section 1.2.4: Human resources)*;
- secure financial resources in relation to requirements.

These priority issues will not be successfully tackled without setting up appropriate mechanisms for governance. In particular, synergy is necessary between RTD and innovation policies and these have also to be articulated with the regional EU policies initiated by the Structural Funds. Coordination is thus needed at regional and national levels regarding EU initiatives.

1.2.3 Cooperation at the global level and with developing countries

The management of the majority of marine affairs (e.g. fisheries, biodiversity, invasive species, climate change, security of maritime transport, the Law of the Sea) can be dealt with only on a global scale, and should be based on sound scientific knowledge *(see also Section 3.5: Integrated governance of European oceans and seas).* Furthermore, any future development of marine science in Europe cannot be said to be truly integrated unless it is embedded within the global fabric. This in turn requires recognition of the global role and responsibilities of Europe in matters affecting marine affairs. Cooperation with other countries, particularly developing countries with insufficient finances and expertise to adequately resource their marine science capability, should be central and prominent rather than peripheral to the integration of marine science in Europe. An example is provided by the START initiative (Global Change System for Analysis Research and Training) initiated by IGBP, IHDP and WRCP. START helps build indigenous capacities in developing regions so that they can participate effectively in research projects of international programmes *(see also Section 4.1: Climate change in Europe).*

Global responsibilities and opportunities for Europe as one of the leading players in marine science can be summarised in the following four areas:

1. Europe has a responsibility to be proactive as a major broker of international treaties, protocols and memoranda of understanding dealing with marine science and the environment

Europe has a long history as a key contributor to international treaties dealing with the sea (including the Law of the Sea), and should continue to be proactive in this area with respect to marine science and the environment *(see also Section 3.5: Integrated governance of European oceans and seas).* Without comprehensive treaties that include developing countries, divisions between the developed and developing world will inevitably escalate owing to the increasing technological capability and access to shared resources available to developed countries. For example, without an international treaty on bioprospecting *(see also Section 5.1: Marine biotechnology: bioprosepcting the planet's largest biotope)*, the value of genetic material stored within the indigenous biodiversity of developing countries will be quickly transferred to technologically advanced countries. Similarly, without international treaties to control greenhouse gases (inducing global warming) or the spread of introduced species in ship ballast water and on hulls, major losses in biodiversity in the developing world can be expected.

2. Europe should provide marine science expertise for sustainability issues in client developing countries

Because European Union Member States are actively involved in resource exploitation in developing countries (e.g. petroleum, fisheries) *(see also Section 2: Natural marine resources)*, they should be obliged to provide client-developing countries with the same marine science capability for managing resources as is available within EU boundaries. For example, negotiations over fishing rights in developing countries should involve the same level of knowledge, and the same precautionary approach to sustainability that would apply if the fishery resources were located in EU waters.

3. Europe has a responsibility to act as custodian of global heritage, particularly biodiversity

Europe should be more actively involved in research to arrest the loss of marine biodiversity, particularly when loss of biodiversity occurs through international actions. As with terrestrial ecosystems, marine biodiversity *(see also Section 3.4: Marine biodiversity: the blueprint for ecosystem regulation* is concentrated in the developing world, and direct assistance is required by developing countries to prevent losses which affect all humanity. For example, substantial loss of marine species and coral bleaching can be expected to result from global warming, increasing the international movement of invasive species, the development of the tourism industry, and unsustainable fishery practices. Europe should provide appropriate support for marine biodiversity and habitat inventories, and for studies aimed at predicting and ameliorating losses of marine plant and animal species. Another objective for Europe should be to identify and establish coastal and marine protected areas (MPAs) in developing countries.

4. Training responsibilities and international cooperation

Europe should be engaged in mutually beneficial training programmes *(see also Section 1.2.4: Human resources)* and cooperative research with developing countries. Such partnership programmes must be relevant to the development of the host country and strengthen its capacity. Joint projects should include training in research, which necessitates long-term partnership and commitment. The time is ripe for a comprehensive approach involving the European Commission, individual Member States, the developing world, and the UN organisations. Building regional centres of excellence and establishing Internet networks are important elements in such an approach.

1.2.4 Human resources

Insufficient human capacity is a limiting factor in all aspects of marine science *(see also Section 6: Critical technologies; Section 7: Research infrastructures).* Enhancing and consolidating capacity will require partnerships between the science funding agencies and the development agencies *(see also Section 1.2.3: Cooperation at the global level and with developing countries)*. Stimulating the development of new technologies could be addressed through, for example, the ESF EUROCORES scheme for collaborative research, which brings together national funding agencies, on a voluntary basis, in a funding partnership for European cooperation in research, without the need to transfer national money, and without a need for new structures. Thus, while EUROCORES has a single international peer-review process, the grants are implemented at the national level.

Careful attention should be paid to the human resources required for the development and operation of the new and sophisticated emergent technologies *(see also Section 6: Critical technologies).* Having emphasised the symbiotic relations between marine science and technology, it is essential to involve technology at the start of new marine science challenges. If the exciting new technologies (sensors, observatories, unmanned underwater vehicles) are to efficiently support European integrated marine science and to be further developed with industrial partners, it is essential to improve the mobility of technologists and managers within and outside Europe.

A fundamental issue which marine scientists and policy makers should address in association with the education sector involves the decrease in uptake of science as a career throughout Europe. There is evidence that school students are finding science classes dull and tedious, curricula have not been updated, and the quality of facilities available to teachers is frequently inadequate. As a result, the proportion of students opting to take science at third level is decreasing. Furthermore, acquiring a post once a researcher has completed a PhD is a challenge; the salaries are not appealing in the public sector by comparison with the private sector and other professional domains and there are no clear career paths. Without this attention to nurturing science at schools, and the valorisation of scientific careers, Europe faces a shortage in research capacity in the future.

A dynamic policy to promote human resources in marine science and technology is an essential prerequisite to integrating European marine science. Key issues include:

- attracting and retaining young people and particularly women into marine research;
- facilitating European and international mobility of scientists and particularly technologists;
- networking new partnerships with industry for the development of new products, services and sustainable development.

1.2.5 Interdisciplinarity, *chantiers* and the Marine European Research Area

Interdisciplinarity

As marine science progresses, it becomes increasingly necessary that new research initiatives be formulated within an interdisciplinary framework. For example, one can no longer study the marine food web without understanding circulation and mixing processes. Ocean forecasting, the dynamics of eddies and gyres, and halieutic models are all topics which require a close interaction with hydrodynamics and the physics of non-linear systems. For example, responding to, and managing the consequences of, a shipwreck 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 risk assessments must be developed through the joint efforts of marine scientists, specialists in international maritime law, coast guard agencies, and representatives from the shipping and other industrial sectors *(see also Section 3.5: Integrated governance of European oceans and seas).*

Chantiers

Interdisciplinary research can best be organised around focused research areas or *chantiers*, where all relevant disciplines of the natural and social sciences converge towards an integrated approach to solving problems. The question to be addressed can be an environmental problem, for example, climate change impacts, coastal sustainability, an oil spill, a toxic algal bloom, the risk of a hazard on the seafloor, or a scientific issue at a particular geographic location (e.g. fault, canyon, shelf break). As for the spatial scale, there is no a priori definition of a *chantier*; it 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.

European Research Area (ERA) and marine science

The concept of the European Research Area (ERA), proposed by EU Commissioner for Research, Philippe Busquin, in 2,000 points towards the need for a full integration of scientific efforts across the spectrum of European science, beyond the mission-oriented policy goals of each EC framework programme. The 6th Framework Programme (FP6) contributes to the implementation of the ERA, and particularly emphasises the need for integration and interdisciplinarity. As the programme is not primarily devoted to basic research, and the majority (> 90%) of funding available for research in Europe is nationally based within the national research agencies, the ERA can be properly implemented only with the coordinated involvement and commitment of the individual EU Member States. The ERA, and associated proposed European Research Council (ERC), would provide a much needed support structure for marine science in Europe. Initiatives such as the proposed ESF European Global Change Board and the existing ESF Marine Board support this approach. They provide a platform for the relevant European players and the European Union. The ERA is also supported by instruments such as the ESF EUROCORES scheme for collaborative research *(see also Section 1.2.4 Human resources).*

The ERA will also be served and developed by the EC 6th Framework Programme (FP6) for Large Integrated Projects and Networks of Excellence. In addition, CREST (Comité de la Recherche Scientifique et Technique) provides a collaborative forum for national research councils, with topic-specific working groups, including one on marine science. The ERA-Net instrument of EC FP6 will also allow networking of national programmes throughout Europe, according to topic areas. All of these initiatives will contribute to capacity building in marine science and to the effective establishment of a marine ERA.

1.2.6 Key research recommendations

Science, society and citizens

- Marine research and its discoveries are of strategic significance to Europe and of importance to its citizens. In addition, effective governance requires participation of informed citizens. The European marine scientific community is encouraged to become more proactive in public debates concerning the marine environment, and in disseminating scientific information and analysis in issues of societal concern such as biodiversity loss, waste disposal, deep sea fishing, genetically modified marine organisms, CO_2 sequestration, climate change etc. The ESF Marine Board network of national experts on scientific public awareness should take an active role to disseminate the latest marine scientific undertakings, discoveries and issues to educational and political institutions, and to the media. The newly created European Centre for Information in Marine Science and Technology (EurOcean), through the development of its Internet Portal, should be in a position to take a proactive role in this area.

Maritime regions, ultraperipheral regions and EU enlargement

- Enhanced national and European investment in regional marine research and infrastructures could significantly contribute to the policy of reducing regional disparity in scientific knowledge, innovation, RTD and competitiveness. Special attention should be given to developing cooperation with Newly Associated States, the Russian Federation, eastern European countries and ultraperipheral regions *(see also Section 7: Research infrastructures).*

Cooperation at the global level and with developing countries

- Europe should actively support marine science and technology in order to develop international collaboration on research issues. Europe has a history as an initiator of, and active partner in, international treaties dealing with the sea, and should continue to be proactively associated with research to support resolution of international issues including threats to fisheries resources, marine biodiversity, regulation of wastes and disposal of structures, deep ocean resources, and climate change. Development of scientific capacity, both at the national and collective levels of the European Union, is necessary to support compliance with statutory obligations resulting from international conventions.

- Cooperation with other countries, particularly developing countries with insufficient finances and expertise to adequately resource their marine science capability, should be central and prominent rather than peripheral to the integration of marine science in Europe. Europe should provide marine science expertise for sustainability issues in developing countries, in particular where EU Member States are actively involved in resource exploitation. Negotiation over resource exploitation (e.g. fishing, hydrocarbons) should involve the same precautionary approach to sustainability that would apply if the resources were located within EU waters. The identification and establishment of coastal and marine protected areas (MPAs) in developing countries should also be a priority objective for Europe.

- Europe should engage in partnerships for the development of training programmes and research in developing countries. A comprehensive approach would involve coordination between the EU Member States, the European Commission, the UN and host countries.

Human resources

- Attracting and retaining young people into marine research, facilitating mobility of researchers and technologists, and developing network partnerships with industry are priorities for developing and maintaining Europe's capacity as a leader in global marine research and technology.

Marine European Research Area

- Over 90% of European marine science is supported by national RTD agencies; considerable benefits would be gained from networking thematically similar national marine research programmes. ESF's EUROCORES and similar mechanisms such as the new instruments of the ERA and EC FP6 (e.g. Networks of Excellence, Large Integrated Projects, infrastructure support, ERA-Net, and networks of managers of Member States' national marine science programmes) should be fully exploited to build up a marine ERA.

2. Natural marine resources

2. Natural marine resources

The ocean includes both living resources and ecosystems encompassing fisheries, biodiversity, genetic richness, molecules of biotechnological interest etc., and non-living resources such as natural sea defences, aggregates, minerals, hydrocarbon reserves, sources of wind and wave energy. It is also the source of leisure amenities for mankind and provides a valuable arena for transport. Sustainable exploitation of marine resources and protection of the marine environment have been identified as key drivers for marine research in Europe **(see also Section 1.1.2: Sustainable development and the precautionary principle).** ***The pace and intensity of exploitation of marine resources is accelerating to unprecedented and often unsustainable levels.***

Europe's commitment to sustainable exploitation of its seas, with implementation of effective procedures for resource management and conservation, must have at its foundation the best marine science and technology **(see also Section 3.5: Integrated governance of European oceans and seas).** ***There are historical and institutional barriers that currently separate some areas of marine science from fisheries and resource exploration throughout Europe. These barriers should be removed by directed collaboration, realignment, resource sharing and mergers. Only in this way can Europe's marine experts come up with imaginative, sustainable and ecologically viable alternatives to the present terminal decline in fisheries and the deterioration of the marine environment.***

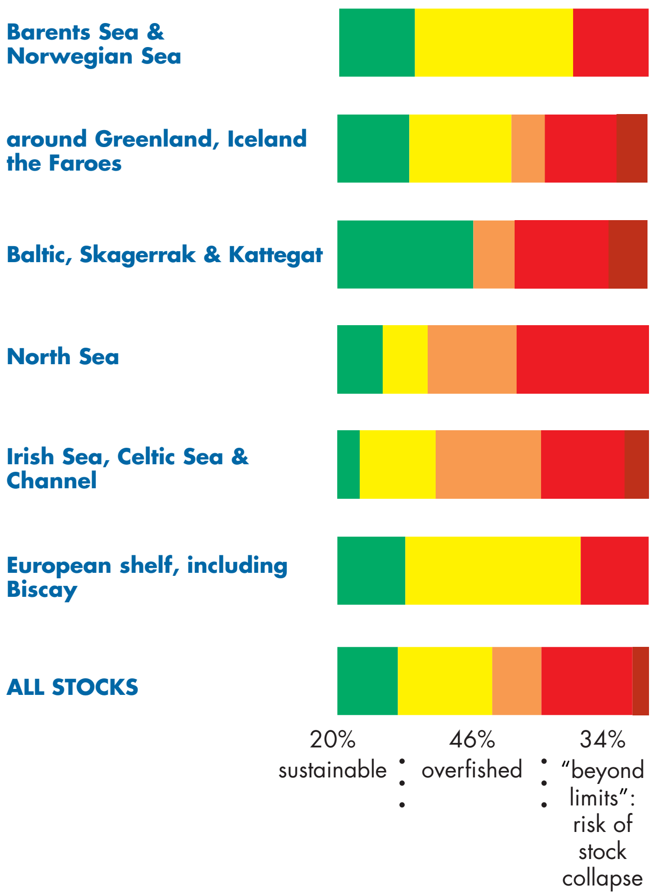
2.1 Towards ecologically sustainable fisheries and aquaculture

European fish stocks have experienced a major decline in recent years, attributable mainly to ecologically unsustainable overfishing. There are major concerns in scientific, political and economic quarters throughout Europe, which demand action. To satisfy market demand for fish, there has been a rapid increase in finfish and shellfish aquaculture, which has in turn created a new set of environmental and technological challenges.

2.1.1 Collapsing fish stocks and environmental impacts

Over 130 commercially important fish stocks have been monitored in the North East Atlantic for over half a century by fisheries agencies, including ICES (the International Council for the Exploration of the Sea), to provide advice for national and European policy makers on quotas and other management and conservation measures. While taking into account climate-driven fluctuations (e.g. due to the North Atlantic Oscillation – NAO; *see also Section 4.2.1: Drivers of thermohaline circulation in the Atlantic Ocean)*, it is apparent that most demersal and pelagic fish stocks are now in serious decline. This decline is attributable primarily to: (i) overfishing of commercial stocks; (ii) discard of unwanted bycatch; and (iii) wholesale disturbance of seabed ecosystems. ICES (in 2000) estimated that by 1998, 34% of European fish stocks were beyond sustainable limits, 46% were overfished, with only 20% of stocks classified as sustainable. This situation is exacerbated by the overcapacity in European fishing fleets. Because of selective overfishing of adults and larger top predators (e.g. cod, whiting, tuna), and the tendency to exploit fish lower down the food chain and younger age classes, the average size of individuals in the North East Atlantic landings

Status of European fish stocks, 1998
(ICES, 2000)



have declined. Coastal fisheries (for sole, plaice etc.) are increasingly affected by pollution discharges containing endocrine disrupters and carcinogens, which affect the fecundity, immuno competence and health of marine fisheries *(see also Section 3.1.4: Biogeochemical dynamics at the land-ocean interface).*

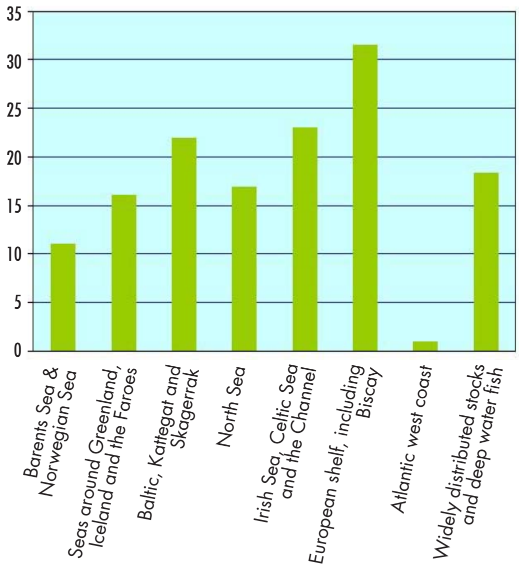
It is estimated that the North Sea stocks have declined to one fifth (20%) of the 1975 levels and several species are on the verge of extinction (e.g. skate, cod). Several European countries have set aside protected zones, referred to as no-take zones, where fishing is prohibited, with the ultimate aim to facilitate recovery of fish stocks and their environment.

Within the deep sea, there has also been a rapid increase in deep-sea trawling for non-quota fish stocks (e.g. roundnose grenadier) especially along European continental margins, which have only recently been regulated. Populations of deep sea cold water fish are particularly vulnerable to overfishing, as these species are slow growing and at risk from irreversible depletion of their population, as recently happened to the orange roughy fishery off New Zealand *(see also Section 5.2.3: Detecting and attributing variability in deep ocean biology).* In addition, these deep pristine ecosystems are very biodiverse and fragile, particularly those associated with the recently discovered cold water corals (*Lophelia pertusa*) which occur along the North Western European shelf *(see also Section 5.2.2: New links between geosphere and biosphere).* These cold water coral ecosystems are at particular risk from deep sea trawling, hydrocarbon exploration and drilling wastes.

It is imperative that future fisheries' management takes action to ensure that fishing becomes a sustainable activity, compatible with the limits of marine resource renewal and with the need to reduce impacts on the marine environment.

On the positive side, there is a better understanding of how natural climate variability, such as the NAO shifts *(see also Section 4.2.1: Drivers of thermohaline circulation in the Atlantic Ocean)*, in the Gulf Stream and nutrient regimes, can modulate marine productivity and fish stocks. This will make future fish stock assessments much more reliable.

In parallel with this, the increasing use of gene probe techniques such as quantitative trait loci (QTL) and amplified fragment length polymorphism (AFLP) *(see also Section 3.4.2: Marine taxonomy and genetics)* within fish stock assessment continues to progress the knowledge and understanding of how populations are isolated or associated, and so how stocks might be re-established, once diminished. DNA profiling allows inter-relations between different population groups to be established; microsatellite DNA loci have been shown to be particularly discriminatory and are presently the markers of



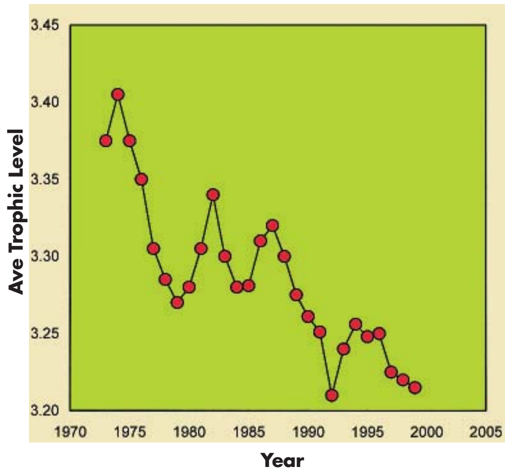
Number of fish stocks assessed by sea area (in total 139) reported by ICES. © D Griffith, ICES

choice for such studies. Protein electrophoresis of brown trout, *Salmo trutta* (a European endemic species of high socio-economic value for recreational angling) using mtDNA (mitochondrial DNA) and microsatellite analysis, has shown that they exhibit one of the highest levels of genetic variability observed in any vertebrate species, and a high level of population structuring. Since the 1970s, research on Atlantic salmon (*Salmo salar*) using an array of genetic markers has demonstrated population structure within tributaries of large European river systems. With the ongoing development of several new genotyping platforms, genotyping throughput per day is expected to increase from 10,000 to 1,000,000 and the cost to reduce from 1 euro to less than 0.01 euro. Rapid transfer of this technology from the target market of pharmacogenomics to fisheries research will greatly improve the ability of genetic analysis to resolve population structures and provide estimates of effective population sizes. By integrating this information with sophisticated predictive modelling, which also needs to be developed, it is envisaged that it will be possible to provide a far greater understanding of the implications of environmental factors and exploitation rates on populations, including fish stocks.

Fisheries science, with its century-long history of expertise and achievements in fish stock assessments, now faces a challenging future: how to convince policy makers to adopt strategies that are sustainable with respect to: (i) fish stocks; (ii) the marine environment; and (iii) the European fishing community.

Future fisheries research should endeavour to: (i) integrate fish stock studies with oceanographic, biogeochemical and biodiversity studies in an ecological perspective, resulting in improved understanding of the interactions between environmental factors and the food web; and (ii) evaluate the ecological and socio-economic driving forces, implications and effects of different management regimes on fish stocks and the marine environment.

Europe should take the lead by integrating its RTD funding for fisheries research with that for marine and oceanographic RTD. Commitment to decadal funding (beyond the current three to five year-funding cycle of national and EC Framework RTD) is essential for tracking impacts of overfishing and climate variability on fisheries.



Average trophic level of the Northeast Atlantic landings 1973-1999. Landing statistics from ICES Fisheries Statistics 1973-1999 (2001). Trophic level was allocated as 2 for phytoplankton eaters (e.g. squid), 3 for zooplankton and benthos predators (e.g. herring, mackerel, flatfishes), 4 for fish predators (e.g. cod, whiting, tunas), 5 for marine mammals. © D Griffith, ICES

This will yield the robust scientific understanding of marine and fisheries issues needed to deliver a programme of fish stock recovery and sustainable fisheries management in Europe.

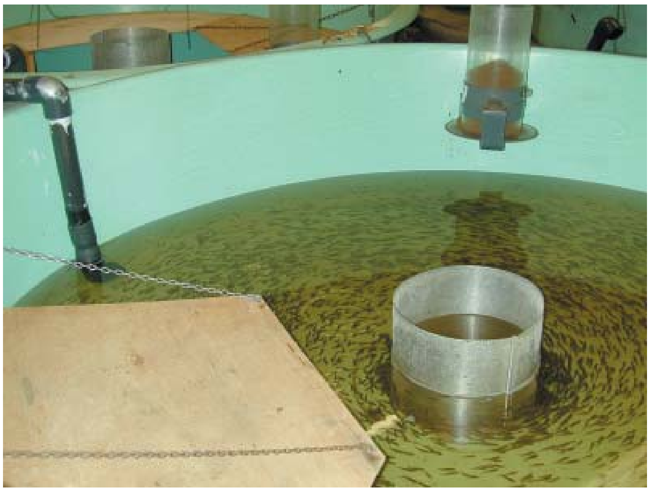
The French trawler 'Drake' off the north-west of Scotland.
© O Barbaroux, Ifremer, France

2.1.2 Harnessing aquaculture

As exploitation of wild fish populations becomes less sustainable, increased marine aquaculture will be required to supply the European and global markets. Aquaculture in Europe, particularly of salmon, has expanded since the 1980s, but with some associated environmental problems such as disease and eutrophication. Aquaculture production is expected to continue expanding, involving optimal farming of new species and the use of offshore enclosure systems. More efficient closed recirculation systems will be required to reduce impact on coastal waters and eliminate interactions between wild and reared populations. Indices of status of coastal ecology and sustainable aquaculture are required to provide consistent and environmentally relevant criteria for integrating effective aquaculture into the coastal ecosystem *(see also Section 2.3.4: Development of indicators).* New types of food for farmed fish should be developed, including increased use of cultured phytoplankton and zooplankton, to break the reliance on ecologically damaging fishmeal. There is a requirement for improved understanding of fish pathologies and husbandry, as well as genetic diversity and selection mechanisms.

Adopting a polyculture approach to aquaculture, by integrating the culture of different species so that the waste of one species feeds another species, would assist in water filtration, removal of organic matter and increased production. Polyculture can be used to overcome environmental problems and to aid in parallel production of other useful products such as bivalves, seaweed, and high protein phytoplankton biomass.

The use of gene probe techniques should be increased as a method for improved productivity in aquaculture; this would assist in identification of suitable strains, disease control and enhanced stress resistance *(see also Section 2.1.1: Collapsing fish stocks and environmental impacts; Section 3.4.2: Marine taxonomy and genetics).* Many species at present cannot be cultured commercially due to technical difficulties and the lack of domesticated strains with characteristics such as growth rates, age at maturity and flesh quality that would equal or exceed wild-caught equivalents, and command a high price in the marketplace (and thus ensure commercial viability). Marine biotechnology can resolve this situation by either selective breeding or genetic engineering. Where the latter is generally viewed with caution, as an alternative the aid of molecular markers can greatly accelerate the selective breeding process. Use of techniques such as QTL and AFLP *(see also Section 2.1.1: Collapsing fishstocks and environmental impacts),* with the potential to rapidly identify species-specific genetic markers for species identification, diagnostics etc. should be adopted by aquaculturists. These techniques and family selection by pedigree analysis are examples of state-of-the-art genomics techniques that can enable very rapid improvement in strain



Salmon hatchery. © Marine Institute, Ireland

characteristics, and so facilitate competitive advantage. Opportunities may also exist to assess the relative resistance of different genotypes to particular disease challenges.

Examples of success in using molecular probes in acquaculture include speciation of bivalve larvae (including the extensively cultured king scallop *Pecten maximus* and the common mussel, *Mytilus edulis*), otherwise difficult to identify. Development of species-specific fluorescent probes with real time PCR (polymerase chain reaction) analysis allows rapid identification of species, and prediction of the time, intensity and location of natural shellfish spat fall and settlement, factors of prime importance in shellfish aquaculture.

2.1.3 Key research recommendations

Towards ecologically sustainable fisheries and aqua-culture

- Many commercial fish stocks have been depleted to critical levels and the associated environment degraded by overfishing and pollution. To achieve sustainable and ecologically viable fisheries and protect fisheries resources, research design should be based on the behaviour of the ecosystem. An enhanced strategic alliance and collaboration between fisheries, oceanography, marine ecology and socio-economic research in Europe would facilitate further progression from species-specific research to ecosystem studies and models, incorporating physical, chemical and biological functions. Thus, future fisheries research should endeavour to: (i) integrate fish stock studies with oceanographic, biogeochemical and biodiversity studies in an ecological perspective, resulting in improved understanding of the interactions between environmental factors and the food web; and (ii) evaluate the ecological and socio-economic driving forces, implications and effects of different management regimes on fish stocks and the marine environment.

- Long-term observations of fish stocks and environmental variability are essential to detect climatic drivers for predicting how greenhouse scenarios might affect fisheries. Application of genetic techniques such as QTL and AFLP to stock assessment will assist in detecting population changes and possible sources for re-establishment of depleted stocks. At the European level, commitment to decadal funding (beyond the current three to five year-funding cycle of national and EC Framework RTD) is essential for tracking climate variability and its impact on fisheries *(see also Section 4: Ocean climate interactions and feedback).*

- Research on technologies for selective and targeted fishing, and reduction of bycatch of other species, including birds and mammals, is essential to ensure that the fishing industry becomes more sustainable and impacts less on the marine ecosystem, adopting a more ethical approach and taking responsibility for marine stewardship.

- Aquaculture production is rapidly increasing to support Europe's demands for consumption of fish. Research is required to: (i) identify new aquaculture techniques for improved husbandry, species diversification and genetic selection; (ii) ensure compatibility with environmental constraints and reduce environmental impacts (e.g. polyculture systems, sustainable feeds, combining ranching with wind farms); (iii) improve the vigour and diversity of stocks (e.g. genetic selection, vaccines, new species); and (iv) ensure compatibility with other coastal area and maritime activities.

- State-of-the-art genomics techniques such as QTL and AFLP and the use of fluorescent probes, with the potential for rapid species identification, diagnostics etc. should be adopted by aquaculturists as well as fisheries scientists. These techniques, in combination with family selection by pedigree analysis, can enable very rapid improvement in strain characteristics, and so facilitate competitive advantage in the aquaculture industry. Genetic markers will also facilitate the identification of finfish and shellfish populations. Research on genetically modified organisms should address the risk of dissemination and impact on the wild populations.

- Methodologies should be developed to evaluate the economic impacts of: (i) implementing new policies; (ii) effects of ecosystem changes on resource characteristics; and (iii) the determinants of fisheries and aquaculture activities *(see also Section 2.3.2: Integrating marine ecosystem and socio-economic sciences).*

- The conflicting requirements of sustainable fisheries and aquaculture, environmental protection and other competing human uses (e.g. shipping, recreation and coastal development) in the coastal zone should be a primary focus for marine socio-economic research and modelling. Fisheries ecological studies must be actively supported, whether in coastal or open ocean areas, in sustainably fished or overfished zones, and in marine protected areas (MPAs). The development of common indicators and indices of ecological status of habitat types in particular geographical areas would be of great benefit to fisheries management *(see also Section 2.3.4: Development of indicators).*

- New types of food for farmed fish should be developed, including the use of cultured phytoplankton and zooplankton, to break the reliance on ecologically damaging fishmeal.

2.2 New energies and wealth from the sea

The ocean holds an enormous reservoir of energy in the form of hydrocarbons (oil, gas, gas hydrates) and renewable energies (wind, wave, tides, geo-thermal and ocean-thermal) and of materials (aggregates, minerals, seawater chemicals) of strategic technological value for society. European maritime industries and marine science should form new partnerships to ensure sustainable exploitation, particularly in the exploration of new resources at ocean extremes.

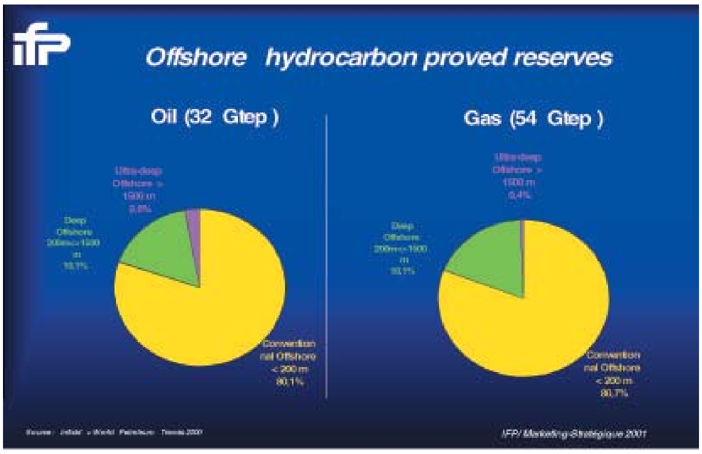
2.2.1 New hydrocarbon frontiers

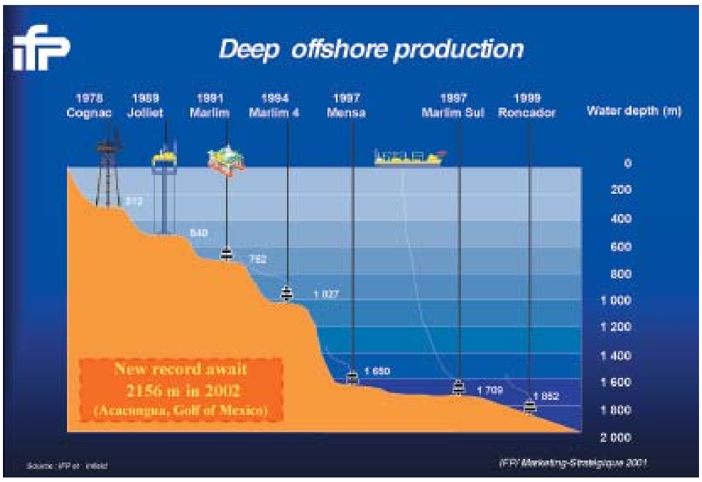
Offshore oil and gas

The growing world human population, with its desire for prosperity, will require new supplies of energy including hydrocarbons, an increasing proportion of which comes from offshore marine oil and gas deposits. Offshore reserves of oil (32 Gtep [billion of tonnes of oil equivalent]) and gas (54 Gtep) are estimated to account for 22% and 37% of world reserves respectively. In 1995, offshore gas accounted for 26% of the world's total supply. Today, one third of the oil and gas produced comes from offshore fields; the development of these fields represents half of upstream capital expenditure. As hydrocarbon reserves in shelf seas are running out, Europe is increasingly developing new operational technologies for operating in the deeper slopes and abyssal regions of the continental margins.

The industry is at a turning point; over 120 floating production systems of various types, at a cost of over 40 billion euros, will be built by 2005 to extract hydrocarbons from approximately 150 new fields, especially in offshore Africa and Brazil. At the same time, operations and expenditure will decline in the North Sea, and the decommissioning options for offshore platforms remains a major challenge for Europe.

With respect to marine research and development, European and international petroleum companies and research institutes work in three ways to increase awareness and detection of world hydrocarbons reserves: (i) increasing the recovery rate of the existing fields; (ii) exploiting new kinds of hydrocarbons, such as very heavy oils and gas hydrates; and (iii) exploring new areas, especially deep and ultra deep offshore waters.





Offshore hydrocarbon production for oil and gas and evolution of marine hydrocarbon platforms. © Institut Français du Pétrole, France

Given the pristine, sensitive and often uncharted nature of marine life along ocean margins and abyssal regions of the deep ocean, environmentally responsible oil companies are increasingly collaborating with the European marine research community to conduct independent and reliable impact assessments prior to exploration and operation of new hydrocarbon fields in the deep sea. In addition, data and information on geological and climatic hazards, storms, currents, ecosystems, and oil dispersion modelling are increasingly required by the industry from the marine research community *(see also Section 3.3: Ocean margin processes and geohazards)*.

Sediment unit cemented by white gas hydrates, from the hydrate ridge in the E Pacific. © G Wefer, University of Bremen, Germany

Gas hydrates

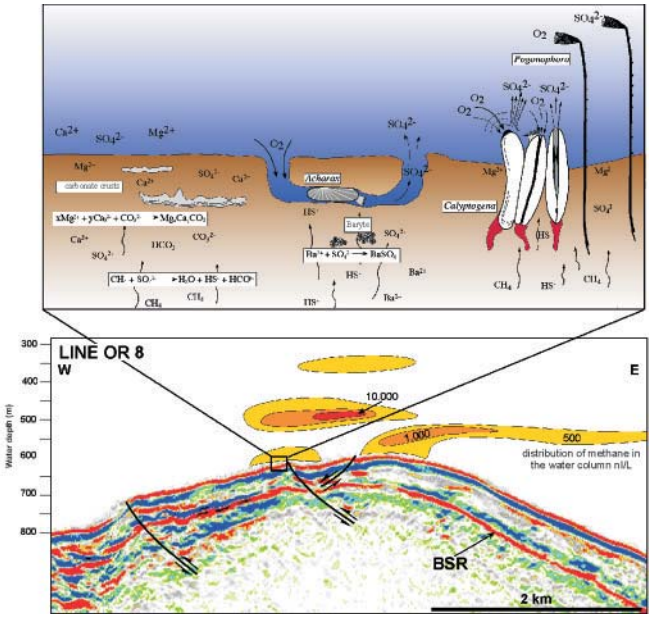
Gas hydrates (*see also Section 3.3.2: Margins as net sinks or sources of carbon; Section 4.3.2: Ventilation of marine biogases and fertilisation feedbacks; Section 5.2.2: New links between geosphere and biosphere)* are ice-like crystalline solids composed of water, methane, and trace gases (e.g. CO_2, H_2S). They are stable in the pores of marine sediments under high pressure / low temperature conditions (e.g. in depths greater than 400m and temperatures below 4°C). Gas hydrate deposits are abundant along ocean margins and have also been detected in mid-ocean settings in the Pacific. They are thought to originate primarily from long-term bacterial reduction of CO_2 and from the decomposition of organic matter under the high pressure conditions of deep sea sediments. It has been suggested that supply of methane from deep-seated sources may initiate hydrate formation. Highly specialised bacterial-Archaeal consortia using methane and CO_2 as nutrient and energy sources have been discovered at exposed sites along cold seep vents.

Initial global estimates of gas hydrate deposits indicate that about 10,000 Gtep of CH_4 bound carbon are stored in ocean sediments, representing twice the worldwide reserves of oil and gas. There is an increased interest and excitement, particularly in Japan, in exploiting gas hydrates as a significant potential energy source.

The occurrence of gas hydrates at the continental margins can be detected from the high acoustic reflectance signals (or bottom simulating reflectors, BSRs) associated with the gas-hydrate interfaces in sediments. However, recent drilling and chemical analyses have shown that gas hydrates and BSRs do not always coincide. There is a requirement for more research on: (i) the biogeochemical origins of gas hydrates; (ii) the physical, chemical and environmental characteristics of the hydrate/ sediment/water/gas systems; and (iii) novel gas hydrate mapping and prospecting technologies.

2.2.2 Renewable energy

Renewable energy sources, such as offshore wind and waves, and to a lesser extent geothermal and tidal energy, represent alternative sources capable of contributing to the world's energy needs in the 21st century. They would also contribute to the reductions in CO_2 emissions required under the Kyoto Protocol. About 6% of Europe's total gross energy consumption is presently produced from renewable sources. This share could increase to 12% by 2010 if the development of wind farms, including those offshore, progresses. The western margin of Europe has one of the highest wind and wave energy climates in the world. Greater potential lies offshore because of the stronger and more consistent winds there, and also the absence of conflict with coastal residents that would occur onshore. There are a number of proposals under consideration by local and regional agencies to build wind farms along European coasts, and some farms are already operational in Denmark.



Gas hydrate occurrence, fluid discharges and faunal communities at the hydrate ridge of the Cascadia accretion complex. Rising plumes rich in methane (up to 10,000 nl/l) originate from fluid discharging faults within the bottom simulating reflector BSR zones. The discharge of methane-, sulphide- and barium-rich fluids, the pumping activity of clams and chemsynthesis in tubeworms and bacterial mats lead to formation of carbonate crusts and barite concretions. © G Reinart, E Suess, in German Research Foundation's Marine Research in the Next Decade (2000)

Energy sources such as ocean heat pumps, waves, tides, and currents are also attracting new attention and represent not only a scientific and technological challenge, but also a valuable technological market niche for Europe.

However, research is necessary to estimate the impacts of new offshore structures and their hardground and turbulence effects on local sedimentation, marine benthic and pelagic life, seabirds, marine mammals and navigation.

2.2.3 Aggregates

There is a growing demand for coarse-grained sediments, sand and gravel, from near shore areas for use in construction, road building, and beach protection and regeneration. Approximately half of the continental shelf surface is covered with sand and gravel from ancient beaches, dunes, and river load. For densely populated industrial countries, these sediments have been identified as an important potential resource for the construction industry. For example, the United Kingdom obtains large proportions of its sand and gravel needs from near shore shallow water regions, such as the English Channel. Along its North Sea coast, sand is primarily extracted for maintenance dredging and coastal protection. The retrieval of these resources, however, has to be carried out in conjunction with intensive survey and research activities in order to reduce impacts on coastal erosion, benthic communities and fisheries.

In addition to the extraction of large volumes of coarse grained sediments, significant volumes of fine grained sediments are removed to maintain navigable depths in shipping channels. These fine sediments, known as dredge spoil, are dumped at sea, posing complex questions regarding their dispersion, incorporation into and impact on ecosystems, and ecotoxicology. Better understanding of sediment dynamics is necessary to help develop protocols for best practices.

2.2.4 Ore deposits

Wave activities on beaches and shelf areas result in a winnowing and enrichment of heavy minerals, creating placer deposits. Economically important examples of this type of deposit include diamond occurrences in offshore Namibia, gold in offshore Alaska, and cassiterite tin in offshore Malaysia, Indonesia, and Thailand. Other minerals of lesser economic importance (including chromite, rutile, magnetite, zircon) are produced from placers in various locations around the world.

Locally, phosphorite minerals, forming on the western coasts of continents below high productivity regions, are of importance. Also, countries without rich carbonate deposits retrieve calcium carbonate from the shelf areas for the production of cement.

The vast fields of manganese nodules that lie on the surface seafloor of abyssal oceans are of potential economic interest because of their high copper, nickel, and cobalt content. In addition, crusts of manganese oxides with high cobalt content form at the flanks of volcanic islands and seamounts. Seafloor hydrothermal activity at mid-ocean ridges produces massive sulphide deposits rich in copper, zinc, iron and to a lesser extent silver and gold. The exploitation of these mineral resources is not currently economically viable, nor is it likely to become so in the near future. If the retrieval of these metals becomes economically plausible as a result of high world market prices, detailed environmental impact studies will be necessary before any exploitation process is allowed to proceed.

2.2.5 Key research recommendations

New energies and wealth from the sea

- The ocean holds a vast reservoir of energy in the form of hydrocarbons (oil, gas, methane hydrates etc.), renewables (wind, wave, tides, geo-thermal and ocean-thermal etc.) and materials (aggregates, minerals, seawater chemicals etc.) of strategic or technological value to society. With appropriate incentives, European marine industries and science should forge new partnerships for a better understanding of the origin, location, and responsible sustainable exploitation of these resources. This will contribute to minimisation of environmental impacts and long-term risks from geological and climatic hazards.

- There is a necessity to improve cooperation between marine research groups and petroleum companies to explore new hydrocarbon reservoirs, especially in deep and ultra-deep offshore areas. Such collaborative research should particularly address the development of the necessary technology, the stability of the sediment layers of the continental margins, and understanding the marine ecosystem, thus reducing the potential impact of hydrocarbon exploitation on marine ecosystems. Research is also necessary to develop adequate observing and prediction systems to monitor oil spills and assess their potential impact.

Gas hydrates

- The occurrence of global quantities of gas hydrates at continental margins is a potentially important new and relatively clean source of energy for Europe. Research on gas hydrates should pay special attention to their biogeochemical origins, the physical, chemical and environmental characteristics of the hydrate/sediment/water/gas systems, their occurrence in association with carbonate mounds, their stability, and novel mapping and exploitation technologies. The environmental impacts of exploration and exploitation of gas hydrates should also be assessed carefully *(see also Section 3.3: Ocean margin processes and geohazards).*

Renewable energy

- Research on requirements for effective location, operation and harnessing of renewable energy sites, and optimal integration into domestic energy grids, is vital so that Europe can meet its increasing energy demands, while addressing concerns about greenhouse gas emissions and adherence to the Kyoto Protocol. Research is also required to estimate the impacts of new offshore structures and their hardground and turbulence effects on local sedimentation, marine benthic and pelagic life, seabirds, marine mammals and navigation.

Aggregates and ore deposits

- Research should be carried out in association with dredging and dumping of sediments to avoid effects of coastal erosion and to maintain the functioning of the natural marine systems, and other activities such as fisheries. Enhanced procedures for environmental impact studies on coastal and marine ecosystems will be required before exploitation of ore deposits takes place.

2.3 Socio-economics and marine resource sustainability

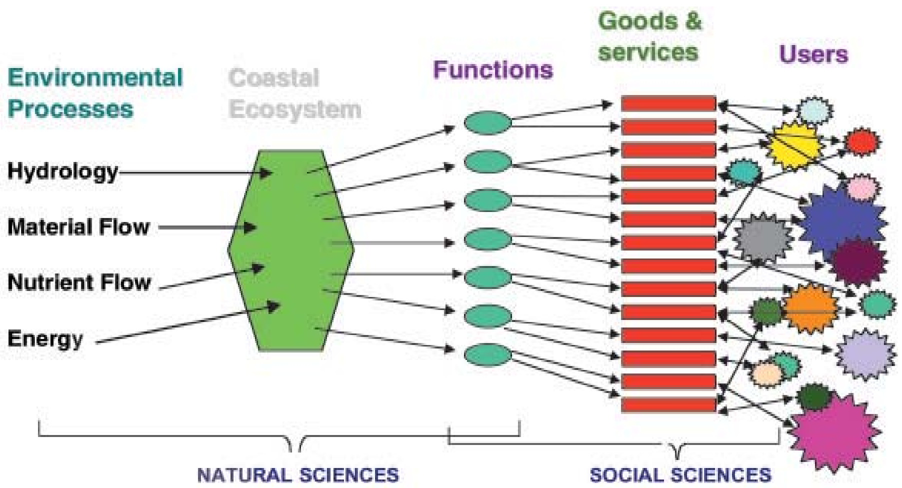
2.3.1 Introduction

Society underestimates or is ignorant of the value of marine and coastal ecosystems and their economic functions *(see also Section 1.2: European and societal dimensions).* It has been suggested that the global value of the marine environment, taking an initial tentative approach as pioneered by Constanza, is US$21 trillion per annum, of which US$8.5 trillion is obtained form the open ocean, and US$12.5 trillion from the coastal and shelf zones. The terrestrial environment as a whole is valued at US$33 trillion per annum. Constanza's valuation, while controversial, emphasises the contribution of non-market goods and services provided by ecosystems to human welfare. 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. In the report of the *Independent World Commission on the Oceans* (1998), the ecosystem service value of the coastal area was an estimated US$12.6 billion.

As detailed in Section 1.2.1 *(Science, society and citizens),* a recent study undertaken for the European Commission estimated that the value of the benefits derived from marine and coastal ecosystem services exceeds 18 billion euros annually. Between 3% and 5% of input to EU GNP is generated directly by marine-based industries and services. The value added directly by these activities is of the order of US$140-230 billion per year. In the United Kingdom alone, marine-related activities were estimated to contribute UK£27.8 billion, or 4.8% of GDP to the economy in 1994-1995.

Fisheries, mariculture and associated processing industries employ more than 600,000 people in Europe and generate an estimated turnover of 12 billion euros. In France, the contribution of marine-related industry to the economy in 1999 was estimated as 16.7 billion euros, with a total of 420,000 jobs. This estimate included industries associated with: seafood (fisheries, aquaculture, auction markets, fishmongers, seaweed harvesting and processing, seafood processing), civil and naval shipbuilding and repair, ship equipment manufacturing, yacht-building, ports and maritime transport (merchant fleet, harbours, insurance etc.), offshore oil and gas, coastal tourism, civil engineering, oceanographic instruments, submarine cable manufacturers, maritime press, navy, coastal protection, and scientific research. Overall, marine related activities in France exhibited a growth of about 5% between 1997-1999. In that two-year period, the fastest growth rates were recorded in offshore services, ship and yacht building, civil engineering and seafood processing. Coastal tourism accounted for 45% of the total, both in terms of value added and in terms of jobs.

Thus, marine and coastal ecosystems, with their highly productive and valuable resource base, have two key properties of importance to meet the demands for environmental and economic goods and services. The first is that individual ecosystems have multiple functions and roles, for example: primary and secondary biological production, regulation of coastal sediment transport, buffers to coastal storms, waste assimilation etc. These functions generate an array of resources that directly or indirectly support human activities. The second key property is the interdependence of individual ecosystems such as seagrass beds, mudflats, saltmarshes, beaches etc. While the benefits that society derives from coastal and marine ecosystems will continue to increase, their associated economic values are not quantified because the majority of such services are not priced by the market. Therefore, new valuation options are needed.



Understanding the linkages among coastal and marine ecosystems and human activities.
© P Burbridge, University of Newcastle upon Tyne, UK

To understand the geomorphological, biological and chemical processes that shape and maintain the functions of the marine resource base requires an integrated approach to marine science and dissemination of the resultant information. To harness and make efficient use of the array of resources offered, the current sectoral management that seeks to maximise the use of individual resources should be replaced by an integrated management strategy that optimises the combination of uses of the resources. The role of marine biodiversity is particularly significant.

The multiple ecosystem functions, links and the wide range of goods and services that are provided by marine or coastal ecosystems are schematically illustrated in the diagram above.

It is immediately evident from the diagram that:

- individual marine and coastal ecosystems are polyfunctional, interdependent and subject to long-term drivers (e.g. climate change, tectonic subsidence etc.);
- the ability of marine and coastal resource systems to sustain diverse economic activities depends on the integrity and carrying capacity of the individual constituent ecosystems;
- the mix of human activities cannot be sustained if the environmental processes that maintain the functional integrity of the ecosystem are degraded;
- some functions facilitated by the ecosystem are in fact true economic functions (e.g. shipping versus airfreight; cost saving of discharge of waste to the sea versus that on land);
- some functions have social or ethical benefits which require novel valuation;
- multiple users interrelate via trade off strategies to obtain sustainable outcomes.

The preservation of the functional integrity of marine and coastal systems has to be an explicit target for the optimal management of European seas; if not, marine resources will be adversely affected by overexploitation and unregulated competing uses *(see also Section 3.5: Integrated governance of European oceans and seas).*

Integrated marine science is needed to describe the polyfunctional properties, carrying capacities and limits of marine ecosystems; integrated coastal zone and ocean governance policies and management are needed to properly evaluate and sustainably extract the marine environment's multitude of benefits for society *(see also Section 3.1: Coastal zones; Section 3.5: Integrated governance of European oceans and seas).* This creative fusion of marine science and environmental economics sets a new generic knowledge-based framework for delivering the practical policies, investment strategies and management actions needed for sustainable use of marine and coastal resources.

2.3.2 Integrating marine ecosystem and socio-economic sciences

To efficiently develop the proposed methodology for linking marine ecosystem functions with socio-economic valuations and benefits, six bilateral themes are proposed below.

New functional typologies

The marine environment is made up of very different ecosystems encompassing estuaries, lagoons, littoral zones, reefs, shelf seas, islands, enclosed basins, canyons, ocean margins, abyssal plains etc. These ecosystems are subject to different climatic and oceanographic conditions, mixing and tidal regimes, and support different biotopes, food webs, biogeochemical cycles, sediment regimes, mineral resources etc. It would be of benefit if these contrasting marine ecosystems were systematically inventoried in terms of their global distribution, functional attributes and economic values, to produce generic functional templates that would progress in a unified and consistent way the socio-economic valuation of any marine ecosystem. Priority should be given to estuarine and coastal systems, as these are already highly manipulated systems of strategic relevance to Europe.

Robust valuations of goods and services from marine ecosystems

The many functions of marine ecosystems, and the processes through which the marine environment sustains many goods and services (e.g. flood barriers, habitats and wildlife, recreational amenity etc.) are not readily apparent. As a result, the social and economic contribution of the marine environment to society is undervalued, and is at risk from anthropogenic impacts. Sectors such as tourism, fisheries, aquaculture and marine biotechnology are directly dependent on a healthy biodiverse marine system, as are recreational and educational uses such as angling, wildlife observation and ecotourism. Many marine biological products, (e.g. fish products, biotechnology products for medical bioactive chemicals), are species-specific and their availability is directly based on preserving biodiversity *(see also Section 3.4: Marine biodiversity: the blueprint for ecosystem regulation).*

As detailed in Section 2.3.1 (*Introduction*), the true value of the marine environment has two components: the first one consists of all the goods and services actually sold in the market while the second consists of the flow of goods and services not sold in the market. Marketable goods and services include fishing, mineral, oil, shipping, defence, aquaculture etc.; they are market-based values and are part of national audits, contributing to national GNP.

There are as yet no market prices for many useful services provided by marine ecosystems to mankind, for example climate control, scenic vistas, amenity, flood barriers, repository for waste disposal etc. Consequently, these services are not audited into national accounts. Alternative methods of valuation have been developed and applied since the 1980s. Of these, the procedure known as contingency valuation methods (CVM) is the most powerful, as it can be applied when all other methods fail. Not surprisingly, CVM is subject to criticism because it is based on people's willingness to pay or accept that ecosystems have an economic value, and is dependent on public awareness of choices.

Valuation of marine science and technology

Applied marine scientific research, yielding relevant and quality-controlled results in a robust and cost-effective way, would assist planners in reducing the risks associated with unsustainable development and extreme environmental events *(see also Section 4: Ocean climate interactions and feedback).* This would also involve the development of marine indicators *(see also Section 2.3.4: Development of indicators).*

Fundamental or basic marine research and technology advances knowledge and understanding, and makes new discoveries, some of which have profound societal or environmental consequences *(see also Section 5.1: Marine biotechnology: bioprospecting the planet's largest biotope)*. Human influence and impact on the marine environment is now global, and confirms mankind as custodian of the ocean's ecosystems *(see also Section 3.5: Integrated governance of European oceans and seas).* The knowledge and understanding that is needed to manage mankind's only planetary life-support system is invaluable. As in other areas of natural sciences, the socio-economic valuation of marine research and resources remains an urgent task.

Embedding socio-economics into integrated marine science projects

Social and economic analyses provide a framework for integrating marine science research results into a marine environment management tool. An integrated marine environment management tool would evaluate the trade-offs and interactions between activities affecting the marine environment, and thus inform decision makers. The structure of the integrated management tool would be based on the research results of the marine sciences that describe the processes, interdependencies and interactions of the different marine ecosystems *(see also Section 3.4: Marine biodiversity: the blueprint for ecosystem regulation).* The economic analysis would then evaluate the economic and social benefits of developments and activities that would alter or affect the various marine ecosystems. The combined management tool would potentially incorporate the dynamic relationships between ecosystems, between ecosystems and human activities and their economic and social benefits, and also the affect of economic and human activity on the physical marine ecosystems. Management decisions could then be made that would reflect the integrated nature of the marine environment and achieve optimal use of the marine environment's resources, both across activities and over time.

Governance and sustainability

Many goods and services provided by the marine environment are classified by economists as non-rival and non-excludable, in other words, there are no associated market-based checks and balances on supply and demand, and so the market fails to produce their optimal allocation. While government intervention is needed to avoid overexploitation or destruction of the resource, it does not automatically cure market failures: information is needed, targets have to be identified and economic instruments of intervention have to be put in place. Governance is possible only if there is adequate understanding of the marine system by all stakeholders and if monitoring systems allow assessment of its development *(see also Section 3.5: Integrated governance of European oceans and seas).*

Protecting the marine environment for future generations

The problem of ensuring the inheritance of healthy marine ecosystems for future generations, strictly linked to the sustainability of growth, is complex because it involves ethics regarding the use of the inherited natural resources of the global village. Agreement on target qualities and quantities of marine services to be passed on to future generations is needed, in order to guide present decisions and value structures. For example, does society wish to pass on a viable or a collapsed fishing industry? Does society wish to mitigate its impact on climate? What are the costs of doing nothing? These are urgent and important challenges at the interface between society, ethics, and science *(see also Section 1.2.1: Science, society and citizens; Section 3.5 Integrated governance of European oceans and seas).*

2.3.3 Critical tools for marine socio-economics

To perform the above tasks requires a great effort and a set of key tools including:

Communication

Common language and terminology must be harmonised at the interface between marine scientists and socio-economists to ensure effective and rigorous dialogue towards common goals.

Relevant data

Data templates (with default values) of the right combination of economic, environmental, natural sciences, temporal and spatial data are needed for key attributes of marine ecosystems to enable a seamless transition from marine research to socio-economic valuation.

Marine indicators

A set of indicators has to be agreed, both as tools for decision making and for assessing environmental performance by various countries *(see also Section 2.3.4: Development of indicators).*

Novel valuation methods

Novel valuation methods are required where the market is absent and/or when external effects are evident. Contingency valuations methods (CVMs), and other valuation methods need to be critically compared in pilot marine projects across Europe.

Coupled marine environmental and socio-economic models

Ecosystem-specific models incorporating socio-economics and scenario feedbacks promise to be useful quantitative tools and protocols for evaluating consequences of different management options on the ecosystem and society. As a first step, these might be usefully tested on a few well-understood urban estuaries of significant economic value to Europe.

Valuation protocols for Europe's marine assets

For a true integration of environmental concerns into economic policies of the European Union, incorporation of the monetary values of the marine assets and flows into the national account system is required. GDP does not consider the natural environment. In the first instance, the system of national accounts actually in use among countries to calculate GDP can be modified by the inclusion of stocks and flows stemming from the interaction between the economy and the environment. Eventually, the proposed European Systems for Integrated Environmental and Economic Accounts (ESEA) and European Systems for Environmental Pressure Indices (ESEPI) made in 1994 could be extended to the marine environment.

2.3.4 Development of indicators

The widely applied OECD (Organisation for Economic Co-Operation and Development) definition of an indicator is:

> *"A parameter, or a value derived from parameters, which points to/provides information about/describes the state of a phenomenon/environment/area with a significance extending beyond that directly associated with a parameter value"* (OECD 1993).

The increasing development and application of robust indicators will provide tools to evaluate marine science and technology, marine socio-economics and environmental aspects of marine resource management.

Research into the development of indicators is at an early stage and includes some refinements to the traditional DPSIR (driving force, pressure, state, impact and response) framework, which is advocated by the OECD.

The European Environment Agency (EEA) is attempting to develop DPSIR indicators to assess the environmental status of European seas, including impact indicators for coastal monitoring of pollution and eutrophication (at present still lacking required quality). The EEA has identified the use of Geographic Information Systems (GIS) in the marine and coastal environment as a priority objective for the future, particularly as a means of achieving increased efficiency for assessment of impacts.

Europe is presently lacking relevant quantitative indicators, socio-economic data and syntheses required for policy development and marine science management. Three categories of indicators should be prioritised for development:

1. Indicators of marine science and technology

Indicators of the status and evolution of marine science include:

- 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.

2. Socio-economic indicators

Socio-economic indicators describing status and evolution of sectoral marine-related activities, including: (i) economic added value; and (ii) employment generated by various branches of marine research and technology.

3. Environmental indicators

Environmental indicators include 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 they are not homogeneous and are generally limited to socio-economic indicators at the European level (e.g. associated with fisheries, coastal environments, leisure activity, maritime transport).

Synthesis and further development of indices is required 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 a demonstration of sustainable development options adapted to regions;
- synthesise existing indicators with a view to developing European indicators, including benchmarking of indicators and practice;
- publish and disseminate regular reports on the state of European seas and marine activities based on these indicators.

These objectives will contribute to the establishment of comprehensive databases on existing scientific, technical, and socio-economic competence relevant to policy making. The objectives should be implemented through active and innovative cooperation with relevant European and national organisations. The resultant data and 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 to improve their governance *(see also Section 3.5: Integrated governance of European oceans and seas).*

These tasks are among the objectives of the European Centre for Information in Marine Science and Technology (EurOcean) incepted by France and Portugal in September 2001, which aims to stimulate the development of marine indicators in Europe for science, technology and socio-economics.

2.3.5 Key research recommendations

- The economic and social values of the marine environment contribute to the GDP and quality of life in Europe. Economic evaluations of the intrinsic resources of coastal and marine areas and the impacts of pollution damage, biodiversity change and improper management of these resources should be assessed.

- The conflicting requirements of sustainable coastal and marine resource management and its competing human uses with environmental protection in the coastal and marine area should receive special attention by socio-economic modellers.

- There is a requirement to develop new functional typologies for contrasting marine ecosystems based on the different goods and services benefiting human activities. Pilot studies should be initiated, using different methodologies, to produce economic values for market and non-market goods and services. These studies should be applied to a European regional seas programme, and to a cost-benefit analysis of conserving marine biodiversity in European waters.

- Development of reliable socio-economic indicators and evaluations are also required. Three categories of indicators should be prioritised for development: (i) indicators of marine science and technology; (ii) socio-economic indicators; and (iii) environmental indicators – indicators of the status of marine resources – that will contribute to the implementation of effective resource management and protection protocols. These environmental indicators would encompass biological, geological, chemical and physical factors characterising the health of coastal and oceanic ecosystems. In addition, indicators should be developed with regard to the nature of pollutants and their relation to human activities and urban concentration. Such indicators would provide input to the reports on the marine environment produced by European organisations such as ICES, EEA, OSPAR etc.

3. Europe's coastal zones and shelf seas

3. Europe's coastal zones and shelf seas

3.1 Coastal zones

The term coastal zone is used to denote an area of transition between non-maritime terrestrial and freshwater ecosystems and wholly marine components of global ecosystems. As boundaries quantifying resources depend on the specific resource in question, and on how this resource interacts with others in the system, the extent of the coastal zone cannot be rigidly defined, and various interpretations exist. For example, the World Bank describes the coastal zone as:

> *"the interface where the land meets the ocean, encompassing shoreline environments as well as adjacent coastal waters. ...For planning purposes the coastal zone is a special area, endowed with special characteristics of which the boundaries are often determined by the specific problems to be tackled."*
> (World Bank 1993).

The LOICZ (Land-Ocean Interactions in the Coastal Zone) definition of the coastal zone is the area between 200m above and 200m below sea level *(see http://www.nioz.nl.loicz).*

Thus, natural coastal systems and the areas in which human activities involve the use of coastal resources may extend well beyond the limit of territorial waters, and many kilometres inland. There is widespread agreement that to understand and manage the coastal zone, both the freshwater catchment areas and the processes along the continental margins should be included. In addition to the lack of natural boundaries, the coastal zone seldom corresponds to existing administrative or planning units; it is thus increasingly referred to as the coastal marine area.

The coastal regions of Europe have been the focus of human settlement and economic activity for many millennia. Depending on the definition used, 20-50% of Europe's population live within the coastal zone and depend on it for their living and quality of life. By the year 2020, 75% of the world's population will live within 60km of marine coasts and estuaries. Tourism influxes add to this impact of human activity on the coastal zone. In the mid 1990s, the Mediterranean coastline alone received annually an estimated 75 million international and 60 million domestic tourists.

There are many conflicting uses of the coastal zone, including industrial, leisure, tourism, waste disposal, fishing, aquaculture, transport, and conservation, all of which require careful management solutions that balance economic benefits with minimising impact on the health of coastal and shelf environments *(see also Section 2.3: Socio-economics and marine resource sustainability).* The high concentrations of energy, sediments, and nutrients that stimulate both high biological productivity and a wide diversity of habitats and species in the coastal zone necessitate management procedures different to those required inland or in offshore areas. While the richness and diversity of coastal resources has long been recognised by human society, the health of marine ecosystems is increasingly at risk from human activities and increased settlement along shorelines and estuaries throughout Europe. Therefore, one of the most important challenges facing the countries within the European Research Area is to maintain the continuity of human use of coastal shelf areas and their natural resources, taking into account increasing development pressures, uncertainties over future pollution impacts and the scale and nature of climate change consequences on coastal shelf seas.

3.1.1 Diagnosing coastal health

How can the health of a marine ecosystem be defined? Pollution, overfishing, coastal urbanisation, saltmarsh drainage etc. are tangible examples of environmental stress factors which could reduce the health of a coastal system. It is obvious that more rigorous and universal indices or indicators are needed to cover the diversity of marine ecosystems and the large variety of anthropogenic stresses that impact on the coastal shelf seas *(see also Section 2.3.2: Integrating marine ecosystems and socio-economic sciences).*

The health of a marine ecosystem could be defined as the degree to which its biological, chemical and physical components are functionally viable and analogous to an equivalent pristine ecosystem unaffected by man. This requires first the recognition of the many and diverse types of natural coastal marine ecosystems that are extant in Europe, and their subsequent classification. Such a typology might include the following key properties for coastal shelf seas:

- climatic zones (polar, temperate);
- physiography (estuaries, fjords, rias, beaches, bays, deltas, marshes);
- hydrodynamics (circulation, tides, stratification, sedimentation, wind, waves, storms);
- trophic state (eutrophic, oligotrophic, benthic, planktonic);
- ecotoxicological state (chronic versus sub-lethal, toxic metals, persistent organics);
- biodiversity (species richness and abundance, distinctness, redundancy, functionality, resilience of benthic and pelagic communities).

The system remains healthy if the proposed activities or developments produce reversible changes and do not fundamentally distort or alter the vital characteristics and functions of the system. Perfectly healthy ecosystems are also naturally variable in response to long-term climate drivers, and this needs to be separated from anthropogenic effects. The above approach is still qualitative, but efforts by LOICZ and other groups to develop new typologies for coastal environments will result in quantitative indices by which to assess, rank and diagnose the health status of contrasting marine systems.

3.1.2 Natural variability

Over the last decade it has become increasingly clear that the Northern Atlantic Oscillation (NAO) *(see also Section 4.2: Ocean thermohaline circulation - Europe's heat engine)* determines to a large extent the natural variability of the ecosystems in European coastal zones and in land-locked or inland seas such as the Baltic, Mediterranean and Black Seas *(see also Section 1.1.1: The ocean in the Earth's system)*. The time scales involved vary from seasonal, to annual, to decadal, to centennial. Moreover, the NAO also interacts with other oceanic phenomena such as the thermohaline circulation, the Tropical Atlantic Variability, the Arctic Variability and El Niño, and is possibly influenced by global warming. Other important drivers of natural variability include a lunar periodicity of 18.6 years producing tidal anomalies, and solar sunspot activity cycles over decadal to centennial periods that affect climate.

Consequently, coastal ecosystems are impacted by cold or warm winters, frequent or sporadic storms, high or low average wave heights, high or low runoff rates, and by changes in erosion/ accretion patterns, sedimentation and resuspension.

Coastal erosion North Sea. © University of Bremen, Germany

Coastal erosion Wadden Sea. © Netherlands Institute for Sea Research

Such natural variability substantially affects the physical and morphological boundaries of coastal ecosystems and inland seas and consequently their chemistry and biology. Hence, before sustainable exploitation of coastal ecosystems can be progressed, the physical, chemical and biological bandwidths of the natural ecosystem have to be determined.

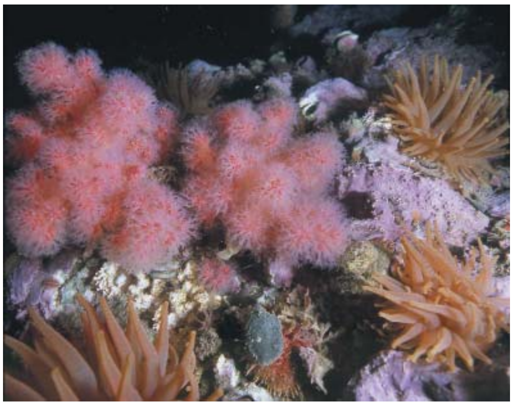
Such assessment is a difficult task since few pristine European coastal ecosystems are extant. Therefore, reconstructing the past and predicting potential future scenarios will require a combination of historical data, long-term data series and high-resolution analyses of sedimentary archives. To establish the natural variability of European coastal ecosystems is a major scientific task in itself, which can be accomplished only by effective European collaboration of palaeontologists, climatologists, meteorologists, oceanographers and coastal scientists critically analysing their historical data and long-term data series, pooling such data with contemporary data, and the subsequent careful interpretation of these large data sets.

Long-term observations of climatic drivers, oceanographic and biogeochemical parameters must be maintained in order to distinguish and attribute coastal marine changes in terms of natural versus anthropogenic causes.

Once the natural variability has been established the second major line of research can start focusing on the sustainable use of coastal ecosystems and enclosed seas. Knowledge of the capacity to absorb natural variability may assist in establishing the limits of physical, chemical and biological perturbations that would not irreversibly change the natural ecosystem.

3.1.3 Experimental management: multiple benefits to coastal seas

European marine scientists have investigated and diagnosed the origins and causes of several major coastal problems such as eutrophication, fish kills, erosion, anoxia, persistent contaminants etc., and suggested solutions for formulating potential new management regimes. While there is often resistance to the initiation of novel management regimes, because of uncertainty associated with their outcome, there is a need for research outcomes to be implemented, otherwise scientific endeavours are wasted.



Rocky bottom locality (ca. 20 m depth) at Kongsfjordnesset in Kongsfjorden, Svalbard with the sea urchin *Strongylocentrotus droebachiensis* and the cnidarians *Gersemia rubiformis* and *Urticina eques.* © B Gulliksen

European coastal zone managers must move from a responsive mode of reconciling conflicting uses of the coastal environment to a more proactive adoption of experimental management regimes to test predictions that have arisen from experimental studies. Examples of options for experimental management are detailed below:

Wind farms (see also Section 2.2.2: Renewable energy)

If parts of the coastal seas are to be developed as wind farms, with arrays of wind turbines to generate renewable energy, the opportunity should also be taken to experimentally explore concurrent multiple and sustainable uses in these areas. For example, by prohibiting seabed trawling within their vicinity, wind farms could also be developed as enhanced fisheries nursery grounds and aquaculture areas, with artificial reefs for new fisheries; mussels may be raised on longlines, lobsters in crab pots, attached oysters and macroalgae may be grown on rafts etc. There is also considerable scope for relocating inshore aquaculture enclosures to the more open wind farms offering good anchorage and improved circulation and dilution of aquaculture waste.

A mosaic of habitats: intertidal sand beaches and rocky shores, subtidal sands, seagrass and kelp beds.
Eastern Isles, Isles of Scilly, UK.

Sea defences

Original coastal habitats have been lost due to erosion despite sea defence efforts such as seawalls, dykes and groins. Sand-nourishment schemes to form sandy spits could offer a chance to restore lost habitats. In the shelter of such a sand bar, mud may accumulate and saltmarshes may develop. Another option would be to develop arcs of sandy isles and sand bars, providing shelter while at the same time providing sites to coastal birds for undisturbed breeding, roosting and overwintering. Depending on sea level rise and the resulting sediment dynamics, such sand-nourishing schemes may last for decades or centuries but will continuously change in size and shape, generating a diversity of coastal habitats otherwise in short supply. Because of the ephemeral nature of such sand deposits, future generations would not be compromised in their use of the coastal zone.

3.1.4 Biogeochemical dynamics at the land-ocean interface

Estuaries, shelf seas and ocean margins are dynamically coupled and biogeochemicaly reactive highways for the transport, transformation and export of terrestrial and anthropogenic products into the ocean.

Towards a shelf sea typology

European estuarine shelf margin systems exhibit a sequence of distinct biogeochemical sub-provinces bounded within hydrodynamicaly coherent regimes. For example, in the case of a transect from the Southern Bight of the North Sea westwards to the Atlantic Ocean, use of both remote sensing satellite imagery and models shows a clearly delineated sequence of: (i) estuarine plumes driven by episodic flush outs of estuarine sediments; (ii) tidally mixed and light-limited coastal regimes; (iii) tidal fronts; (iv) seasonally stratified deeper waters; and (v) shelf edge upwelling zones. The planktonic food web, nutrients and trace metal biogeochemistry and the degree of bentho-pelagic coupling are unique and reproducible within each shelf province. On the other hand, in the Mediterranean, with its narrow shelves and small tides, a simpler system of biogeochemical sub-provinces may occur. This biogeochemical typology proposed for shelf seas could form the basis of a new functional ordination scheme that could be nested within hydrodynamic models, describing European shelf sea systems. Provided that critical observations of biogeochemical concentrations, rates and parameters are recorded, then it should be possible to address scenarios of societal importance (e.g. eutrophication, pollution inputs, climate change drivers and ecosystem restructuring) in a manner consistent with biogeochemistry.

Pollution and associated risks in the marine environment

It is estimated that the number of synthesised chemicals now totals over 2.8 million, and is growing at a rate of 250,000 new formulations annually. Of these, 300 to 500 per year reach the stage of commercial production with a global production of 100 to 200 million tonnes. It is also estimated that up to one third of the total production of these synthetic organic chemicals finds its way into the environment, and the sea is the ultimate repository. Some of these chemicals are inert and toxicologically benign (e.g. polymers); others are highly toxic and persistent (e.g. dioxins, PCBs, petroleum polyaromatics). Environmental degradation of reactive compounds reduces this burden of impact, but also generates a further suite of degradation products covering a spectrum of reactivities, persistence and toxicity. The direct introduction of industrial (e.g. oil, chlorinated organics, dioxins) and domestic (e.g. sewage, detergents, pharmaceuticals) waste products and the widespread environmental application of agrochemicals (e.g. fungicides, pesticides, herbicides) and aquatic biocides (e.g. antifoulants, antibiotics) have been the focus of marine pollution research to date.

Estuarine reactors

Europe's estuaries span a wide range of sizes (10-1,000km), forms (rias, fjords, lagoons, inland seas), flushing times (< 10 days to > 1,000 days) and biogeochemical reactivity (turbid, stratified, anoxic, eutrophic, acidic). These size and time constraints have profound consequences on the cycling of carbon, nitrogen, trace elements and pollutants. By modelling catchment-based industrial, domestic and natural weathering fluxes, it is increasingly possible to reliably estimate inputs of elements and pollutants to river fluxes. However, the downstream transformation of these fluxes and the fate of substances in estuaries and shelf seas are generally poorly understood and require urgent systematic research covering different European estuaries.

Estuaries are biogeochemical reactors. For example: (i) intense bacterial degradation of organic matter not only depletes oxygen but may also result in outgassing of vast amounts of CO_2, which for some European estuaries could amount to 5-10% of the regional emissions of fossil fuel derived CO_2; (ii) macrotidal estuaries exhibit steep gradients in pH, redox, ionic strength and turbidity which trigger numerous non-conservative flocculation and sorption reactions affecting trace metals and hydrophobic organic pollutants; and (iii) high nitrate (NO_3) and phosphate (PO_4) levels in European estuaries often stimulate algal blooms, some of which are toxic or harmful in coastal marine waters.

3.1.5 Key research recommendations

- To meet the challenge of progressing integrated coastal zone management (ICZM) and governance, baseline interdisciplinary research is required. This will contribute to the resolution of the conflicting requirements of multi-user needs. The strategies for ICZM should be based on integrating oceanographic, fisheries, geological and biological research with the requirements of sustainable resource use, maritime transport and offshore industries, and environmental protection. ICZM should embrace strategic integration of initiatives such as renewable energy schemes with offshore aquaculture, and artificial reefs with protected nursery grounds *(see also Section 3.5: Integrated governance of European oceans and seas)*.

- Across Europe and its ultraperipheral regions, coastal developments and management actions are impacting on regional biodiversity. Prioritisation should be given to investigating the environmental impacts and biodiversity consequences of increasing tourism and leisure in the littoral zone, port developments, intense aquaculture in inshore locations, selective fishing of top predators, and deep ocean disposal of domestic and industrial wastes and CO_2 *(see also Section 3.4: Marine biodiversity: the blueprint for ecosystem regulation)*.

- Estuaries, shelf seas and ocean margins are reactive highways for the transfer and transformation of terrestrial and anthropogenic products into the ocean. The transformation of these fluxes is generally poorly understood. Systematic research on biogeochemical budgets of nutrients (carbon, nitrogen, phosphorous) and their ecological effects are required for contrasting estuaries and shelf systems. Research should also focus on the fate of terrestrial carbon and pollutants in the ocean, and on the climatically important role of ocean margins as net sources or sinks of carbon *(see also Section 4.3.1: Oceanic CO_2 sinks, feedbacks and limits in a greenhouse world)*.

- Europe faces dramatic increases in the numbers of organic and biotechnological compounds and pathogens discharged into the marine environment. These pollution mixtures exceed the monitoring capabilities of Europe's environmental agencies and there is a risk that major impacts on ecosystems will not be detected. Europe should rapidly adapt new array-biotechnological chips to provide non-invasive, affordable, and high-throughput systems for ecotoxicological screening of water quality. This would allow ecologically more meaningful toxicity-based discharge consents and toxicity-directed chemical monitoring strategies that can cope with the multitude of new chemicals discharged annually into European coastal waters. It would ultimately contribute to the development of reliable ecotoxicological indices of status of oceanic and coastal waters.

- Natural and anthropogenic causes of ecosystem variability should be characterised and distinguished, particularly in the coastal seas. Long-term high-quality observations of climatic drivers, oceanographic, biogeochemical and anthropogenic parameters should be synchronised at critical points in the European coastal and marine areas.

3.2 Strategic observing and monitoring systems

3.2.1 Observation networks for vulnerable coasts

National coastal datasets are collected for statutory or monitoring purposes rather than for long-term marine scientific observations. Only a limited number of marine time series observations for scientific purposes have been run in the Atlantic, Baltic, North Sea, and Mediterranean.

There is an urgent need to invest time, effort and funds in gaining additional value from the scattered data and scientific knowledge that exist in time series. Meta-analyses of existing studies grouped into a mosaic of coastal ecosystems will help define local variability and locations with the highest sensitivity to environmental change. This will contribute to the fulfilment of the objective of the European strategy to protect and conserve the marine environment.

Ultimately, a harmonised European network of cost-effective permanent coastal ocean observing systems at key European coastal sites will need to be established. These should be fitted with intelligent sensors and telemetry, capable of providing real-time data for diagnostic and prognostic studies on coastal and shelf oceans to support decision makers in coastal zone management and the marine industry *(see also Section 6: Critical technologies).*

Coastal regions are predicted to become particularly vulnerable to global warming, including sea level rise, changing erosion, flooding of lowlands, inundation of installations and settlements (urban and tourist), salt intrusion into groundwaters, littoral zone exposure to extreme winds, and increased river flows from wetter seasons. Consequently, a European coastal observing network could develop warning systems of extreme events, predicted to occur more frequently under greenhouse scenarios.

Incidents such as harmful algal blooms and oil spills constitute an increasing threat to the European coastal ecosystems. Even though most of the oil introduction in the marine environment occurs in a diffuse way, major impacts are related to catastrophic events and should be reduced by appropriate security measures.

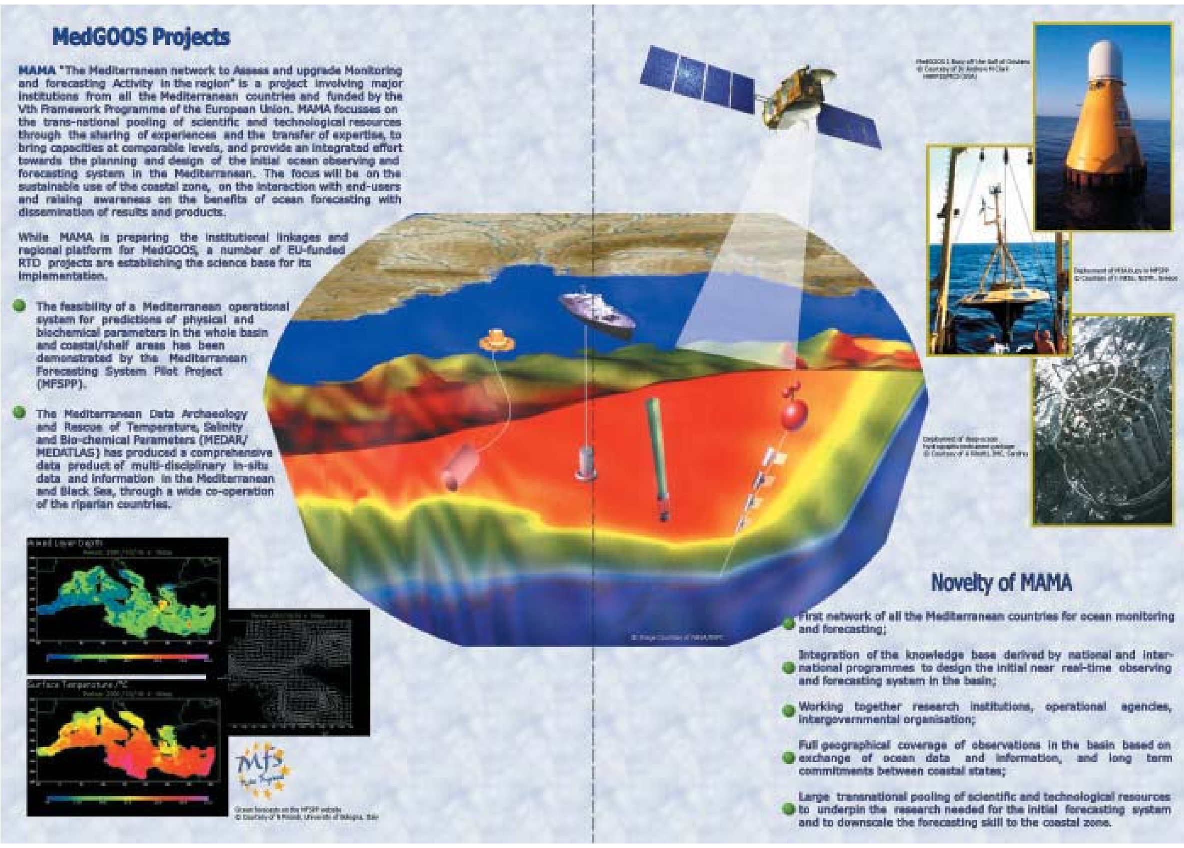
3.2.2 Operational oceanography

Operational oceanography has been described by EuroGOOS *(see opposite page)* as the process of routinely making, disseminating and interpreting measurements of seas, oceans and atmosphere to:

- provide continuous forecasts of the future condition of the sea as far ahead as possible;
- provide the most usefully accurate description of the present state of the sea, including living resources;
- assemble climatic long-term datasets which will provide data for description of past states, and time series showing trends and changes.

Operational oceanography facilitates safe and efficient marine operations (e.g. navigation, search and rescue operations, constructions at sea etc.). It mitigates against natural hazards (e.g. storm surges, tsunamis etc.), and detects and forecasts ocean components of climate variability (e.g. NAO). Operational oceanography supports sustainable exploitation of marine resources (e.g. fisheries – detection of fronts, fish farming – early warning for algal blooms and extreme events). It also assists in preserving the health of marine ecosystems (e.g. detecting and monitoring oil spills, detection of algal blooms and anoxic conditions).

Operational oceanography includes systematic observations of the ocean and the coastal marine environment, efficient (near real-time) transmission / interpretation of data and the use of data for the production of reliable forecasts. The aim of ocean operational forecasting is to produce predictions of the 3-D physical sea state and related marine biochemical components for a



certain period. To produce such predictions, the systems should include observational networks with real time data acquisition capabilities and analysis systems, numerical models and data assimilation procedures. Products (data and forecasts) can then be disseminated to end users. Operational systems currently available provide data and forecasts of physical characteristics such as: wind velocity and direction over the sea, wave height, direction and period, 3-D current fields, sea level variations (tides, storm surges), floating sea ice, and temperature and salinity profiles. The rapid developments in monitoring technologies *(see also Section 6: Critical technologies)* and biochemical modelling expand the range of products to include: indicators of marine pollution and contamination, movement of oil slicks, concentrations of nutrients, primary productivity, sediment transport and erosion.

In 1989, the UN International Oceanographic Commission (IOC) envisioned the development of the Global Ocean Observing System (GOOS) as a permanent system for observation, modelling and analysis of marine and ocean variability to support operational ocean services worldwide. GOOS was conceived as end-to-end and user-driven to develop a locally relevant, global-scale observing system for multiple use that is sustained and integrated. It is a complementary programme to the Global Climate Observing System (GCOS) and the Global Terrestrial Observing System (GTOS), designed in response to the need for sustainable development as proclaimed by the UN Earth Summit Conference in 1992 (Rio Conference on Environment and Development - UNCED; Rio Declaration). GOOS provides accurate descriptions for the present state of the oceans, including living resources, continuous forecasts of the future conditions of the sea for as far ahead as possible, and serves as the basis for forecasts of climate change. EuroGOOS, established in 1994, represents a furthering of European collaboration in marine science monitoring. EuroGOOS provides a forum for a consortium of 30 national agencies from 16 European countries to work towards joint operations, and its publications provide in-depth analysis of relevant operational oceanography science and technology.

The challenges that face operational oceanography include the assimilation of satellite data into models, and the production of high spatial resolution reliable data detailing the ocean surface (wave fields, current fields, wind fields). While several research initiatives have to date attempted to achieve this, there is still an absence of products regarding current fields. This is particularly true for coastal zone areas. Research effort should focus on the development of systematic means of acquisition (and production) of information. The challenge is then to get the information from whatever source (sensor, spaceborne etc.) and to be able to deliver it in a timely manner. Thus, there is a requirement for the research to look beyond the oceanographic problem per se and include the data processing, data merging and data and product delivering processes also.

3.2.3 Ocean monitoring, and Global Monitoring for Environment and Security (GMES)

As in meteorology, dynamic models lie at the heart of ocean monitoring, and the design of future monitoring systems will increasingly be based on OSSEs (Observing System Simulation Experiments). An international experiment, GODAE (Global Ocean Data Assimilation Experiment), is planned to investigate how much the Argo system (a global array of oceanic bouys distributed to collect oceanographic data) of undulating drifters will contribute to the performance of operational ocean models. Future designs will include conditional sampling, by which measurements are made by autonomous underwater vehicles (AUVs) at locations that provide the greatest contribution to enhancing forecasting ability.

The European global models used today in operational oceanography (e.g. Forecasting Ocean-Atmosphere Model, FOAM, and MERCATOR) are expected in the near future to include more realistic representation of bottom topography (e.g. adaptive grids), better simulation of vertical motion (non-hydrostatic models), and more effective data assimilation techniques. Modelers have already highlighted the fact that they do not yet have an adequate map of the shape of the seafloor; current attention towards designing a global bathymetry database with the appropriate accuracy required by the modelers will address this.

The main limitation factor in ocean forecasting remains the lack of real-time data that would properly constrain the numerical models. In Europe, adequacy of current monitoring networks is limited by:

- inconsistencies within and lack of integration between existing monitoring systems;
- inadequate frequency of monitoring;
- lack of continuity of monitoring systems (e.g. due to changing technologies, sampling procedures, network design);
- overspecificity of available monitoring and observation systems (i.e. difficulties in providing data for multiple purposes).

Major progress has been achieved during the past twenty years in using satellites to remotely sense the ocean *(see also Section 7.2.4: Satellites and aircraft),* and they now play an essential role in monitoring and detecting changes and ocean forecasting. Satellite data are also used to feed numerical models in order to understand and predict possible changes, and for independent verification of model performance.

Systematic observation and monitoring networks are deteriorating in many parts of the world, due to, among other things, a lack of long-term investment; many other geographical areas are still very sparsely covered. Arresting the deterioration of monitoring networks is a priority for Europe and globally. Monitoring requires an integrated system, with remote sensing and *in situ* components, and associated data handling, distribution and storage facilities. The synergy between monitoring requirements for research and those for operational policy and commercial purposes is evident. It is not sufficient that monitoring costs are borne purely by research budgets. A recent European partnership (European Space Agency, the European Commission's DG Environment and DG Research) has emerged as a mechanism to address this. This joint initiative of ESA and the EC plans to ensure an autonomous European operational capability for the Global Monitoring for Environment and Security (GMES), and to have an operational system in place by 2008. The core elements within GMES are: (i) satellite remote sensing; (ii) *in situ* monitoring; and (iii) data assimilation into models for useful products. GMES will provide a mechanism to coordinate research costs with monitoring costs. The trial period for GMES will be developed within FP6, with the ocean as one of the themes.

There are intrinsic research and technological developments associated with the effective development of a European capacity for GMES, with the implementation of GMES, and with the maximisation of the results ensuing. The GMES initiative has identified inadequacies in the available data as a major constraint to the use of information for policy support. These inadequacies derive from the limited scope and extent of monitoring networks and surveys, and the often poor quality, incompleteness and lack of compatibility of the data they produce. They also derive from the challenge of matching long-term monitoring systems to the changing information needs of policy, as well as to technological changes.

Among the institutional, organisational and policy issues identified are the inadequate or unreliable funding of, and support for, long-term monitoring or data gathering (e.g. repeated surveys) by European Union and national agencies. This is in addition to poor links between monitoring, research and information use (including inadequate mechanisms or funding to enable data to be explored and analysed for policy purposes, or to translate short-term research results into sustainable monitoring systems).

Technology issues that should be addressed include:

- the need to stimulate technological transfer from fields such as space and medical science;
- performance and adequacy of observation instruments;
- inadequate information technologies for data acquisition, including monitoring and survey, and production;
- limitations in existing technologies for transmission and use of information.

The ESF Marine Board is ideally placed to enhance connection between the scientific community and ESA, and the EC DG Research and DG Environment, contributing to effective and optimal implementation and application of the marine element of GMES *(see also Section 7: Research infrastructures).* Other relevant instruments for research into monitoring capabilities include the *ESF Forward Look on Earth System Science: Global Change Research.*

3.2.4 Key research recommendations

Strategic observing and monitoring systems

- Coastal areas are predicted to become increasingly vulnerable to the effects of global warming. Effects include sea level rise, increased frequency and intensity of storms, increased wave height, flooding of lowlands, inundation of installations and settlements (urban and tourist), changing erosion patterns, salt intrusion into groundwaters, littoral zone exposure to extreme winds, and increased river flows due to wetter seasons. A European long-term coastal observing network is required to contribute to monitoring and forecasting extreme events predicted to occur more frequently under greenhouse scenarios.

- New systems based on new technologies and understanding of the sea will permit long-range forecasts of benefit in managing the seas and oceans, and in predicting changes and variability of climate. There is an overall requirement within operational oceanography for long-term ocean monitoring, predictions of ocean circulation at monthly/seasonal time scales, and climate simulations. Few systems are currently in an operational state, and effort is required to improve: (i) observing and modelling methods and technologies; and (ii) capacity building and global collaboration. Updating European bathymetric charts is necessary to contribute to the development of more accurate models for operational oceanography.

- Research is required for the development of systematic means of acquisition (and production) of information from satellite and other sensor data delivered in a timely manner. Research should look beyond the oceanographic problem per se and include the data processing, data merging and data and product delivering processes also.

- The marine element of GMES (Global Monitoring for Environment and Security), as devised by the European Space Agency (ESA), DG Research and DG Environment of the European Commission (EC), provides a mechanism to coordinate and optimise research efforts with monitoring efforts and improved information systems for the operational service providers, leading to enhanced product development. There are intrinsic research and technological challenges associated with both the effective implementation of GMES, and the maximisation of the results and products ensuing. The scientific, technical, socio-economic and institutional elements of the marine research community should be supported and coordinated to ensure effective involvement in GMES. The ESF Marine Board is ideally placed to enhance connection between the scientific community and ESA, the EC's DG Research and DG Environment, contributing to effective and optimal implementation and application of the marine element of GMES *(see also Section 7: Research infrastructures)*.

3.3 Ocean margin processes and geohazards

Ocean margins with their steep slopes separate the deep open oceanic ecosystem from shallow shelf seas. Margins are globally vital interfaces for the shelf-ocean exchange of sea water, momentum, heat, sediments, nutrients, and biota. Some unique properties of ocean margins include strong slope currents contributing to the Atlantic THC, local upwelling supporting new productivity, rich biodiversity and fisheries, globally important depocentres (areas of deposition) of carbon, tectonic and geothermal activity, sediment instability and wasting, and large reservoirs of oil, gas and hydrates.

Since the 1990s, marine scientists and geologists in Europe have begun to build up a strategic base of information about the exchange and mesoscale dynamics and biogeochemical fluxes of carbon, nitrogen and phorphorus, in addition to benthic biodiversity and activity, sediment stability, and sub-seabed microbiotic activity of ocean margins.

3.3.1 Material exchange and fate

Continental margins are the location for the final deposition of most sediments on Earth; up to 90% of the sediments generated by erosion on land are deposited there. Ocean margin sediments bear the strong imprint of tectonic settings, sea level changes, deep ocean dispersal and human intervention in sediment supply. Marine geologists in Europe have obtained key geochronological records of terrestrial and marine sedimentation events. These, together with new seafloor observations and time series on sediment dynamics, have enabled preliminary estimates of present day sediment supply to be made for some ocean margin types. The frequency of quaternary oscillations in sea level has prevented sediment supply and dispersal systems from reaching equilibrium. Furthermore, present day supply of continental weathered river borne sediments to shelf seas has been enhanced by deforestation and agriculture, and cut off by damming of Europe's rivers. Major uncertainties therefore remain about the fate and fluxes of sediments, in terms of flood plain storage, the amount trapped on shelves versus that escaping to the ocean, and the scale and frequency of mass sediment flows along ocean margins.

Deep ocean observation platforms fitted with advanced acoustic, and optical sediment sensors are needed to supply data on sediment dynamics and stability *(see also Section 7.2.3: Marine observational systems)*. This information is vital for risk assessment to submarine cables and hydrocarbon exploration structures.

3.3.2 Margins as net sinks or sources of carbon

The annual direction of carbon flow along European margins is largely unknown. Recent biogeochemical and oceanographic flux studies along contrasting regions of the North West European margins quantified a high level of primary production, associated with upwelling of nutrients along the shelf break. Most of the organic production was incorporated into the food web or was degraded at mid depth; very little organic carbon became buried in the sediment. In contrast, in the North American Atlantic margins there is a significant accumulation of carbon along slope depocentres. Upwelling margins off the Iberian Peninsula bring up subsurface waters supersaturated with CO_2 for ventilation to the atmosphere; subsequent nutrient-fuelled phytoplankton production draws down CO_2 into its biomass, and exports a proportion of the organic carbon to the deeper ocean where some becomes buried in the sediment. Winter cascading of cold shelf waters along canyons will also draw down CO_2, but the net annual direction of carbon flow along European margins remains enigmatic.

Two fundamental questions remain unanswered:

1. **What is the fate of terrestrial carbon fluxes to shelf seas?**
2. **Are ocean margins net sources or sinks of carbon?**

Finding answers to these questions is critical in establishing the oceanic budget of carbon and in understanding the fate of anthropogenic chemicals transported from shelf seas to the open ocean.

3.3.3 Geoclimatic hazards along ocean margins

The coastal and shelf-margins cover only 20% of the world ocean, but are regions of significant geoclimatic risk. Seabed operations such as oil and gas exploration and production, and telecommunication cables located along the deep ocean margins are confronted with a wide range of possible geohazards, including gravity slides, tectonically triggered earthquakes, and sudden releases of methane from gas hydrates *(see also Section 2.2.1: New hydrocarbon frontiers; Section 3.3: Ocean margin processes and geohazards).*

The North East Atlantic and Mediterranean margins are deeply incised and dissected by large canyons and gullies that extend from a depth of 200m or less at the shelf edge down to the abyssal plain. Canyons are preferential corridors for the downward transport of destabilised sediments that accumulate as submarine fan deposits at the base of the slopes and in the deep sedimentary basins. The scale and frequency of turbidity currents in these areas is not known.

Submarine landslides occur in both tectonically passive and active margins and are the most common processes affecting slope stability. Giant submarine landslides (> 1,000km^2) have been reported from every continental margin, while the Norwegian and West Mediterranean seas hold some of the largest slides (> 50,000km^2) on record. A much larger number of small slides, yet to be mapped, are thought to be of comparable importance in terms of volumes and seabed impact. Factors controlling slope stability and landslide triggers are poorly understood, despite a large number of investigations and surveys. Trigger factors most probably include earthquakes, rapid sedimentation events, changes in slope currents and sediment destabilisation from gas hydrates.

Gas hydrate deposits are widespread along ocean margins, and occur under high pressure / low temperature conditions (e.g. in depths > 400m and temperature < 4°C). Their zones thus depend on tectonics, bottom water temperature and sea level changes. Any destabilisation of gas hydrates could result in major submarine landslides, a catastrophic release of methane (a prominent greenhouse gas) to the atmosphere and the generation of tsunami waves (as occurred on the coast of Papua New Guinea in 1998). This is potentially a major geoclimatic hazard for both deep sea operations and coastal communities and assets, and is an example of an environmental issue that is controlled to some extent by climate. It has been estimated that vertical shifts of the gas hydrate stability zone in the order of 200m occurred at glacial/interglacial timescales, substantially affecting slope stability at certain locations. To what extent sea level changes or the warming of ocean bottom waters can result in a shift of the gas hydrate stability zone is still unknown.

Finally, extraction of hydrocarbons from deep reservoirs *(see also Section 2.2.1: New hydrocarbon frontiers)* along the margin may alter their thermal and fluid flow regimes which could destabilise fault zones and trigger earthquakes and submarine landslides. Geotechnical and sedimentological research in association with the hydrocarbon industry is required to mitigate against these risks.

3.3.4 Key research recommendations

Ocean margin processes and geohazards

- As the coastal shelf margins are regions of significant geoclimatic risk, sea bed operations such as oil production and communication cables are vulnerable to geohazards, including gravity slides, earthquakes, and sudden releases of methane from gas hydrates. Deep ocean observation tools and systems fitted with advanced geotechnical sensors are required to supply data on sediment dynamics and stability at ocean margins *(see also Section 5.3: Vents and seeps)*. This will allow assessment of the scale and frequency of mass sediment flows along ocean margins, and contribute to risk assessment for submarine cables and hydrocarbon exploration structures.

- There is a requirement to investigate the sources, properties, transport and budgets of terrestrial and marine sediments in contrasting European coasts, emphasising the biological influence (stabilisation, cohesion, irrigation, storage) of the global carbon cycle. Evaluation of the carbon depocentre role of different ocean margins and an assessment of the potential for atmospheric CO_2 sequestration at the European continental margins is also necessary.

- Research is required to analyse the role of gas hydrate reservoirs as dynamic components of the global carbon cycle, recharge and discharge fluxes and their controlling factors. There is a requirement to investigate the mechanism of gas hydrate destabilisation and potential geoclimatic hazards and to evaluate the impact of gas hydrates on slope destabilisation. Geotechnical and sedimentological research in association with the hydrocarbon industry is needed to mitigate against these risks *(see also Section 2.2.1: New hydrocarbon frontiers)*.

3.4 Marine biodiversity: the blueprint for ecosystem regulation

The ocean is regarded as the cradle of evolution and provides habitats for most of the phyla on Earth. Marine biodiversity refers to the inherent biological variety of marine ecosystems at the genetic, species and habitat level. Marine ecosystems provide a series of goods and services *(see also Section 2.3.2: Integrating marine ecosystem and socio-economic sciences)* that are intrinsically dependent on marine biodiversity. In addition, marine organisms play crucial roles in many biogeochemical processes that sustain the biosphere *(see also Section 4.3: Ocean biogeochemical impacts and feedbacks in a greenhouse world).*

The effect of marine biodiversity on ecosystem functioning is becoming a major focus for research. Ecosystems with high biodiversity are thought to be more resilient under stress: the more species an ecosystem carries, the greater the likelihood that in the decline or absence of one species, another species will adopt its functional role. Practical, diagnostic and robust measures of biodiversity thresholds and ecosystem functioning are now needed to underpin conservation, sustainable development and the socio-economic valuation of marine biodiversity.

Direct threats to marine biodiversity include overexploitation of species, introduction of exotics including toxic species, destruction of habitats by non-targeted fishing methods, fragmentation and loss of natural habitats, the impacts of coastal aquaculture and pollution, (including acoustic pollution from increased shipping, hydrocarbon exploration and extraction, military activities etc.), and the destruction of sedimentary systems (through fishing, mining, dredging and dumping) *(see also Section 2: Natural marine resources).* Indirect threats include the management and manipulation of rivers and coastlines for industrial development, tourism and residential purposes and the many disturbances linked to leisure activities. Maintaining marine biodiversity cannot be done in isolation and requires an ecosystem approach to resource management and sustainable development. The Convention on Biological Diversity (CBD; s*ee Appendix II*) provides an international framework for biodiversity conservation via an ecosystem approach.

Given the scientific uncertainties and economic importance of marine biodiversity, it is important to focus Europe's research efforts on three strategic areas, elaborated below. These include: (i) an assessment and inventory of the biodiversity of European seas, using marine taxonomy and genetics; (ii) the functional role of biodiversity; and (iii) climate and anthropogenic effects on marine biodiversity.

3.4.1 Biodiversity of European seas

The seas continue to yield exciting new discoveries, including the marine cave fauna in the Mediterranean, the shallow hydrothermal seeps in Greece, and cold seeps and cold water corals at European ocean margins *(see also Section 5.2: New ecosystems at oceanic extremes).* For the large scale monitoring of biodiversity changes in Europe, marine scientists should focus their limited resources on agreeing a set of key species at different taxonomic levels, and on tracking and mapping their distributions at key sites spanning the climatic and biogeographical regimes in European seas. Extensive integrated survey efforts are required to enable large-scale biogeographic distributions and biodiversity gradients to be GIS mapped spatially and temporally. Areas of high genetic and species diversity should be identified for conservation, and categorised as marine protected areas (MPAs).

The Convention on Biological Diversity led to the establishment of the Global Biodiversity Information Facility (GBIF) in Copenhagen, where data on biodiversity can be lodged and

Juvenile northern gannet with fishing line embedded in beak, observed along the Porcupine Seabight. © M Mackey, Coastal and Marine Resources Centre, University College Cork, Ireland

sourced *(www.gbif.org)*. The European contribution to GBIF is provided by ENBI (European Network for Biodiversity Information), of which ERMS (European Resgister of Marine Species) covers the marine aspect. Other initiatives addressing global marine biodiversity include the global Census of Marine Life *(CoML www.coml.org)* and the Ocean Biogeographic Information System, which provides a portal to marine species distribution data *(http://www.iobis.org)* and acts as a tool to unify global biological oceanography. These initiatives provide a mechanism for standardisation of databases, improving access and interoperability. This will ultimately lead to a more effective use of species as indicators in biological oceanography *(see also Section 2.3.4: Development of indicators)*.

3.4.2 Marine taxonomy and genetics

Taxonomy, with its globally accepted standardised nomenclature system, provides the foundation for biodiversity research, allowing development of species inventories. With the funding shift from morphological to molecular-based phylogenetics, classical taxonomic skills are rapidly disappearing, and marine ecology may soon lose the ability to classify unknown species, estimated to account for approximately 90% of the marine ecosystem.

Molecular techniques increasingly used in aquaculture and fisheries *(see also Section 2.1: Towards ecological sustainable fisheries and aquaculture)* have opened new possibilities for identifying genetic variability and distinguishing species (such as cryptic or sibling species). The socio-economic value of the application of genetics to marine biodiversity can be summarised under three themes, detailed below.

1. Describing marine biodiversity – a genetic inventory

Screening samples of a vertebrate species for several polymorphic microsatellite loci allows genetic relations of animals to be established and population structure to be identified, of particular importance when determining impacts of climate change. The current pace of whole genome sequencing will allow identification of new or existing interesting organisms, followed by sequencing. This inventory could provide the basis for the development of several novel products for the biotechnology industry *(see also Section 5.1: Marine biotechnology: bioprospecting the planet's largest biotope)*.

DNA profiling allows inter-relations between different population groups to be established; microsatellite DNA loci have been shown to be particularly discriminatory and are presently the markers of choice for such studies *(see also Section 2.1: Towards ecologically sustainable fisheries and aquaculture)*. Mitochondrial DNA (mtDNA) can be used to identify specific female relations within a group, population bottlenecks, and more ancient phylogenetic groupings; it is currently being used to assess the degree of relation between groups of cetaceans. The amplified fragment length polymorphism (AFLP) technique has the potential to rapidly identify species-specific genetic markers for species identification, diagnostics etc., and offers the possibility to further investigate the genome of fish and other species *(see also Section 2.1: Towards ecologically sustainable fisheries and aquaculture)*. Instead of concentrating on a few highly polymorphic genes, this technique allows the simultaneous visualisation on a single gel of about 200 loci.

2. Marine biodiversity and sustainable exploitation of commercially important marine species

Biodiversity provides the raw material that supports the fishing industry. Catch statistics and fisheries research indicate that the survival of several commercially important fish species is threatened by current exploitation rates and methods *(see also Section 2.1.1: Collapsing fish stocks and environmental impacts).* Understanding the population dynamics in terms of the factors that control population structures and estimation of effective population sizes are required to facilitate more effective exploitation strategies. More cost effective and efficient genetic analysis, which has to-date been limited by the cost and throughput of the techniques available, will greatly contribute to enhanced understanding of population dynamics *(see also Section 2.1: Towards ecologically sustainable fisheries and aquaculture).*

Common dolphins bowriding the FRV *Scotia*, on the Rockall Bank. © M Mackey, Coastal and Marine Resources Centre, University College Cork, Ireland

3. The potential of marine biodiversity to support aquaculture

As exploitation of wild populations becomes less sustainable, aquaculture will be required to supply the global market for fish and fish products *(see also Section 2.1: Towards ecologically sustainable fisheries and aquaculture).* The use of molecular markers can greatly accelerate the selective breeding process. Identification of quantitative trait loci (QTL) and family selection by pedigree analysis enable rapid improvement in strain characteristics, and so facilitate competitive advantage. Opportunities may also exist to assess the relative resistance of different genotypes to particular disease challenges *(see also Section 2.1: Towards ecologically sustainable fisheries and aquaculture).*

3.4.3 Functional role of marine biodiversity

Key species

The overall functioning and character of marine ecosystems is shaped by a small number of key species that exert a major impact on community metabolic processes such as primary and secondary production, remineralisation, vertical export and bioturbation, and predation. The impact of these species can be disproportionate to their abundance or biomass. Whereas genetic diversity stabilises a population, it is the functional diversity driven by key species that stabilises the ecosystem.

Pelagic species

The pelagic habitat is dispersive due to advection and mixing. Dominant planktonic species either have high growth and low mortality rates, or life cycle strategies that enable them to survive in a disperse and turbulent fluid. Phytoplankton productivity and succession tends to be dominated by a few species or genera: for example, in mesotrophic temperate seas, the diatoms *Skeletonema*, *Chaetoceros*, *Thalassiosira* and the haptophytes *Phaeocystis* and *Emiliania* dominate in the early or late spring bloom, followed by the dinoflagellates *Prorocentrum* and *Ceratium* in summer and autumn. Oligotrophic picoplanktonic species *Synechococcus* sp and *Prochlorococcus* sp. are suggested to be the most numerous organisms on Earth, and require ecological research. This also applies to the key zooplankton grazers *Calanus helgolandicus*, *C. finmarchicus* and *C. glacialis* which provide trophic links to pelagic fish, and act as gateways for the faecal export of organic matter to the deep ocean.

The functional link between benthic and pelagic systems is often strongly determined by benthic-filter feeders such as mussels (*Mytilus gallopro-vincialis*, *M. edulis*) or scallops (*Pecten maximus*, *Chlamys islandica*) which biodeposit massive amounts of phytogenic matter which fuels benthic productivity.

Benthic species

The benthic habitat is spatially fixed, heterogeneous and stable for longer periods. Dominant organisms in the benthos tend to be competitive space-holders. The diversity of soft bottom communities is strongly driven by organisms that manipulate the physical properties of sediments and create microhabitats for meiofauna and bacteria.

One of the functional roles of key soft bottom animals involves increasing fluxes and mixing or stabilising the sediments. Such animals include: (i) builders of reefs or aggregates; (ii) bioturbators which burrow, biodeposit, resuspend and irrigate sediments, for example, large molluscs, echinoderms and crustaceans such as *Nephrops* and *Thalassionoide*, and large polychaetes (e.g. *Arenicola marina*, *Sabella pavonina* and *Lanice conchilega*). Key flora for soft bottom habitats include macroalgae (e.g. *Fucus*, *Laminaria*), seagrasses (e.g. *Zostera, Posidonia*) and mangroves which also stabilise the seabed and create microhabitats around their rhizoids or roots.

Communities in the rocky littoral zone, are more affected by competition for space and by key predators. Sedentary organisms such as the various sea weeds, sponges, gorgonians, corals, bryozoans, and bivalves are probably the most highly diverse and spectacular marine communities in Europe.

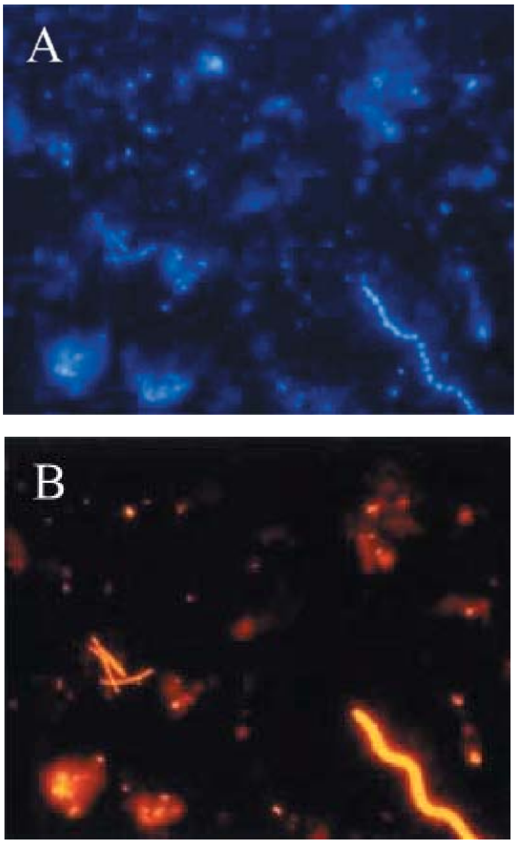
Key vertebrates for top-down control

Vertebrates are often ignored by general oceanographers and marine ecosystem ecologists when focusing on ecosystem processes, as it is usually considered that vertebrates contribute very little to the overall energy flow. However, vertebrates are often key species since they structure marine food webs. The processes of this function are not well known. Research by fisheries biologists, ornithologists, mammologists and marine conservation scientists should be coupled to a more general ecological knowledge of the seas and marine food webs to better understand the relative importance of top-down regulation of marine food webs versus the traditional approach in which bottom-up control (i.e. nutrients and primary production) is emphasised. Particular efforts should be made to incorporate the expertise of vertebrate biologist and ecologists into marine biodiversity networks.

Microbial biodiversity

One gram of marine sediment or sea water may contain from 10 million to 1,000 million single-celled microorganisms including prokaryotes (bacteria and Archaea) and eukaryotes (photosynthetic chromophytes, dinoflagellates, protozoan ciliates). Such abundance, diversity and activity renders microorganisms the principal drivers of marine biogeochemical processes in the ocean.

The taxonomic classification of marine microorganisms is less developed, as many cells lack morphological detail and most cannot be grown in culture. Alternative chemotaxonomic classification based on cellular chemical requirements or function, or on biochemical markers (photosynthetic pigments, sterols, lipids, biopolymers) have provided a useful functional classification of marine prokaryotic (bacteria and Archaea) and eukaryotic (microalage, protists) microorganisms. Microorganisms are genetically very diverse, and this has been exploited recently by the application of DNA probes for *in situ* phylogenetic and functional classification of unculturable and wild microorganisms. Important examples include methane oxidising bacterial consortia, pelagic photosynthetic bacteria, several strains of Archaea and the tiny (< 1µm) abundant and ubiquitous *Prochlorococcus* species.



Heterogenous bacteria visualised by (a) DAPI (4',6-diamidino-2-phenylindole dihydrochloride) staining and (b) fluorescence *in situ* hybridization (FISH).
© B J MacGregor, K Ravenschlag and R Amann (2002)

3.4.4 Effects of climate and anthropogenic changes on marine biodiversity

While the properties of marine ecosystems will undoubtedly be altered by climate, the lack of systematic knowledge of long-term ecosystem responses makes it difficult to predict these changes. Predicting the response and feedback of marine biota to climate change is required. Impacts of climate change are being attributed to evidence of community shifts, arrival of tropical species in temperate waters, occurrence of Mediterranean species in the North East Atlantic, and in anomalous North Atlantic Oscillation (NAO) cycles affecting distribution and abundance of phytoplankton, zooplankton and fish species. It is essential to continue long-term monitoring in order to differentiate seasonal, annual and decadal variability and anthropogenic change.

Experimental and numerical studies using climate-simulating mesocosms (climatrons) could unravel the basic biogeochemical links and responses of climate-critical planktonic species (e.g. diatoms, coccolithophorids, N_2 fixers, bacteria, viruses, Archaea) to physical drivers of climate change (e.g. temperature, pH, CO_2, solar radiation) and their biogeographic consequences.

3.4.5 Key research recommendations

Biodiversity, taxonomy and genetics

- Marine scientists must agree a set of key species at different taxonomic levels, and track and map their distributions at key sites spanning the climatic and biogeographical regimes in European seas. Large-scale biogeographic distributions and biodiversity gradients should be GIS-mapped spatially and temporally. Areas identified as having high genetic and species diversity should be the focus for conservation efforts, including designation as marine protected areas (MPAs) and exclusion zones. Particular attention should be afforded to establishing the functional biodiversity associated with cold water corals and gas hydrates *(see also Section 5.2: New ecosystems at oceanic extremes)*.

- As retiring taxonomists are not being replaced, there is a requirement to invest in taxonomic education and establish effective career paths for taxonomists. Taxonomic keys also require updating and standardisation.

- Marine taxonomists and population biologists should integrate their work with genetics expertise. Transfer of techniques such as QTL and AFLP and fluorescent markers to a range of marine organisms will greatly improve the ability of genetic analysis to resolve population structures and provide estimates of effective population sizes. Further integration of this information with predictive modelling will provide a greater understanding of the implications of environmental risks and exploitation rates on populations. Genomics techniques such as QTL and family selection by pedigree analysis enable rapid improvement in strain characteristics, and should be used by aquaculturists *(see also Section 2.1: Towards ecologically sustainable fisheries and aquaculture)*.

- Improved understanding of complex marine populations and genomics will yield more robust biodiversity indices required to underpin conservation and socio-economic valuation. Europe's classical taxonomic archives, specimen collections and genetic databases are scattered and require integration, and inclusion in the Global Biodiversity Information Facility (GBIF).

Functional role of biodiversity

- Research by fisheries biologists, ornithologists, mammologists etc. should be integrated to improve understanding of the importance of top-down regulation of marine food webs versus the traditional approach in which bottom-up control is emphasised. A concerted European action should be developed to understand the role of the relatively few key marine vertebrates and their impact on ecosystem functioning. Efforts should be made to increase the involvement of vertebrate biologists and ecologists in marine biodiversity networks.

Microbial biodiversity

- Gene probes should be developed for *in situ* detection of the abundance and activity of biogeochemically important processes, and for classification and detection of viral particles and their infective impacts on bacterial and phytoplankton

••••••▶

blooms. These biogeochemical probes should be coupled with phylogenetic probes for the application of rapid semi-automated technologies (e.g. microarrays, analytical flow cytometry) for large-scale oceanographic mapping of microbial biodiversity in terms of biogeochemical activity *(see also Section 4.3.2: Ventilation of marine biogases and fertilisation feedbacks)*.

- Research is required into the role of microniches and microscale dynamics in sustaining symbiotic consortia of microorganisms. The role of infochemicals, toxins, attractants, biopolymers etc. in shaping pelagic microbial communities and in biotechnological products requires further investigation.

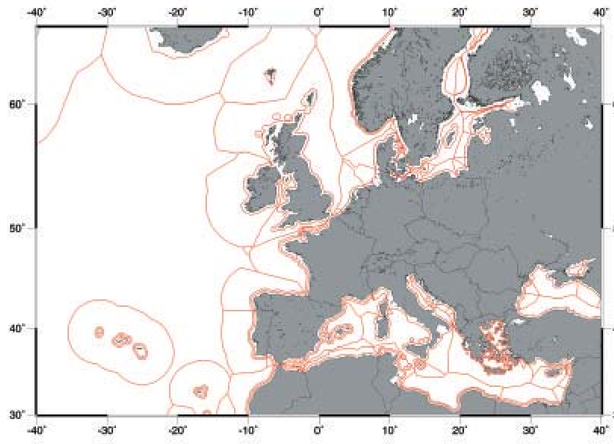
Effects of climate and anthropogenic changes on marine biodiversity

- Predicting the response and feedbacks of marine biota to climate change is required. Research on the impacts of climate change on microorganisms should include assessment of those that: (i) are important in shaping the marine food web; (ii) control ocean biogeochemistry; (iii) have potential for bioprospecting and biotechnology; and (iv) have a potential human health impact (e.g. harmful algal blooms).

- Experimental and numerical studies using climate-simulating mesocosms (climatrons) could unravel the basic biogeochemical links and responses of climate-critical plankton to physical drivers of climate change and their biogeographic consequences.

3.5 Integrated governance of European oceans and seas

As stated, the three drivers for research needs in marine science and technology in Europe have been identified as: (i) impacts and feedbacks of ocean-climate change; (ii) scientific and socio-economic bases for sustainable development; and (iii) oceans as an ultimate frontier for marine research and for resource management *(see also Section 1.1: Drivers for integrating marine science in Europe)*. The overriding issue impacting European seas and coastal waters is that of human pressure, and the challenge of effective governance across national boundaries is especially pressing. Oceans and seas are no longer regarded as a source of inexhaustible resources, and require a co-ordinated approach towards the responsible management of their resources. While management of coastal resources has been addressed since the 1970s through the philosophy of ICZM, there is a need to extend this approach beyond the limit of the terrestrial influence and into the seas and oceans; this concept is frequently termed Integrated Ocean Management (IOM), or ocean governance. IOM calls for some institutional adjustments to develop the necessary interdisciplinary and intersectoral procedures, beyond the current sectoral and ad hoc approach, to achieve the goals of effective governance with the objective of sustainable development of marine resources. While there are a number of national, European and international agreements regarding management of living marine resources, there is a requirement to integrate these policies with effective management of other marine resources and the environment, and with the requirements for advancement of science. Already several countries (e.g. Canada, USA, Australia, New Zealand) have developed national ocean policies. In the European context, such an initiative could be referred to as European Ocean and Seas Integrated Governance (EOSIG).



European seas delineated by national EEZ. © J Woods, Imperial College London, UK

The European Union could provide leadership on ocean policy to its Member States and beyond to developing nations, in particular those with which cooperative resource exploitation ventures are maintained. Effective ocean governance will consolidate the EU's commitment to global marine affairs, and will provide a forum for implementation of ethical issues *(see also Section 1.2.1: Science, society and citizens)*.

A first step would necessitate the development of a comprehensive policy by the EU and its Member States to achieve ocean management and sustainable development goals. As a second step, a procedure for implementing this policy would be developed within the context of the three pillars of sustainable development (economic, social, environmental) and also the progressive institutional adjustments necessary. The resultant harmonization of ocean and coastal policies should guide the public and private sectors and promote a stewardship ethic.

Integrated coastal zone and ocean governance policies and management are needed to properly evaluate and sustainably extract the marine environment's multitude of benefits for society. A future EOSIG policy would be of direct relevance to the enforcement of the Exclusive Economic Zone (EEZ) of maritime EU Member State.

Articles 55-75 of the UN Convention on the Law of the Sea have defined the Exclusive Economic Zone as consisting of that area of sea adjacent to a coastal state not exceeding 200 miles from the baseline of the territorial sea. The state shall have sovereign rights over the zone for the purpose of exploring and exploiting, conserving, and managing the living and nonliving resources of the sea, seabed, and subsoil within it. A number of EU Members States are currently engaged in mapping the seafloor of their EEZ and also the potential resources therein. Consideration should be given to European cooperation in this domain, within the framework of EOSIG.

As it is necessary to incorporate credible science within the foundation of management decisions, the role of the marine scientist is fundamental to the development of a sound ocean policy, or EOSIG. As with ICZM, baseline interdisciplinary research is required to meet the challenge of progressing ocean governance, by describing the polyfunctional properties, carrying capacities and limits of marine ecosystems. As a priority, an EOSIG policy and governance procedure would address the need to more effectively respond to issues related to:

- a better understanding of ocean processes and resources;
- management of living marine resources, including fisheries;
- design, implementation and management of marine protected areas;
- reducing the negative impact of pollution in the marine environment;
- use and management of non living resources;
- development and support of ocean and coastal science programmes;
- development and support of marine technology and infrastructures;
- better knowledge and understanding of deep sea environmental seafloor and biodiversity interactions and potential;
- improved exchange and management of information on marine science and technology, as support for research development policy and management;
- marine related commerce and transportation.

Thus, a mechanism is required for incorporating best available science into the ocean management decision making process. A partnership programme of all relevant stakeholders within Europe should be established to design both the scope and content of an integrated ocean policy.

3.5.1 Key recommendations

- Europe needs to rapidly move towards a sound and true governance of its oceans and seas, integrating all the components for a comprehensive and responsible management of it marine assets. The EU Member States, the European Commission and the European Parliament should be proactive and instrumental in this matter. This will lead to an effective assessment and management of the resources within the EEZ of each maritime Member State.

- A forum of marine scientists and policy makers should be convened to ensure effective communication and synergy between both parties for timely deliverance of relevant and sound scientific knowledge to policy makers, contributing to the design of the scope and content of an integrated ocean policy.

- To meet the challenge of progressing integrated ocean management and governance, baseline interdisciplinary research is required. The strategies for ocean governance should be based on integrating oceanographic, fisheries, geological and biological research with the requirements of sustainable resource use, maritime transport and offshore industries, and environmental protection *(see also Section 3.1: Coastal zones)*.

4. Ocean climate interactions and feedback

4. Ocean climate interactions and feedback

4.1 Climate change in Europe

It has long been recognised that the ocean is a major driver in the Earth's climate system, through its dominant role in the hydrological cycle, its global thermohaline circulation, and its enormous capacity for chemical storage and biological transformation of CO_2. Both the most recent scientific assessment of climate change by the Intergovernmental Panel on Climate Change (IPCC 2001) and the Science Implementation Plan of the International Research Programme in Climate Variability and Predictability (CLIVAR) strongly emphasise the need to understand the role of the ocean in climate change. There is now compelling observational and modelling evidence (IPCC 2001) that the relentless emissions and atmospheric accumulation of anthropogenic greenhouse gases (CO_2, CH_4, N_2O and halocarbons) since the early 19th century are quantitatively responsible for the global warming trends, sea level rise and climate extremes recorded since the 1980s. Even if emissions are stabilised now, anthropogenic climate change will continue for several centuries because of the long time scales required for oceanic feedback.

The international scientific community developed a set of four global research programmes in response to the scientific challenges of global change, known as the Earth System Science Partnership, detailed below:

1. The World Climate Research Programme (WCRP) deals with understanding the physical climate system, its evolution, variability and predictability.
2. The International Geosphere-Biosphere Programme (IGBP) addresses the biogeochemical and ecological aspects of global change.
3. The International Human Dimensions Programme of Global Environmental Change (IHDP) has developed a research agenda on the role of humans in causing global changes and how they are affected.
4. The DIVERSITAS programme was created to address, in an interdisciplinary way, the causes and effects of the loss of biological diversity and to design tools for a more sustainable use of biological diversity. In association with IGBP, it is developing a set of activities on the link between biodiversity and ecosystem functioning.

A further initiative was established by IGBP, IHDP and WCRP to consolidate the role of developing countries. Known as the Global Change System for Analysis, Research and Training (START), this initiative aims to build indigenous capacities in developing regions of the world so that they can participate effectively in research projects of the international programmes *(see also Section 1.2.3: Cooperation at the global scale and with developing countries)*.

4.1.1 Climate change: observational evidence

The global average surface temperature has increased by 0.6 ± 0.2°C since the late 19th century. It appears that the 1990s were the warmest decade and that 1998 was the warmest year in both the instrumental record since 1861 and the proxy temperature records covering the last millennium in the Northern Hemisphere.

The most recent period of warming (1976-1999) has been global, but the largest increases in temperature occurred over mid and high latitudes of the continents in the Northern Hemisphere. This is causing major retreats in Alpine and continental glaciers, reduction of up to two weeks in the winter ice cover of lakes, and an approximate 40% reduction in the thickness of the Arctic sea ice since the 1970s.

Precipitation, cloudiness and atmospheric vapour pressure have all continued to increase respectively by: 0.5-1%, 2%, and 5-10% per decade, over the middle to higher latitudes of the Northern Hemisphere.

The regional pattern of decadal temperature change in Europe has recently been shown to relate to the North Atlantic Oscillation (NAO) in atmospheric pressure fields. New analyses indicate that the global ocean heat content has increased significantly since the late 1950s, with more than half of the heat accumulating in the upper 300m of the ocean, corresponding to a rate of temperature increase of 0.04°C per decade. The resultant thermal expansion of the upper ocean is the principal driver of the measured sea level rise of 1-2mm per year. Even if greenhouse gases were stabilised, sea level is predicted to continue to rise for several centuries because of slow mixing and the enormous thermal inertia of the ocean.

Table 4.1. Global CO_2 budget in PgC/yr based on intra-decadal trends in atmospheric CO_2 and O_2 *(IPCC 2001)*

Positive values are flux to the atmosphere, negative values represent uptake from the atmosphere.

	1980s	1990s
● Atmospheric increase	3.3 ± 0.1	3.2 ± 0.1
● Emissions (fossil fuel, cement)	5.4 ± 0.3	6.3 ± 0.4
● Ocean-atmosphere flux	-1.9 ± 0.6	-1.7 ± 0.5
● Land-ocean flux*	-0.2 ± 0.7	-1.4 ± 0.7
**Partitioned as follows*		
● Land-use change	1.7 (0.6 to 2.5)	NA
● Residual terrestrial sink	-1.9 (-3.8 to 0.3)	NA

4.1.2 Causes of climate change

Since the industrial revolution, the atmospheric concentration of CO_2 has increased from 280ppm in 1750 to 367ppm in 1999. Present-day concentrations had not been exceeded during the previous 42,0000 years and probably not during the past 20 million years. CO_2 is the dominant anthropogenic greenhouse gas contributing 60% to radiative warming, with CH_4 (20%), N_2O and halocarbons contributing to the balance.

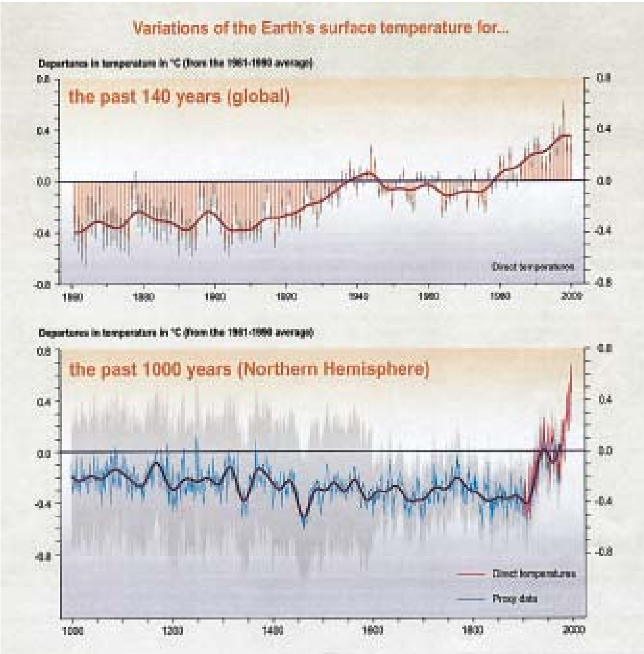
Recent carbon isotopic studies and precision O_2 budgets, have confirmed that fossil fuel burning is the principle source of the CO_2 increase (70-90%), the balance being deforestation and land use change. Since the 1980s, enhanced growth of terrestrial plants due to higher levels of atmospheric CO_2 and the application of nitrogen fertilisers have caused the terrestrial environment to become a net but finite sink of carbon. At present, the principle sink of atmospheric CO_2 is the physical and biological drawdown of 1.7-1.9 Gt of carbon (Gt C) per year, or 25-35% of emitted CO_2, into the interior of the ocean.

However, without deep mixing, the buffering capacity of sea water will dramatically limit the ability of the ocean surface to take up CO_2 at higher atmospheric levels of CO_2. Ultimately, the ocean could absorb 70-80% of emitted CO_2, but these processes would take centuries due to slow diffusion and mixing compared to accelerating anthropogenic inputs.

4.1.3 Climate variability: lessons from the past

Data on water mass characteristics and ocean circulation have been continuously and systematically recorded only for approximately the past one hundred years. Information on long-term climate fluctuations is somewhat limited. Proxy data, derived from tree rings, corals, sediment cores and ice cores offer the possibility of extending the records far back into the past.

Palaeoclimate studies in the last decade gave evidence that long-term climate events are driven by variations in the Earth's orbital parameters,



The Earth's surface temperature has increased by about 0.6°C over the record of direct temperature measurements (1860-2000, top panel) – a rise that is unprecedented, at least based on proxy temperature data for the Northern Hemisphere, over the last millenium (bottom panel).
© IPCC, Synthesis Report, Climate Change 2001

which led to a change in the seasonal and latitudinal distribution of energy received from the sun (Milankovitch forcing). The data indicate that water mass distribution was restructured basin-wide between warm and cold time periods. During transition times between these periods, thermohaline circulation, and thereby also the marine heat transport to higher latitudes, was weakened. Numerical ocean models have shown that thermohaline circulation can take on more than one stable equilibrium condition *(see also Section 4.3.1: Oceanic CO_2 sinks, feedbacks and limits in a greenhouse world)*. For a deeper understanding of climate relationships, climate records have to be improved to provide a time resolution of decades to centuries. These records also form the basis for improving numerical oceanic and climatic models. Besides high resolution records, new proxies to decipher past environmental conditions have to be developed and calibrated.

Rapid climate change

Climate records from Greenland ice cores document climate anomalies over a time frame of millennia, showing drastic temperature changes of up to 7°C within periods of 10 years or less during the last glacial period. These fluctuations show that the climate of the last cold period was much more variable than had been assumed on the basis of known marine climate records. With the analysis of high resolution palaeoceanographic time series data, it became apparent that the climate shifts are influenced by the circulation and hydrography of the adjacent North Atlantic. These rapid climate changes are especially recorded in the form of changes of temperature-sensitive planktonic communities and sporadic occurrences of ice-rafted debris, documenting increased iceberg drift in the northern North Atlantic. During these times, carbon isotopes and cadmium values of benthic foraminiferal carbonate derived from sediment cores point to restriction or even suspension of the thermohaline convection in the North Atlantic.

As recently as the early 1990s, it was generally accepted that due to mixing and homogenisation of the surface sediment by organisms (bioturbation) it would be difficult to improve the temporal resolution of palaeoceanographic data series below the range of 1,000 years. However, the recovery of sediment cores from high accumulation sites and / or anoxic environments and high resolution sampling with sample spacings of two centimetres or less result in interpretable signals that can be correlated over wide areas with temporal resolutions of decades to centuries. Comparable oscillations were also documented in sediment cores outside the North Atlantic region, explained by the remote effect of North Atlantic climatic events on atmospheric and oceanic circulation or on the atmospheric heat and moisture transport. In addition to the short-term anomalies of the last glacial period, documenting climate variations of the subsequent Holocene epoch will also be an important area of future research. Ice and sediment cores from different regions show quasi-cyclic fluctuations that are also partly known from analysis of tree rings and coral cores.

Palaeoceanographic proxies

A set of proven palaeoceanographic tools are available for reconstructions of climate patterns. These include, for example, stable isotope ratios in biogenic carbonates for palaeotemperature and palaeonutrient determination, and microfossil assemblages for reconstructions of surface water temperatures. Another indicator for surface water temperatures is provided by the long-chain, unsaturated C_{37} to C_{39} ketones that are derived from haptophyte algae, primarily from coccolithophorids. Palaeoproductivity can be estimated from the organic carbon, carbonate, and opal content in the sediment.

Changes in continental climate can be estimated from changes of ferrigenous minerals and clay mineral assemblages of eroded terrestrial sediment supplied to the ocean, and also by pollen grains. Palaeonutrient concentrations can be deciphered by $\delta^{13}C$ and cadmium values of benthic foraminifera or by nitrogen isotope values of organic matter. The ratio of stable boron isotopes in foraminiferal tests has recently been used to reconstruct past pH values of sea water.

The described examples of palaeoproxies show a high potential for the reconstruction of past climate, circulation, and productivity. In general, physical-chemical parameters such as temperature or nutrient concentrations are more accurate to determine, whereas biological parameters such as productivity can only be derived with uncertainty. Research efforts are required in the field of organic geochemistry, especially for biomarkers to characterise palaeoenvironmental parameters, including for example past CO_2 concentrations, differentiation between marine and terrestrial organic material, nutrient contents, and the redox state of the water column. Furthermore, biomarker research should address the variations in the composition of the phytoplanktonic and zooplanktonic communities (i.e. ratio of silicate to carbonate producers), because of its impact on past CO_2 concentrations.

A vast amount of time series palaeo data on physical-chemical and biological parameters of the ocean already exists. These proxy data, however, are predominantly used for regional or local studies of the palaeo-ocean and they differ in quality and temporal resolution. Hence, future work must aim to make this huge archive available in the form of consistent time slices and time series to allow for a large-scale synoptic view of the processes of climate change. The data compilation can be facilitated by using relational databases such as those available through Pangaea (the World Data Centre for Marine Environmental Science: *www.pangaea.de*) *(see also Section 7.2.6: Data acquisition, management and policy),* and should include quality control and a reassessment of the stratigraphy, to minimise errors or dating differences (e.g. due to different calibration methods). Such a processing of proxy data would also provide a benchmark against which to assess model experiments of past climates *(see also Section 4.1.4: Modelling natural and anthropogenic climate change).* This strategy allows the quantification of differences between proxy data and model output, and identification of errors in model performance or problems within the data field. On the other hand, if the data-model agreement is sufficient it is possible to examine the mechanisms of climatic change, and to reconstruct variables which are not preserved in the geological record. This would significantly increase confidence in the model predictions of future climate.

4.1.4 Modelling natural and anthropogenic climate change

The recent incorporation of ocean coupling with atmospheric processes has dramatically improved climate models, which can now reproduce both palaeo- and recent climate observations, including natural modes of climate variability (e.g. El Niño Southern Oscillation, ENSO). These coupled models are also reproducing global warming trends; IPCC (2001) unambiguously attributes these trends to rising anthropogenic greenhouse gases.

Numerical ocean-atmosphere-land coupled climate models are the only tools available to predict future climate change. Based on a range of emission scenarios, climate models forecast a globally averaged surface temperature rise of 1.4-5.8°C by 2100, with the largest increases in Arctic and high latitude regions of Europe, Asia and North America. Glaciers and ice caps are predicted to continue their retreat and snow cover and sea ice are projected to decrease in the Northern Hemisphere. The mass of the Antarctic ice is predicted to increase because of greater precipitation. Extremes in temperature, precipitation and storms will be globally more frequent.

Most models show a weakening of the Atlantic thermohaline circulation (THC) in a greenhouse world. This weakening will: (i) reduce (but not stop) net greenhouse warming for the North Atlantic; (ii) reduce convective drawdown of heat, salt and CO_2; and (iii) reduce nutrient upwelling, biological productivity and export of organic carbon to the deep ocean.

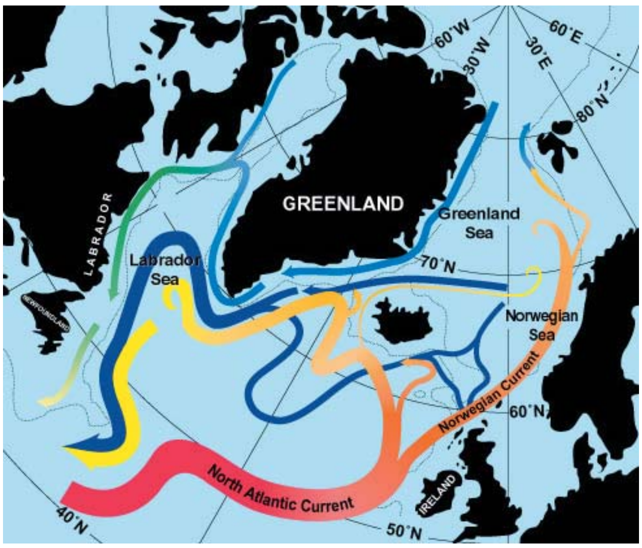
Although some climate models predict ENSO like changes to the sea surface temperature of the tropical Pacific, potential greenhouse effects on other modes of natural variability (e.g. NAO, monsoons etc.) are not known. Yet these could have the most dramatic consequences in terms of regional climate extremes.

All IPCC scenarios predict that sea level will rise by 10-80cm by 2100. The range of regional variation in sea level rise is substantial compared to the global average rise, with the Arctic Ocean and adjoining seas predicted to experience the greatest rise.

The following major uncertainties still exist in current ocean climate models.

- Globally important small-scale processes such as western boundary currents (e.g. the Gulf Stream), flows through narrow gaps (e.g. between Greenland and Iceland), vertical mixing, deep transport of heat, salt and CO_2 are inadequately scaled and represented.
- The Atlantic thermohaline circulation (THC) is poorly observed and crudely modelled; thus, the consequences of THC changes on abrupt climate change cannot be fully evaluated.
- Ocean biogeochemical flows of CO_2 and organic carbon are still poorly represented in models.
- Changes in precipitation and resultant runoff from catchments to the ocean under greenhouse scenarios are poorly understood and represented in coastal sub-models.

Main currents in the North Atlantic



An oceanic roundabout. As warm ocean currents in the subpolar gyre gradually cool, they warm Europe and may trigger seesaws in climate. © McCartney *et al.*, 1996

There are extensive needs for long-term climate simulations, models of climate variability and seasonal climate predictions. Efforts should also be directed towards regional modelling. Global circulation models (GCMs) can simulate global changes (temperature, sea level rise, humidity etc.), but in order to tackle environmental problems (desertification, biodiversity, climate change, natural hazards etc.) it is necessary to have predictions at the regional or local level.

Issues include the lack of validated models, the lack of coherence between models (thematics and scales) and difficulty in linking models. There is a need for validated methods to turn data into information, resulting in integrated assessments, and the development of indicators *(see also Section 2.3.4: Development of indicators)*. For the validation of models it is essential to have good observations; all countries and institutes should provide information about their activities in systematic observations in accordance with the reporting guidelines suitable for each case. Current methods for dealing with uncertainty and error in environmental data are inadequate. There is also a need to improve methods to assimilate data into models.

It is essential that results of research activities are transferred to operational networks in order to guarantee both long-term continuity, and that real time and historical data reach the appropriate international data centres *(see also Section 3.2: Strategic observing and monitoring systems).*

The computational complexity of ocean simulations far exceeds that of weather forecasting. In climate modelling the high computational complexity is due to the ocean component of the coupled system. Oceanography and climatology will be the prime users of petaflops computers (billions of calculations every microsecond) when they become available. Meanwhile, scientific research and pre-operational trials will continue to proceed more slowly in Europe than in the United States if European oceanographers do not have access to the most powerful computers available at each stage. There is a strong case for the European Commission to invest in a computing centre and a high-speed network for ocean and climate modelling. This will have to be continuously upgraded during the transition from teraflops to petaflops. At each stage it should provide computing power of an order of magnitude greater than is available for ocean modelling in the EU Member States. Such a system would ensure that European scientists would assist in global planning for environmental protection against climatic extremes. Recent developments include the investment by the German Federal Ministry for Education and Research, to provide the German Climate Computing Centre (DKRZ), Hamburg, with one of the world's fastest climate research computers. The supercomputer will come into operation in spring 2003 (cost 34 million euros), and will initially process climate simulations 40 times faster than at present, providing more accurate and faster simulations of the world's climatic conditions.

An assessment of the responses of various marine biota to climate change is necessary *(see also Section 3.4.4: Effects of climate and anthropogenic changes on marine biodiversity).* Experimental and numerical studies using climate-simulating mesocosms (climatrons) could unravel the basic biogeochemical links and responses of climate-critical planktonic species (e.g. diatoms, coccolithophorids, N_2 fixers, bacteria, viruses, Archaea) to physical drivers of climate change (e.g. temperature, pH, CO_2, solar radiation) and their biogeographic consequences.

4.1.5 Key research recommendations

Climate change in Europe

- Numerical ocean and climate models of the climatic events of the past require improvement. Research is required to improve the temporal resolution in the reconstruction of climate history in oceanographic relationships in scales from 10 to 100 years. Continuous development of proxies is required for reconstructions of past surface CO_2 concentration, temperature, pH values and nutrients. Improvement of proxies for the reconstruction of palaeosalinity, an important variable for modelling, is required. Documenting climate variations of the Holocene epoch will also be an important area for future research.

- There are extensive requirements for long-term climate simulation models of climate variability and seasonal climate predictions. Efforts should also be directed towards research on regional modelling. There is a requirement for validated methods to turn data into information, in the form of integrated assessments and indicators, and for improved methods to assimilate data into models. There is a strong case for the European Commission to invest in a computing centre and a high-speed network for ocean and climate modelling.

- There is a research priority to gather the vast amount of palaeoclimate records into databases and to analyse them spatially and temporally. The combined use of palaeoclimate data and palaeoclimate models would advance the understanding of mechanisms of climate change.

- Predicting the response and feedbacks of marine biota to climate change is required. Experimental and numerical studies using climate-simulating mesocosms (climatrons) could unravel the basic biogeochemical links and responses of climate-critical planktonic species (e.g. diatoms, coccolithophorids, N_2 fixers, bacteria, viruses, Archaea) to physical drivers of climate change (e.g. temperature, pH, CO_2, solar radiation) and their biogeographic consequences.

4.2 Ocean thermohaline circulation - Europe's heat engine

About 90% of the Earth's population north of latitude 50°N lives in Europe. This is because Europe's climate is 5-10°C warmer than the global average for this latitude, the largest such anomaly on Earth. A change or shift in the Earth's climate is thus likely to have a pronounced impact on present human society and marine and terrestrial ecosystems.

Europe's relative warmth is maintained by the poleward surface branch of the ocean thermohaline circulation (THC) that transports up to 1.3 petawatts (PW = 10^{15} W) of heat per year, equivalent to about one million 1-megawatt nuclear power stations.

The THC is driven by the sinking of dense cold sea water in the North Atlantic and by mixing in the ocean interior and by upwelling in the Southern Ocean. Most ocean climate models when run under future greenhouse gas scenarios predict the following events.

- A weakening of the THC in the North Atlantic because of increased freshening and warming of the Arctic and sub-polar seas, leading to reduced convection. Since the overflow and descent of cold, dense waters across the Greenland-Iceland-Scotland Ridge is a principal means by which the deep ocean is ventilated and renewed, the suggestion is that a reduction in upper-ocean density at high northern latitudes will weaken the THC.
- Abrupt breakdown of THC under strong climate forcing is also characteristic of the dynamics of modelled THC. This is consistent with sediment palaeoclimate records from the North Atlantic *(see also Section 4.1.3: Climate variability: lessons from the past),* showing that massive and abrupt climate change occurred within a few decades in the Northern Hemisphere, especially during and just after the last ice age. Both palaeoclimate records and models suggest that changes in the strength of the THC can occur very rapidly, within a few decades or even years.

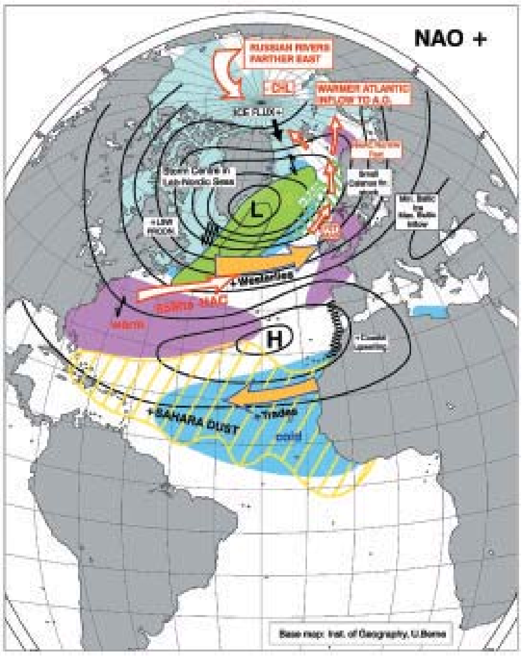
However, the ocean fluxes at high northern latitudes are not the only constituents of THC. Interocean fluxes of heat and salt in the southern hemisphere, wind-induced upwelling in the circumpolar belt and atmospheric teleconnections also influence the strength and stability of the Atlantic THC.

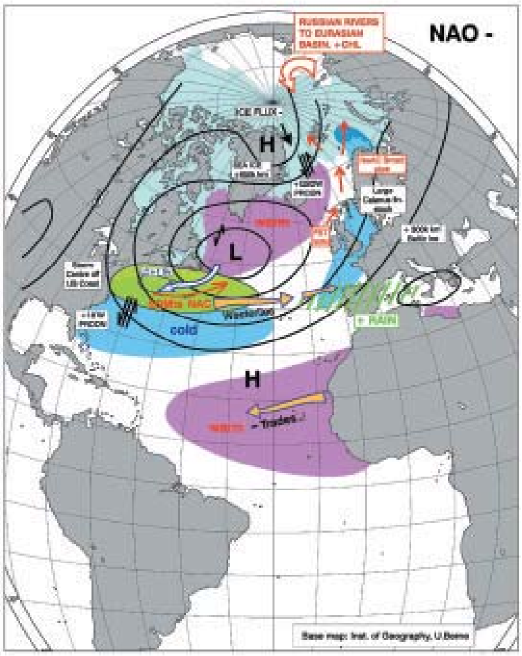
The UK RAPIDs programme represents a large scale (£20 million) long-term (six years) investment by NERC (the Natural Environment Research Council) to research the role of the Atlantic THC in climate change. The aim of the programme is to improve the ability to quantify the probability and magnitude of rapid climate change. The programme aims to deliver: an assessment of the probability and magnitudes of future rapid climate change; an improved observing system for the THC; better understanding of the processes that drive the THC; improved palaeo-climatic data and new methods for using these data with models; and improved models predicting rapid climate change. It forms part of a key collaboration with the Norwegian ocean climate project NoCLIM, which is investigating climate variability in the northern European seas.

4.2.1 Drivers of thermohaline circulation in the Atlantic Ocean

North Atlantic Oscillation (NAO)

Overlapping the long-term climatic effects of the THC on the North Atlantic, there is a decadal mode of variability called the North Atlantic Oscillation (NAO). A positive NAO situation occurs when high barometric pressure differences persist between the Azores High and the Iceland Low and this gives rise to increased westerly winds, mild winters in northern Europe and dry conditions in the Mediterranean.





North Atlantic Oscillation plus mode and minus mode.

The NAO is also linked to the atmospheric circulation over the whole Northern Hemisphere including the annular mode or Arctic Oscillation (AO). The NAO exerts a major influence on the strength of the Gulf Stream, the convection in the Labrador Sea, precipitation, ice export from the Greenland Sea, trade winds, storms, wave height, fisheries and the marine and terrestrial ecosystems. The NAO is the major factor controlling air-sea interaction over the Atlantic Ocean and is thought to modulate the site and intensity of oceanic convection.

The causes and mechanisms of present-day NAO variability are incompletely understood, or are represented only in coupled models. For this reason ocean climate models are inconsistent in their NAO predictions in a greenhouse scenario. Yet, understanding the dynamics of NAO and its incorporation into future ocean climate models will be critical to assess greenhouse impacts on regional climate variability and extremes in Europe.

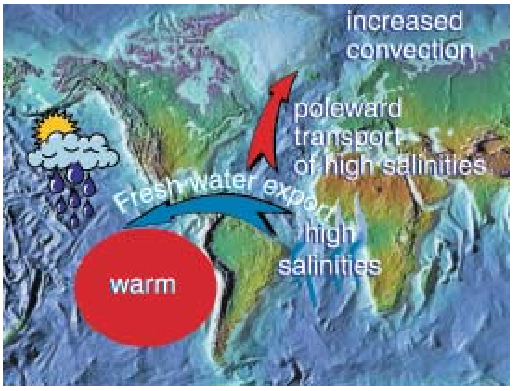
Tropical teleconnections and monsoonal feedbacks

The Atlantic THC is also affected by long-range oceanic and atmospheric coupling. Equatorial waters are rich in complex circulation structures, for example, counter currents, and large zonal detours of north-flowing warm currents and south-flowing deep cold branches of the THC. These THC fluxes are poorly observed and modelled components of the THC, and may represent significant components of the meridional fluxes.

Variability with periods of a few years has been observed in the tropical Atlantic, with strong effects on regional climates, specifically precipitation. It appears to be due to an atmospheric teleconnection originating from the Pacific El Niño-Southern Oscillation (ENSO).

The thermohaline circulation of the Atlantic also exchanges with the neighbouring oceans. Warm and salty Indian Ocean waters are returned into the Southeast Atlantic and propagate northward with the overturning circulation. Modelling studies indicate that enhanced input of saline Indian Ocean waters strengthens and stabilises the Atlantic THC inferring that monsoonal modes could also modulate the Atlantic THC.

Pacific / Atlantic Interactions



Mechanism of Pacific – Atlantic interactions on multi-decadal times scales. © M Latif

Mid-oceanic and shelf sea convection

Sinking or subduction of low stability dense waters occurs in the cold Greenland, Labrador and Weddel Seas making these oceanic regions globally important heat sinks and contributors to the large scale THC. Similarly, slope convection of Arctic water and overflow of European North Sea water through cross channels in the Greenland-Iceland-Scotland Ridge contribute to the THC. There are very few long-term oceanographic observations of these processes, and existing models are too coarse spatially to adequately deal with these boundary fluxes.

Hydrological drivers

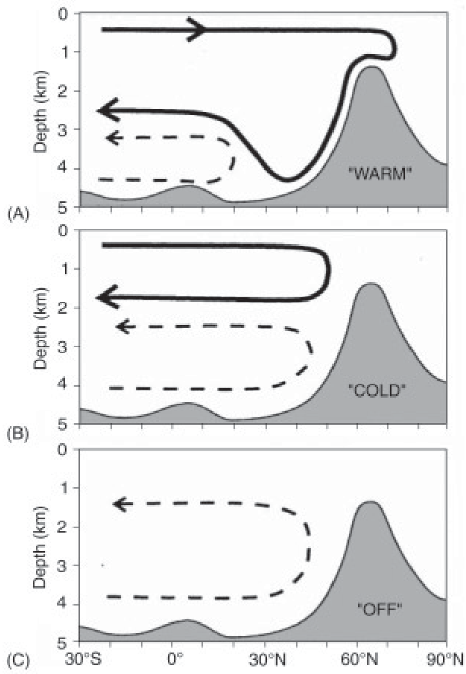
The ocean contains 97% of the Earth's water, and the atmosphere holds about 0.001% of the total. Small changes in ocean evaporation and precipitation patterns can have a large-scale impact on terrestrial and polar water cycles. The water cycle can also affect the THC of the ocean. Deep water convection could be prevented if surface salinity (and so density) decreases from higher freshwater input. The main factors controlling the surface salinity are the distributions of evaporation, precipitation, ice and continental runoff; therefore, knowledge of the freshwater fluxes in the ocean is of fundamental importance. In spite of the importance of the ocean in the global hydrological cycle, its role is still not well known or understood, and its average state and variability is largely unknown.

How stable is the THC in a greenhouse world?

High resolution palaeoclimate records from dated ice and sediment cores have revealed a number of dramatic climate changes that occurred over surprisingly short times (from decades to a few years). Three modes of THC have been identified in records and models: (i) warm or interglacial; (ii) cold or stadial mode; and (iii) off or Heinrich mode *(see also Section 4.1.1: Climate change: observational evidence)*. In the present warm mode, the THC reaches north over the Greenland-Iceland-Scotland Ridge into the Nordic Seas, while in the cold mode it stops south of Iceland. In the off mode, deep water formation in the North Atlantic ceases. It is not known if future greenhouse warming would cause such non-linear and abrupt changes in climate.

The IPCC 2001 report detailed a comparison of several ocean climate models run for the period 1850 to 2100 under a standardised greenhouse scenario of CO_2 increasing to 700 ppm by 2100. With most models, the Atlantic THC of about 15 ± 3Sv (Sv = Sverdrup = 10^6 m^3s^{-1}) weakened to 5-11Sv by 2100, and one model showed no trend. With a significantly greater CO_2 increase of 1% per year for 100 years, there was a complete shut down in the THC in the case of two models. It is not known whether the THC will indeed undergo a drastic weakening in a greenhouse world, and whether such a weakening would be an irreversible transition to a different equilibrium circulation state or mode. With significantly reduced THC, heat transport to Nordic Seas would decrease and a greenhouse cooling of up to 6°C may occur over the North Atlantic.

Unfortunately, present models do not yet deal adequately with many of the mechanisms believed to control the THC, and observations cannot yet supply many of the numbers needed. The problem lies in the wide range of spatial and temporal



Schematic of three major modes of Atlantic ocean circulation. (A) Warm or interglacial mode; (B) cold or stadial mode; (C) 'off' or Heinrich mode. In the warm mode the Atlantic thermohaline circulation reaches north over the Greenland-Iceland-Scotland ridge into the Nordic Seas, while in the cold mode it stops south of Iceland. Switches between circulation modes at certain thresholds can pace and amplify climatic changes. S Rahmstorf, Abrupt Climate Change (2001). © Academic Press

scales involved. Remote effects from other oceans and feedback loops via the atmosphere that affect the THC require modelling on a global rather than a regional scale. Smaller scale processes such as exchanges through topographic gaps, eddy fluxes and turbulent mixing must either be resolved or properly parameterised.

The ocean climate models also do not contain an adequate description of the global carbon cycle, particularly the role of biological drawdown of CO_2, feedback and sedimentation of biogenic carbon to the deep sea.

4.2.2 Mediterranean Sea: a sensitive decadal barometer of climate change

The Mediterranean Sea is a semi-enclosed multi-basin ecosystem with a large-scale decadal thermohaline circulation (THC) analogous to the deep ocean climate system. Its negative estuarine water balance and circulation makes it a trap for anthropogenic inputs. The food web of the open Mediterranean is hyperoligotrophic and limited by phosphorus rather than nitrogen. However, there is increasing incidence of coastal eutrophication along populated coasts and river delta systems particularly off the European and east Mediterranean coastal zones. There is evidence from fossil plankton and sapropel formation in the sedimentary records of widespread changes in the hydrology, circulation and productivity of the Mediterranean Sea coincident with precession cycles. Given the decadal response times and scope for rapid biogeochemical changes, it is clear that the Mediterranean Sea is a sensitive barometer for anthropogenic and climate change.

Large scale changes already underway

The Mediterranean THC system appears particularly sensitive to climate forcing. A dramatic example occurred in the 1980s and early 1990s. The source of the deep water layers for the entire Eastern Mediterranean changed from the normal Adriatic Sea to a new source in the south Cretan-Aegean Sea. This Eastern Mediterranean Transient (EMT) sea water with its inherent properties (temperature, salinity, nutrients, O_2) is presently displacing and uplifting overlying water masses. A decadal persistence of EMT flux could eventually affect regional climate, nutrient regimes and productivity of Eastern Mediterranean and exchange fluxes in the Straits of Sicily.

Greenhouse sensitivity

The IPCC 2001 report indicates a general agreement in the predictions from most of the atmosphere ocean global circulation models (AOGCM) tested. Assuming a 1% per year increase in CO_2, in the Mediterranean region the average temperature is predicted to increase by 3.5-5.5°C and precipitation rates to decrease by 10-30%. These changes will have a pronounced impact on the functioning and modalities of the Mediterranean Sea.

The North Atlantic Oscillation-Indian Ocean (NAO-IO) dipole ultimately controls the Mediterranean THC, and the overturn of nutrients, productivity and oxygen ventilation of the deep Mediterranean. The Mediterranean Sea and its catchment are strongly forced by global atmospheric regimes of the NAO and the IM (Indian monsoons). The NAO and IM supply of water, heat and momentum drive the circulation, biogeochemistry and food webs of the Mediterranean.

Greenhouse induced changes in the NAO modes, regional wind and precipitation regimes and increasing sea surface temperatures and stratification, may reduce the Mistral cooling and winter overturn in the Western Mediterranean Sea, and induce long-term de-oxygenation and ecosystem changes in the Balearic basin.

4.2.3 Key research recommendations

Ocean thermohaline circulation – Europe's heat engine

- The Atlantic thermohaline circulation (THC) is the regional heat engine responsible for the temperate climate of Northern Europe. Preliminary observations and models suggest that the THC is weakening in response to greenhouse forcing. Multidisciplinary long-term observational networks are required to monitor the evolving dynamics of the THC. Research effort should focus on key deep Arctic or sub-Arctic gateways for outflowing cold dense water, and the return flows of warm surface currents in the world ocean.

- Global models of ocean-climate coupling and the THC must be downscaled to faithfully incorporate: (i) flux-critical processes of convection, overflows and boundary currents; (ii) teleconnections between the Pacific El Niño and North Atlantic Oscillations (NAO), and between the NAO-IO dipole and Mediterranean climate; and (iii) local and regional impacts on, and responses of vulnerable European seas to greenhouse forcing. The impact of outflow of Mediterranean waters into the Atlantic and their behaviour in the Atlantic Iberian region also requires further attention. The influx of less salty water from semi-closed seas such as the Baltic Sea and White Sea to the Atlantic Ocean and Arctic Sea requires investigation.

- With observation networks in place, there will be a requirement for new methods to assimilate data into Atlantic and Mediterranean circulation models, to forecast decadal modes of variability, including the NAO and its regional climate and ecological consequences.

- Investigation of palaeoclimatic records in laminated sediments with high temporal resolution will assist in resolving timing and duration of abrupt changes in climate, temperature and oceanic circulation at tropical and high latitudes (e.g. the slopes of the Greenland-Iceland-Scotland ridges).

Mediterranean Sea

- Greenhouse scenario models should be set up to investigate the oceanographic and dynamic sensitivity of the Mediterranean to climate change, including thermohaline circulation, interbasin exchange, nutrient dynamics, deep ventilation and thermohaline export to the Atlantic.

- Novel high resolution downscaled climate models will be required to get regionally reliable predictions of climate forcing for different marginal seas and sub-basins that make up the Mediterranean Sea.

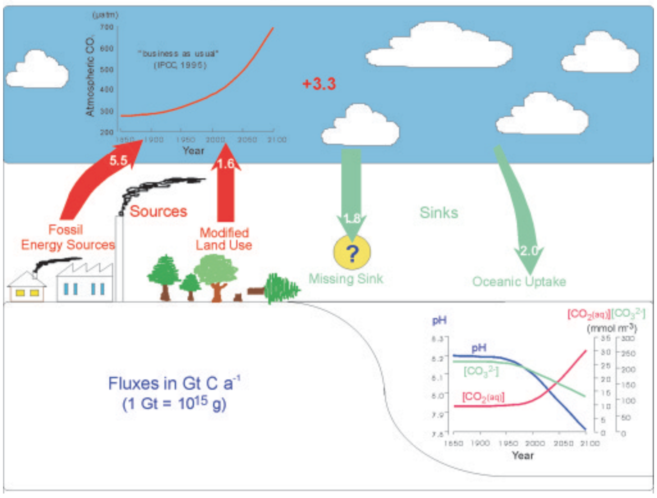
4.3 Ocean biogeochemical impacts and feedbacks in a greenhouse world

The biogeochemical production, transformation and exchange of elements, compounds and gases between the oceans, continents and atmosphere regulate climate and conditions for life on Earth. Over the past 200 years, in particular the past 30 years, mankind has significantly altered the chemical and biological composition of the coastal seas, land and atmosphere, altering the close interplay between the climate system and biogeochemistry. Increased global warming will accelerate these changes in the oceans in coming decades. How global-scale, human-induced perturbation of ocean biogeochemistry will impact on climate and environmental change is largely unknown.

4.3.1 Oceanic CO_2 sinks, feedbacks and limits in a greenhouse ocean

The ocean acts as a major sink for anthropogenic CO_2, absorbing approximately 2 Gt of carbon per year, or 25-35% of fossil fuel emissions. Atmosphere-ocean exchange across the surface area of the global ocean, together with ocean circulation, plays a crucially important role in controlling the future growth rate of CO_2 in the atmosphere. About 90 Gt of CO_2 per year are exchanged annually between the atmosphere and the ocean, and ocean waters contain approximately 50 times more carbon than the atmosphere. Hence ocean biogeochemical processes of solubilisation, photosynthesis, respiration, biomineralisation and sedimentation of organic and inorganic carbon to the deep ocean exert a profound control on atmospheric CO_2. Knowledge of the future uptake of CO_2 by the ocean is the minimum essential to predict future atmospheric CO_2 levels for given energy-use scenarios.

Anthropogenic Impact on the Global Carbon Cycle



Margin sediment fluxes. © German Research Foundation

Warming and acidifying the oceans

In the IPCC prediction scenario, surface water pCO_2 concentrations will continue to increase from present values of 360 µAtm to ~ 750 µAtm by 2100. This will shift the carbonic acid equilibria in the upper ocean, resulting in reductions in the buffering capacity, pH (from 8.2 to 7.8) and the concentration of carbonate ion by ~ 50%. Under these warm acidic conditions, further absorption of atmospheric CO_2 by sea water will decrease markedly, and the productivity and sedimentation of $CaCO_3$ (calcite)-forming plankton (e.g. coccolithophorids) to the deep ocean may reduce by 20-30% (*see also Section 3.3.2: Margins as net sinks or sources of carbon).* The inevitable shifts in biological community composition due to global CO_2 increase would not only affect biodiversity, but calcification itself, and also influence the net uptake or release (i.e. net sequestration) of CO_2 by the oceans.

New nutrient regimes

Projections (IPCC 2001) of increased thermal stratification in the upper ~ 200m ocean, and the weakening of the ocean thermohaline circulation (THC) will reduce the supply of major nutrients (nitrate, phosphate, silicate) and of bioregulating trace metals (iron, cobalt, manganese, zinc, copper) from deep to surface waters. This will reduce overall oceanic productivity and alter the location and biological diversity of planktonic ecosystems, and their capacity to fix CO_2 and export it as organic carbon to the deep ocean. By accelerating the accumulation rate of CO_2 in the atmosphere, the physical and biogeochemical reductions in the oceanic drawdown of carbon may trigger runaway greenhouse conditions with large scale socio-economic implications for mankind.

It is clear that future greenhouse conditions could significantly alter the vertical structure and fluxes of nutrients in the ocean, with major global and regional shifts in productivity, distribution and diversity of planktonic regimes in the ocean.

Plankton paradox

It is not possible to a priori predict with confidence how pelagic marine ecosystems, their structure, succession, trophodynamics, biodiversity and biogeochemical feedbacks will respond to climate change drivers such as changes in temperature, convection, nutrient composition, pCO_2 etc. This is a major and critical gap in knowledge and European marine scientists must develop question-driven interdisciplinary programmes to quantify the mechanisms and rates of biogeochemical responses of carbon, nitrogen and sulphur, focusing on climatically critical processes and organisms.

Ocean carbon sequestration and climate engineering

The United States is presently undertaking extensive trials in the Pacific Ocean to assess whether deep ocean disposal of liquid CO_2, or iron fertilisation in high-nutrient low-chlorohpyll (HNLC) regions, can be used for large-scale sequestration of CO_2 in the ocean, and thus reduce climate impacts, in adherence with the Kyoto Protocol. There is considerable concern internationally amongst marine scientists about the feasibility, ethics, legality and ecological impact of these ocean carbon sequestration plans. The European marine community should address these challenges by open debate and long-term studies of impacts of ocean carbon sequestration *(see also Section 3.5: Integrated governance of European oceans and seas)*. This includes direct disposal of super-critical CO_2 at intermediate depths and ocean fertilisation with iron, nitrogen or phosphorous.

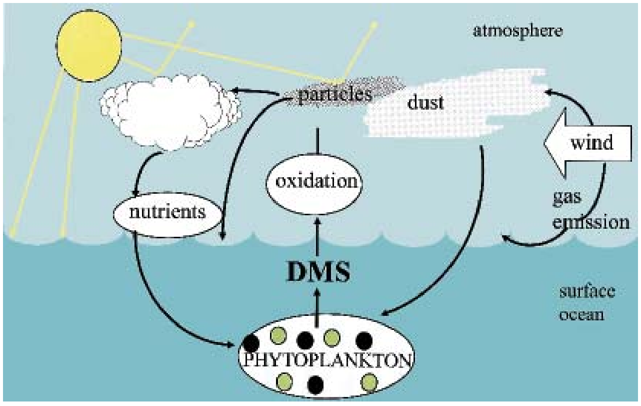
4.3.2 Ventilation of marine biogases and fertilisation feedbacks

The ocean is a globally important source of, or sink for, several long-lived radiatively active gases (e.g. CO_2, N_2O, CH_4, O_2) and short-lived reactive gases (e.g. dimethylsulphide, halocarbons).

While it is possible to model the effect of greenhouse conditions on changes in the partition, solution and gas-phase chemistries and fluxes of these gases based simply on their physical chemistry, consideration must be given to the fact that these gases are biogenic (they are produced, consumed, degraded and transformed by organisms such as phytoplankton, bacteria, protozoa and viruses). Thus, it is crucial to incorporate the unique biogeochemical cycles and feedback of microorganisms into future ocean climate models. This will allow accurate tracking and understanding of the role of marine biogases in climate change.

Dimethylsulphide (DMS)

The ocean biogeochemistry of dimethysulphide (DMS) as shown in the diagram below is an excellent well-studied example of a climate-marine biogas link. The diagram is based on the CLAW (Charles Lovelock Andreas & Warren) hypothesis in which a feedback loop is postulated to exist between marine phytoplankton, sulphate aerosol formation and cloud albedo that might



Biogases in the Ocean: Dimethyl sulphide and climate feedback.
© S Turner and P Liss, University of East Anglia, UK

stabilise the Earth's temperature. Once DMS reaches the atmosphere, and is oxidised to SO_2, it is thought to produce cloud condensation nuclei which whiten clouds and increase the albedo and reflection of sunlight back to space, thereby cooling the Earth.

Nitrous oxide (N_2O)

Nitrous oxide (N_2O) is a powerful long-lived greenhouse gas which also plays a key role in stratospheric ozone cycling. Its atmospheric concentration is currently increasing. Atmospheric N_2O has strong oceanic sources, but ocean fluxes and atmospheric budgets are still uncertain. The climate sensitivities and balance between coastal and open ocean sources of N_2O are poorly understood, as are the present global N_2O budget and the oceanic feedback of N_2O under future climate scenarios.

Methane (CH_4)

Methane (CH_4) is an important greenhouse gas, whose concentration in the atmosphere has doubled since 1900. Although the present ocean CH_4 fluxes (~ 10-15 Tg per year) are relatively modest (~ 5%) compared to anthropogenic and terrestrial sources of CH_4 emitted into the atmosphere, massive releases of CH_4 from gas hydrates in marine sediments may have played a major role in past climate forcing. The gigantic reservoir of oceanic gas hydrates inferred from geophysical observations and groundtruthing by ocean drilling forms a largely overlooked component of the global carbon cycle *(see also Section 2.2.1: New hydrocarbon frontiers; Section 3.3.3: Geoclimatic hazards along ocean margins).* The method and pace at which this reservoir becomes recharged or destabilised under tectonic or climatic forcing factors is a major question in a world affected by global change processes, and may provide a key to hitherto unexplained events in the geological record. Tectonic motions and changes in sea level and/or marine bottom temperatures lead to changes in pressure and temperature conditions that could result in the sudden release of large amounts of methane, possibly with catastrophic results. Rapid shifts in the isotopic composition of dissolved inorganic carbon stored in the oceans around the Palaeocene-Eocene time boundary, and at the onset of the Dansgaard-Oeschger events, may be attributable to the release of methane from gas hydrates.

Volatile halocarbons

The marine emissions of the biogenic methyl halides CH_3Cl and CH_3Br account for about 25% of the stratospheric halogen budget, and so contribute significantly to the loss of stratospheric ozone (O_3). An increase of only 5% in the atmospheric levels of CH_3Br would reverse the benefits gained from the global reductions in CFCs.

Increased photoreactivity

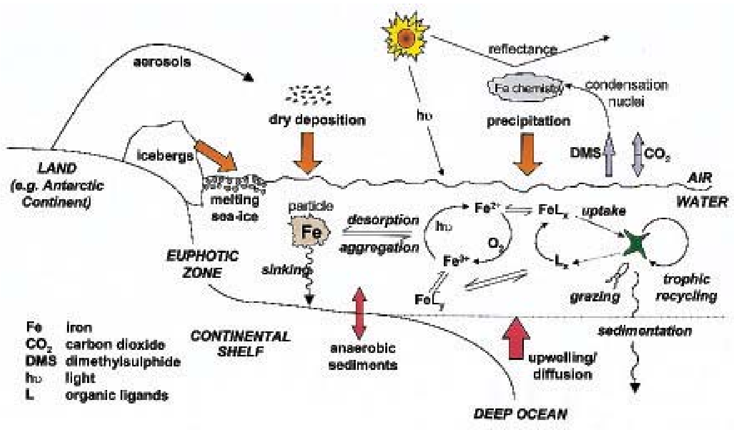
The magnitude and spectral characteristics of solar irradiation reaching the ocean surface is undergoing changes, particularly in relation to increases in UV-B irradiation associated with O_3 (ozone) depletion at high latitudes. Increased UV-B is already impacting on phytoplankton species devoid of photoprotecting pigments, and is implicated in the widescale bleaching of coral reefs in the Indian Ocean. Solar irradiation fuels not only photosynthesis but also a myriad of photochemical transformations of many organic and inorganic compounds in the marine environment. The impact of radiation changes on marine biogeochemical reactions needs to be better understood and included in the next generation of ocean climate feedback models.

4.3.3 Trace metal biogeochemical controls

Iron in an iron-depleted ocean

European and US marine scientists have demonstrated that biological productivity in up to one third of the world ocean is limited by the supply of iron (Fe) from continental and atmospheric dust sources. The pH and oxic conditions present in the ocean severely limit the solubility of iron

Iron Biogeochemical Cycle in the Southern Ocean



and its bioavailability in sea water. Extremely low and biolimiting iron concentrations (< 0.01 nM Fe) occur in the high-nutrient low-chlorophyll (HNLC) surface waters of the Southern Ocean and equatorial and Northeast Pacific Ocean. Experimental *in situ* addition of iron to these waters stimulated massive phytoplankton blooms, mainly of diatoms, who exhibit potential for rapid sedimentation and export of carbon to the deep ocean. Although there was a corresponding drawdown of pCO_2, and production of DMS, these experiments were too short in duration to record significant sedimentation of carbon.

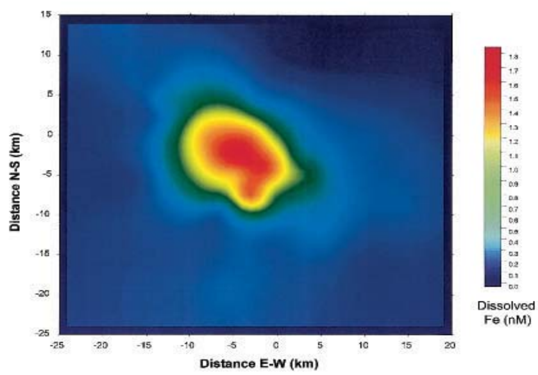
To reliably and quantitatively assess the biogeochemical, ecological and climatic consequences of iron fertilisation and dust aerosols, long-term steady-state mass-balanced studies would be needed. Iron releases from HNLC islands (e.g. South Georgia, Kergulen) or with simulated dust deposition experiments are the next stage in this endeavour to understand the iron-ocean carbon coupling and climate.

Bioregulation versus ecotoxicity

Recent ultra clean trace metal studies have revealed for the first time that many of the bioessential trace metals (e.g. Fe, Zn, Mn,) exist at ultra low levels (< 1nM) in the open oceans and can therefore limit marine productivity. At the higher levels (10-100nM) found in coastal waters some trace metals may become toxic (e.g. Cu, Cd). This leads to the hypothesis that present day estuarine and shelf ecosystems that are chronically exposed to higher levels (10^2-10^4 nM) of anthropogenic trace metals, may have operated under long-term trace metal control, originating from the massive increase in riverine and atmospheric inputs of trace metal (such as Pb, Cu, Zn, Hg, Sn) since the industrial revolution.

Future greenhouse predictions of sea level rise, coastal erosion, and increased storminess may resuspend coastal marine sediments and their trace metals giving rise to toxicity in coastal waters.

Iron Fertilised Patch of Southern Ocean Seawater



Surface distribution of dissolved Fe through a fertilised patch of Southern Ocean seawater (SOIREE Day 7, 61°S, 141°E, February 1999). © A Bowie, Plymouth Marine Laboratory, UK

4.3.4 Key research recommendations

Oceanic CO_2 sinks and feedbacks in a greenhouse world

- All future greenhouse scenarios predict a globally warmer, more stratified and acidic upper ocean that could significantly reduce both convective and biogeochemical export sinks of atmoshoperic CO_2 into the deep ocean. This would accelerate accumulation of CO_2 in the atmosphere, with an associated risk of accelerated greenhouse warming. To reliably predict future CO_2 levels, research is essential to further elucidate the drawdown mechanisms, absorption limits and oceanic budget for anthropogenic CO_2 under greenhouse scenarios.

- The United States and Japan are presently undertaking extensive trials in the Pacific Ocean to assess whether deep ocean disposal of liquified CO_2, or iron fertilisation, can be used for large-scale removal of CO_2 into the deep ocean. Europe should conduct independent studies and evaluations in order to objectively debate the environmental feasibility, usefulness, ethics and impacts of ocean carbon sequestration options. Interactions between decision makers, scientists, the public and environmental NGOs should be promoted to avoid any misunderstanding about such sensitive issues *(see also Section 3.5: Integrated governance of European oceans and seas)*.

Ventilation of marine biogases and fertilisation feedbacks

- Research on present-day air-sea fluxes of climate-critical biogases (CO_2, DMS, N_2O, CH_4), particularly their regional and seasonal variability, is required so that their role in global climate change can be elucidated. The biogenic sources, distributions and pathways responsible for production, transformation and efflux of climatically reactive marine biogas compounds should be investigated and modelled under present and future climate conditions.

- Single celled marine microorganisms (bacteria, Archaea, protozoa, phytoplankton etc.) are abundant, diverse and productive and are the principal drivers of marine and global biogeochemistry. Support should be directed towards adapting biogeochemical gene probes, coupled with phylogenetic probes, to enable the application of high-throughput bio-analytic technologies (e.g. analytical flow cytometry, microarrays) for shipboard use in large- scale oceanographic exploration of microbial biodiversity, food web dynamics and biogeochemical feedbacks in diverse oceanic environments *(see also Section 3.4.3: Functional role of marine biodiversity)*.

- There is a requirement to develop coupled physical biogeochemical ocean climate models that incorporate carbon speciation and nutrient dynamics, in order to predict changes and feedbacks in global and regional ocean productivity under greenhouse scenarios.

- Experimental climate-simulating mesocosms (climatrons) should be set up to unravel the links and responses of climate critical plankton (e.g. diatoms, coccolithophorids, N_2 fixers, bacteria, viruses, Archaea) to physical drivers of climate change (e.g. temperature, pH, CO_2, solar radiation) *(see also Section 3.4.4: Effects of climate and anthropogenic changes on marine biodiversity; Section 4.1: Climate change in Europe)*.

5. New frontiers in marine science

5. New frontiers in marine science

5.1 Marine biotechnology: bioprospecting the planet's largest biotope

The sea is regarded as the origin of life on Earth and the oceans include the largest habitats on Earth hosting the most ancient forms of life *(see also Section 3.4: Marine biodiversity: the blueprint for ecosystem regulation).* Over billions of years, marine microbes have moulded the global climate and structured the atmosphere. Knowledge of these biochemical processes that adapted, diversified and evolved in very different and extreme environments is the basis for discoveries in biotechnology. The vast richness of the marine biotope is an untapped resource for exploration by marine biotechnology, as a source of species with potentially spectacular benefits. The potential applications offered by the screening of marine species extend to medicine and pharmacology, food production and agrochemistry, industrial innovation, environmental remediation, cosmetics and fundamental scientific understanding.

5.1.1 Marine biotechnology in Europe

Marine biotechnology initiatives exist within small RTD groups at national universities and marine institutes throughout Europe. The German marine research programme that promotes links with industry contributes 50% support to the development of marine natural products with pharmaceutical and chemical potential. France has a special programme on the study of high value-added molecules from hydrothermal microorganisms and from algae. The United Kingdom funds biotechnological initiatives on marine biofouling and marine microbial biodiversity, which have potential for commercial exploitation. Norway's efforts have focused on aspects of disease problems in fisheries and aquaculture. It is clear that there is a need for a European coordination of collaboration between industrial partnerships and biological and oceanographic research to maximise synergy, discovery, and job creation in marine biotechnology for Europe.

5.1.2 Bioprospecting novel products and pharmaceuticals

There is a requirement for the research community to realise the promising new perspectives that are inherent within the diversity of marine organisms and their functions, coupled with the latest developments in biotechnology. Extraction of new bioactive compounds to be used in medicine and industrial processes requires the mobilisation and integration of complementary expertise in: marine biology, molecular biology and chemical and physical oceanography. European marine ecosystems with specific biological characteristics should be studied as possible sources of novel compounds. Sampling should concentrate on specific groups of marine organisms such as microorganisms and invertebrates that indicate a potential for novel compound development. Marine microorganisms are a source of new genes whose exploitation is likely to lead to the discovery of new pharmaceuticals. Secondary metabolites produced by marine bacteria and invertebrates have already yielded pharmaceutical products such as novel anti-inflammatory agents, anticancer agents, and antibiotics. Examples are shown in Table 5.1.

The inherent biochemical diversity of large algae as well as cyanobacteria is the basis for a range of products, for example polysaccharides from red algae (carragheenan), widely used as jelling or thickening agents in the food industry and cosmetics, and alginic acids used in building materials. Secondary metabolites extracted from algae have potential as antibacterial agents, pesticides and antifouling agents.

Deep-sea hydrothermal vents provide fascinating microorganisms with the ability to produce enzymes, polymers such as poly-ß-hydroxyalkanoates,

Table 5.1: Biotechnology products from marine organisms

Products	Specific products	Source	Uses
● Algal polysaccharides	Carragheenans	Red algae (Chondrus)	Cosmetics – thickener, Pharmaceutical – mucoprotector anticoagulant, antiviral
● Glycosaminoglycans	Chondroitin sulphate	Fish bones	Pharmaceutical
● Collagen		Fish, echinoderms	Cosmetics
● Chitosan	Glucosamine	Crustacean shells fungi	Cosmetics – colloids Pharmacy microencapsulation
● Lipids	Long chain PUFA (AA, EPA, DHA) β carotene	Microalgae seaweed fish	Prevention of heart disease, mental development in premature infants, antitumoural, lipid metabolism
● Peptides	Hormones, cyclic peptides	Fish hydrolysates	Antioxidant, immunostimulants, Nutraceutical products

Table 5.2: Examples of research areas in marine biotechnology

Research area	Application potential of results
● Genomics	Databases, novel genes and gene products, profiling
● Proteomics	Databases, potential targets
● Bioprospecting	New products, novel model targets Potential for semi-synthetic modifications
● Environmental biotechnology	New products, new processes, biosensing and biomonitoring, bioremediation and phytoremediation, corrosion detection and control, biofouling
● Bioinformatics, computer assisted graphics and imaging technology, computational biology	New products, new information, databases, new algorithms, specific predictions based on models of biological processes, adaptability
● Nanosciences and technology	New information, feasibility of carrying out biological and chemical processes at the molecular and atomic level; new biomaterials
● Aquaculture	Polyculture, environmentally friendly system for production; microbial control; probiotics; models of host-parasite interactions; improvements in health, quality and productivity of marine organisms; culturing organisms for production of economically important products
● Exploitation of fish biomass for economically valuable products	High added value and efficient waste recycling; enhancing the value per unit weight of the organism; bioactive proteins, peptides and other molecules produced at very low cost

and other bioactive molecules. High molecular weight biological polymers and chitosan are found associated with proteins in the exoskeleton of many invertebrate species. Chitin polymers are natural, non-toxic and biodegradable and they have many applications in the food, pharmaceutical and cosmetic industries.

Overuse of broad spectrum antibiotics has resulted in the emergence of antibiotic-resistant pathogens. New broad spectrum antibiotics are needed. Different strategies to combat this resistance, such as anti-adhesion therapy, microflora management, probiotics, as well as new antibiotics are emerging from marine biotechnology research.

Organisms that have adapted to environmental extremes (extremophiles) can be screened with molecular biological probes for unusual medical or industrial applications. Examples include the high temperature enzymes from hydrothermal bacteria, or the antifreeze glycoproteins from Antarctic fish and psychrophilic microorganisms for cryopreservation technologies. In view of the global importance of microbes, and considering that less than 5,000 of an estimated 3 million bacterial species have been identified and that each species produces about 300 different molecules, it is essential that microbial diversity features strongly in future biotechnology programmes.

5.1.3 New biotechnologies for sustainable aquaculture

The reliable and large-scale supply of marine finfish and shellfish still remains a major prerequisite for marine biotechnology *(see also Section 2.1.2: Harnessing aquaculture; Section 3.4.2: Marine taxonomy and genetics)*. Overfishing and pollution have severely reduced the natural fish stocks, and demand for fish products has resulted in a rapid rise in finfish and shellfish aquaculture. Since the 1980s, aquaculture yields have been affected by disease and environmental impact and this has encouraged the development of vaccines, antibiotics and alternative polyculture biotechnologies.

The main biotechnological challenges for improving aquaculture yield are species diversification, optimal feeds, health and disease-resistance of cultured populations with minimal environmental impact.

The development of new cell culture techniques will bypass the need to collect or culture rare animals, and allow the sustainable production of novel drugs and other marine products. This will be accomplished through an improved understanding of the biology of potentially useful species, the production of the desired compounds, the development of cell immortalisation strategies and novel biotechnological scale-up procedures.

New flexible bioreactor technologies are needed to fully exploit the spectacular range of biodegradation strategies and exotic bioactive products from cultured marine or genetically modified microorganisms. This includes antibiotics, antitumour compounds, anticancer compounds, antioxidants, UV-sunscreen compounds, biopolymers and non-toxic biosurfactants useful in environmental waste treatment. The search for non-toxic non-fouling natural products from microbial and higher taxa organisms is a very active strategic research area with potentially high dividends.

5.1.4 Diagnostic tools

Microorganisms and some invertebrates provide the basis for development of sophisticated biosensors (e.g. bioluminescence systems and green fluorescent protein found in the jellyfish *Aequorea victoria*) and diagnostic reagents (e.g. phycobiliprotein markers of fluorescent immunoassay) for medicine, aquaculture and environmental biomonitoring. New diagnostic reagents are increasingly being discovered from marine sources.

Bioluminescence. © S Haddock, The Bioluminescence Web Page Image

5.1.5 Marine biomasses

About 50% of the 100 million tonnes of finfish and shellfish harvested globally from fisheries and aquaculture, is wasted (e.g. discards of bycatch) or misutilised (e.g. fishmeal for fish farming). There is considerable biotechnological scope for recovering biologically active products such as: (i) low temperature enzymes; (ii) antioxidants from enzymatic hydrolysates; and (iii) polyunsaturated acids (e.g. arachidonoic, eicosapentaenoic, docosohexaenoic) from wasted oils. New information reveals that consumption of some monounsaturated marine oils may also have important health benefits.

5.1.6 Genomic and proteomic screening of marine organisms

Genetic screening will become more important in the near future when the full relevance of bioinformatics and data mining are realised in the development of gene probes for antibiotics and other molecular targets. Increased knowledge with regard to gene sequences, resulting from genomics research, will result in improved design of specific gene probes to search for variations of gene products in these gene libraries. The molecular screening of genes and communities is complemented by a functional analysis of the obtained clone libraries after appropriate expression in industrial high-throughput units to detect novel biomolecules such as enzymes and antibiotics. This molecular approach shows great promise in making the genetic resources of most marine microorganisms accessible and should be further supported *(see also Sections 3.4.2: Marine taxonomy and genetics; and Section 3.4.3: Functional role of marine biodiversity).*

5.1.7 Cultivating marine organisms for biotechnology

Marine organisms have traditionally been, and still are, good models for the study of communication, neurotransmission, defence, adhesion, host interactions, disease, epidemics, nutrition and adaptation to large, often extreme, variations in their environment. There are numerous examples of marine models contributing to understanding basic concepts within biology and medicine. The possibility of cultivating these organisms, and to study them in the laboratory at a cellular, molecular or genetic level, has opened new options for sustainable husbandry and experimental marine biology.

In conclusion, a European initiative in marine biotechnology will mobilise the current human capital now divided between different countries and addressing issues in a stochastic and disjointed manner. This initiative will also challenge a new generation of young scientists to contribute their talents and energy to the field and thus further its success. A European initiative will integrate these activities with clear synergies and enthusiasm stemming from a new focus, and with broad appeal to industry, to biomedicine and to society.

© R Osinga and H Belarbi, Wageningen University, the Netherlands

Sponges

Sponges produce a variety of interesting compounds: cytotoxic compounds, antibiotics, anti-viral agents, anti-inflammatory and cardiovascular compounds, and anti-fouling compounds. Biotechnological production methods for sponge biomass are needed to enable durable exploitation of this valuable natural resource. A possible strategy for the production of sponge biomass involves the cultivation of sponges as functional animals in controlled, closed bioreactor systems.

5.1.8 Key research recommendations

- Marine biotechnology research has the potential to bioprospect the vast genetic richness of the ocean to discover new materials, for pharmaceuticals, agrochemicals and cosmetics. A European flagship project in marine biotechnology is required to bring together the excellent but sub-critical RTD groups in Europe into a common endeavour with industrial biotechnology partners. Enhanced research efforts in marine genetics would also contribute to improved competitiveness in biotechnology *(see also Section 3.4.2: Marine taxonomy and genetics)*. In addition, bioprospecting should be integrated into future oceanographic expeditions.

- A European network promoting dissemination of marine biotechnology discoveries, and collaboration between marine biologists, biotechnologists and industrialists should be established to screen biotechnology products from different marine organisms, encourage sustainable exploitation of new biotechnology discoveries in Europe and to limit environmental impacts. Effective networking would result in efficient technological development and rapid commercialisation of novel products.

- The molecular screening of genes and communities will increase the detection of novel biomolecules such as enzymes, antibiotics and other bioactive compounds. The associated development of non-toxic agents to protect against biofouling and corrosion would have far reaching impacts on the marine environment. There is thus a need to improve primary and large-scale culturing facilities for screening the production and molecular regulation of novel bioactive products from marine microorganisms.

5.2 New ecosystems at oceanic extremes

5.2.1 Scientific challenges

Since the 1990s, a number of exciting discoveries in the marine environment have considerably altered the perception of life in the oceans, and their significance has radiated into other fields of life sciences. Discoveries include deep sea chemosynthetic food webs (involving bacteria, crabs, shrimps and bivalves) at hydrothermal vents, cold water corals along ocean margins, methane oxidising bacteria and Archaea laying down massive carbonate mounds on continental slopes, tiny unicellular prochlorococcus cells that dominate photosynthesis in oligotrophic oceans, the extraordinary abundance and diversity of marine viruses and their regulatory feedbacks in food webs and the significant presence of Crenarchaea, to name but a few.

New or largely unknown habitats with specifically adapted organisms and novel biochemical pathways are continually being found. Many such organisms are key players in the transformation of organic and inorganic matter within the global element cycles.

In almost all cases, these new discoveries were made possible by advancements in submersibles, marine communication, bioanalytical and molecular technologies. More than most other fields of science, marine science and oceanography are critically dependent on advanced technologies, to access the deepest, remotest, smallest and rarest life forms that occur in the most extreme and surprising locations on this ocean-covered planet *(see also Section 6: Critical technologies)*.

5.2.2 New links between geosphere and biosphere

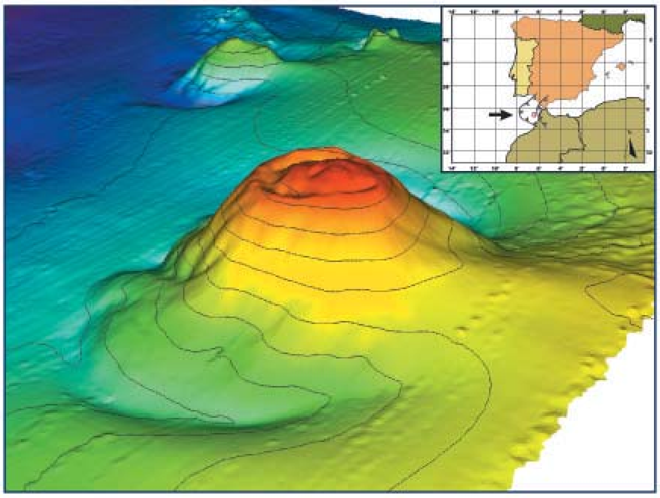
The geosphere provides the driving force for life in a variety of special deep sea ecosystems. The unique assemblage of chemosynthetic life found along hydrothermal vents in the late 1970s is an already classic example. These alternatives to photosynthesis-based ecosystems, their specific biochemical pathways and symbiotic relationships now appear to be more widespread in the marine environment, as evidenced by some amazing new discoveries, detailed below.

The deep biosphere and limits of life on Earth

Bacteria have recently been discovered living hundreds of metres within the deep ocean sediments and basement rocks sampled by the Ocean Drilling Program. Both environments were previously considered to be totally abiotic. The microbial life detected deep inside the ocean floor, termed the deep sub-seafloor biosphere, has been isolated from the sediment surface for several million years, and has raised new questions about the ultimate origins and limits of life on Earth. The investigation of the origins and limits of life on Earth and of the specific adaptations of these microorganisms is a major and exciting scientific challenge for the next decade.

Massive carbonate mounds

Advanced seismic surveys have recently discovered clusters of giant carbonate mounds 200m to 300m high along continental margins.

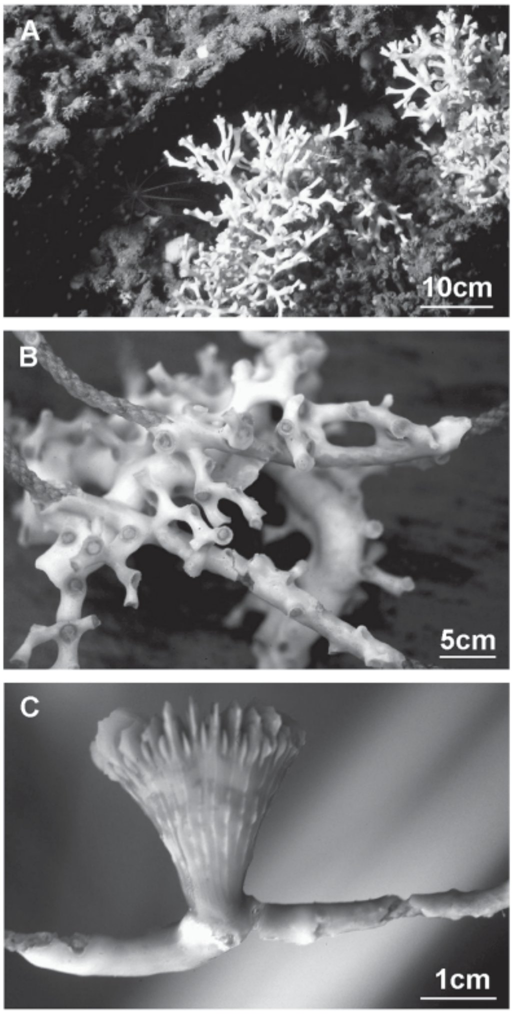


A multibeam image of the Al Idrisi mud volcano discovered in May 2002 by RV *Belgica* on the hitherto largely overlooked Iberian-Moroccan accretionary wedge. Towering 200m above the seafloor, 4km in diameter, its top is less than 200m below water, with visible lobes indicating possible recent activity. © J P Henriet, Ghent University, Belgium

Carbonate mounds apparently originate from microbial processes associated with anoxic methane oxidation, although other processes of mound genesis are also possible. Typical features of carbonate mounds include abundant microbial exopolymers in the sediment, which alter the diffusion of fluids through the sediment and stabilise the mound slopes. Carbonate mounds provide susbtrates for unique macrobenthic assemblages, including the recently discovered cold water corals that have been found throughout the North West European margins. Research is required to clarify the role of microbial drivers of biomineralogy and biodissolution in the formation of geological structures in the deep ocean.

Cold water corals

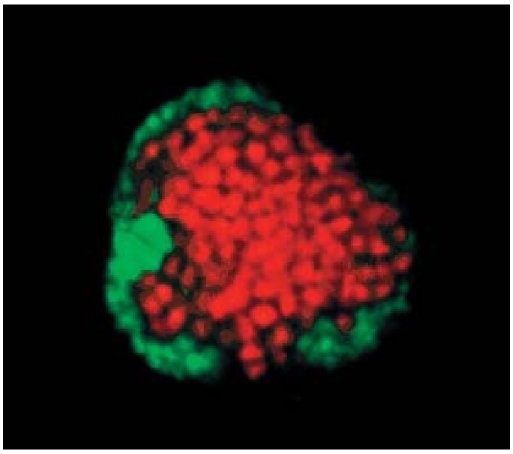
Exciting discoveries include an unexpectedly wide distribution of cold water corals (*Lophelia pertusa*) in the deep aphotic continental slopes of Europe, where the corals apparently survive on a supply of organic particles transported by strong slope currents. This contrasts with the shallow, warm water corals that live on internal supplies of organics from endosymbiotic photosynthetic zooxanthellae. The carbonaceous skeletons of *Lophelia* contribute to the stabilisation of the sediments and support mound growth by enhancing the deposition of sediment particles. The cold coral communities shelter other animals and they are important for recruitment of different organisms including fish. Preliminary research indicates that their presence supports various cetacean populations. Visual and acoustic observations of cetaceans, including not only benthic feeders such as sperm whales, long-finned pilot whales and beaked whales, but also pelagic species such as Atlantic White-sided, common and bottlenose dolphins, have been recorded from *Lophelia*-rich areas of the North Atlantic margin, some with unexpectedly high abundance. The understanding of the biological processes and organisms involved in shaping the seafloor is a question of fundamental interest.



Major scleractinian cold water corals that are commonly found in deep-water reefal frameworks: (A) *Lophelia pertusa*, Sula Reef, Norway, 276 m water depth; (B) *Madrepora oculata*, rapid growing colony on a plastic rope from Galicia Bank, 900 m water depth; (C) a rapid growing *Desmophyllum cristagalli* with parental corallite on a plastic rope from Galicia Bank, 900 m water depth. © A Freiwald, Ocean Margin Systems, Hanse Conference Nov 2000 (in press)

Prokaryotic scavengers of deep methane

The deep oceanic hydrate horizons host a newly discovered, prolific deep biosphere *(see also Section 2.2.1: New hydrocarbon frontiers; Section 3.3.3: Geoclimatic hazards along ocean margins)*. Using recently developed molecular probes and micromanipulation experiments, unique consortia of bacteria and Archaea have been discovered along gas hydrate-rich sediments of continental slopes. These prokaryotic consortia bypass thermodynamic obstacles by simultaneous oxidation of methane and reduction of sulphate. They also provide a good barrier against the escape of methane from the methane-rich sediments into the water column and subsequently to the atmosphere where it would act as a greenhouse gas. However, the environmental factors affecting the turnover of methane by these prokaryotic consortia need to be further investigated to quantify the balance of methane release, biological consumption and evasion into the atmosphere.



A microbial consortium mediating anaerobic methane oxidation (after Boetius *et al.* 2000). High numbers of aggregated cells of Archaea (red) and sulfate reducing bacteria (green) were found in sediments above gas hydrates (Hydrate Ridge, continental slope off Oregon, USA). The aggregated cells were exposed to a green-fluorescent RNA-probe targeting sulfate-reducing bacteria (Desulfococcus-Desulfosarcina group) and a red-fluorescent RNA-probe targeting Archaea (ANME-2 group). The aggregate has a size of approximately 10 micrometer. The image was taken by confocal laser scanning microscopy.

Rich communities of macrobenthic organisms are associated with methane deposits; many harbour symbiotic bacteria utilising chemical energy sources from the interior of the sediments. Such symbiotic associations between benthic fauna and chemosynthetic microorganisms occur not only at hydrothermal vents, cold seeps, and gas hydrates, but also at mud volcanoes and pockmarks in the seafloor and may be much more widespread than hitherto assumed. In all cases the supply of geochemical energy is driven by sub-seafloor flow systems. How the geochemical composition and dynamics of fluid flow in sediments regulates chemosymbiotic diversity in the deep ocean remains a major unknown.

5.2.3 Detecting and attributing variability in deep ocean biology

The deep ocean had until recently been considered to be a very stable environment, undisturbed by climatic or human action. This view is now changing. For example, long-term observations in the Porcupine Abyssal Plain have indicated drastic shifts in the population of sea cucumbers in the deep sea. The reasons for these changes are not clear. Such changes could be natural long-term oscillations within the population, or they could be attributed to changes in the supply of phytogenic organics from the upper ocean. In the deep Pacific Ocean a decline in the sedimentation of organic matter was observed and attributed to climatic changes. These observations indicate that deep ocean ecosystems are more variable than hitherto assumed, and that the deep ocean ecosystems may also be affected by climate change.

The discovery of traces of PCBs and other xenobiotics in deep abyssal sediments and fauna indicate that even the most remote parts of the deep oceans are affected by long range and diffuse sources of pollution. It is not known if eutrophication products in coastal and shelf seas can leak out to the open ocean and affect the deep sea biota. At present, the number of observations are too few and inconclusive. To understand

© A Carpentier, Ifremer, France

Orange roughy

The orange roughy (*Hoplostethus atlanticus)* is a deep water fish (occurring in depths of 800m to 1,500m) associated with carbonate mounds and is found in the Atlantic, Pacific and Indian oceans. The species is slow growing, achieving ages of up to 187 years in European Atlantic waters. It is known to reach maturity at 20-30 years, and it has a low fertility rate. It forms dense aggregations and commercial fisheries exist in Australia, New Zealand, Namibia, the Mid-Atlantic Ridge and west of Scotland. In 2001, a new fishery developed off the west coast of Ireland, which has been targeted by French and Faeroese vessels since the mid 1990s. In 2001, an estimated 3,779 tonnes of orange roughy were landed from the North East Atlantic, an increase from 2,442 tonnes in 2000. The fishery and its associated ecosystem are under threat, as no management measures for deep water fish stocks are in place within the EU, and there is great debate as to whether this is a sustainable fishery, or merely an example of mining a fish population. It is essential that assessment methods are developed, to provide the scientific advice required to underpin a management plan for the fishery, and to protect its ecosystem *(see also Section 2.1.1 Collapsing fish stocks and environmental impacts).*

how the flux of material from land, or the alteration of surface ocean processes, ultimately affect the deep sea ecosystems it is essential to improve long-term observation of key terrestrial biomarkers and xenobiotics at specific deep oceanic locations.

Although continental margins and the adjacent deep sea areas are not yet intensively exploited, oil and gas exploration are moving to deeper subsea hydrocarbon fields *(see also Section 2.2.1: New hydrocarbon frontiers).* Although the London Dumping Convention prohibits waste disposal in the ocean, experiments have explored the possibility of municipal waste deposition, and international discussions are underway evaluating the disposal (sequestration) of anthropogenic CO_2 in the deep ocean *(see also Section 4.3.1: Ocean CO_2 sinks, feedbacks and limits in a greenhouse world).* The main uncertainties derive from poorly known dynamics of the deep waters and the sensitivities of biological systems in these oceanic extremes. Research must identify sensitive habitats and species ahead of any exploration or direct impacts, to improve the basis for management and protection of the fragile equilibria in deep sea ecosystems *(see also Section 3.5: Integrated governance of European oceans and seas).*

Finally, the impact of unregulated deep ocean fishing *(see also Section 2.1.1: Collapsing fish stocks and environmental impacts)* for deep sea slow-growing species and the resultant perturbations on deep benthic and pelagic food webs is also of concern. Removal of fish species from a system which is primarily limited by food supply and not by predation is likely to have different and far ranging impacts on the ecosystems of deep extreme environments. These impacts are as yet unknown. Therefore, there is an urgent need for basic knowledge of the biology, the recruitment and growth rates of deep ocean fish. Marine protected areas (MPAs) will be needed to safeguard the recruitment of such species and the biodiversity of the associated ecosystems. The choice of such areas has to be guided by scientific insight and not by requirements of the fisheries industry.

Fundamental biological and ecological questions regarding the extreme slope and abyssal habitats remain to be solved. How do geological conditions influence the distribution of species at margins? How do organisms depend on large- and small-scale physical processes (e.g. deep water currents, impact of internal waves, turbulence in the benthic boundary layer etc.)? What are the physiological adaptations to extreme food limitation? How does an intermittent food supply influence reproduction? How can such a high species diversity develop? Is this system resilient or sensitive to impacts?

5.2.4 The requirement for new tools

It is clear that progress in new research on deep sea ecosystems and their vulnerability is critically linked with application of advanced technology for observation and experimentation at oceanic extremes *(see also Section 6: Critical technologies).* New improvements are required in several areas including:

- development of new sampling tools to retrieve and monitor live organisms from oceanic extremes;
- development of dedicated remotely operated vehicles and experimental seabed landers to determine *in situ* biological and biogeochemical fluxes;
- culturing facilities and bioreactors for microbial extremophiles;
- long-term observatories with multidisciplinary sensors and telemetry for tracking variability and change in the deep ocean ecology.

In conclusion, the ecosystems found in the ocean are in many respects fundamentally different from terrestrial ones. This offers exciting possibilities to study basic aspects of the evolution and limits of life on Earth. New biochemical or physiological capabilities may be discovered which have evolved to make use of the energy sources from deep derived fluid flows or to adapt to extreme environmental conditions. Mankind's view of life is so dominated by the familiar environment on land that an appreciation of the full capabilities of living systems found in the vast biosphere of the ocean has not been achieved. This is the major scientific and technological challenge for the next decade.

5.2.5 Key research recommendations

New ecosystems at oceanic extremes

- New organisms, evolutionary lines and geochemical processes are continually being discovered at deep seafloor, sub-seafloor and extreme environments. Research is required to investigate the links between geosphere and biosphere, including the role of organisms in the formation of seafloor structures, mineral precipitation and dissolution, and use of energy derived from the geosphere. Marine protected areas (MPAs) will be needed to safeguard the recruitment of species and the biodiversity of the associated ecosystems. The choice of such areas has to be guided by scientific insight and not solely by the requirements of the fisheries industry.

- Research is required to analyse the role of gas hydrate reservoirs as dynamic components of the global carbon cycle, recharge and discharge fluxes and their controlling factors. There is a requirement to evaluate the impact of gas hydrates on slope destabilisation. An assessment of the role of the oceanic gas hydrate reservoir as hosts of deep biosphere ecosystems is also required. Major consideration should be given to a European research programme on gas hydrates to facilitate an integrated implementation of the various recommendations related to gas hydrates in this Position Paper.

- It is necessary to develop new technologies for observation, sampling and experimentation in the largely unknown ecosystems of the deep ocean as well as techniques for cultivation of organisms from extreme habitats. Deep ocean vehicles and observatories should be upgraded with smart sensors, in situ experimental capabilities and two-way telemetry for remote exploration, experimentation and monitoring of extreme ecosystems and their response to climatic and episodic events, and to integrate these with historic data for decadal to centennial scale analysis. Such observatories are required to establish baseline studies that adopt an ecosystem approach, a priority in advance of exploitation of deep ocean resources *(see also Section 3.5: Integrated governance of European oceans and seas)*. Improved long-term observation of key terrestrial biomarkers and xenobiotics at specific deep oceanic locations will increase understanding of how the flux of material from land, or the alteration of surface ocean processes, ultimately affect the deep sea ecosystems.

- Research on the specific adaptations of organisms to a range of extreme conditions found in habitats of the deep sea is required. Research on the vertebrate populations supported by these habitats should also be initiated, and can largely be done in an interdisciplinary manner concurrent with geological and oceanographic surveys. The results of such baseline studies will contribute to effective management and governance of ocean resources.

5.3 Vents and seeps

The composition of sea water is controlled not only by the chemical and physical weathering of continents; it is also influenced by the leaching of basaltic rocks and the serpentinisation of mantle rocks exposed in mid-ocean ridges, by dewatering of sediments at convergent margins and by fluid expulsion from hydrocarbon-bearing reservoirs mostly on passive margins. In the mid 1970s, it was discovered that fluids were discharged through narrow vents onto the floor of mid-ocean spreading centres, at high rates and at temperatures of up to 250°C; these are referred to as hot vents. In the 1980s, another process of oceanic mass transport was revealed: the dewatering of sediments at active continental margins; these are referred to as cold vents. Meanwhile, offshore exploration steadily moving from shelf to slope revealed striking features of fluid expulsion at the seafloor in hydrocarbon provinces: pockmarks, mud diapers, and surficial gas hydrates. As both hot and cold vents are important sources of nutrients and energy, fluid flow on mid-ocean ridges and margins has to be considered in order to understand mass and energy budgets. It is nowadays well known that discharge areas are oases for communities of chemosynthetic organisms *(see also Section 5.2.2: New links between geosphere and biosphere)* and furthermore, that they are sites of active mineral precipitation in the form of chimneys and crusts of sulphides, carbonates, oxides and sulphates.

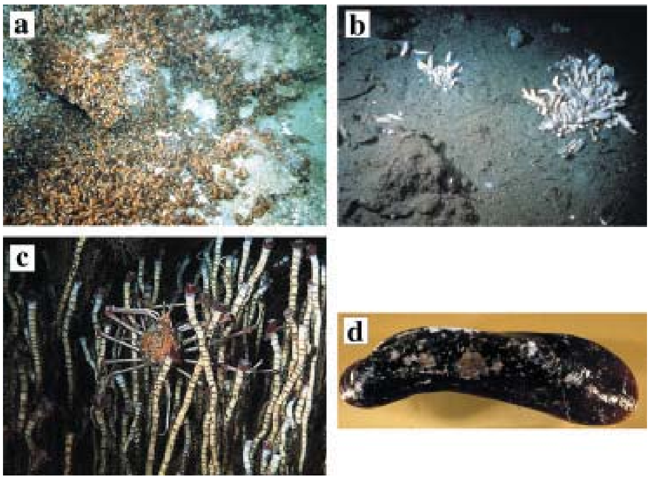
5.3.1 Ridge-flank thermal convection between crust and ocean

Ridge-flank circulation systems occupy a large portion of most ocean basins and globally circulate about 350km^3 of water per year. It is thus estimated that about 25% of the global endogenous heat flux and about 30% of the oceanic heat flux is transmitted by convective hydrothermal circulation.

At spreading centres, sea water penetrates into the oceanic crust, is heated to 300-400°C, and reacts with crustal rocks and with solutions released from underlying magma chambers. Resulting hydrothermal fluids, enriched in sulphur compounds, barium, manganese, methane and other dissolved materials, rise to the seafloor where they are discharged in two modes: focused or diffuse. Discharged fluids are thus the final product of a chemical reaction zone that may extend to 5 or 6km below the seafloor. Focused discharges are high-temperature (250-400°C) and, on mixing with sea water, produce the black and white smokers with their deposits of metal sulphides and other components (sulphates, oxides etc.). Diffuse discharges are low-temperature (5-50°C) and spread over broader areas on the ridge flanks. Their fluids were produced by the mixing of heated solutions with cold sea water present both in the sediments and within fissures of the crustal rocks. They contain lesser amounts of components such as hydrogen sulphide and methane and have lost much of their mineral content below the seafloor before emerging into bottom waters. Diffuse convective heat transport can be up to 5-10 times higher than focused heat transport, and it appears that bioproductivity is more enhanced in areas of diffuse emergence than around focused vents.

Serpentisation of mantle rocks exposed in rift flanks and fracture zones has been identified as a surprising source of primary hydrocarbons, including methane and more complex hydrocarbons. Considering the volumetric importance of oceanic serpentines, such catalytic reactions and the resulting fluxes deserve attention.

Hydrothermal solutions can modify the composition of sea water. Their iron and manganese compounds, on precipitating, absorb trace components present in the sea water. There thus exists a complex system of interactions and exchanges between crust and ocean, which form an essential component of geochemical cycles and mass budgets of the lithosphere, hydrosphere and marine biosphere.



Cold seep communities: (a) mussel field dominated by Bathymodiolus sp.at El Pilar dome (Barbados accretionary prism); (b) Calyptogena phaseoliformis aggregates from the Japan trench; (c) vestimentiferan bushes in the Gulf of Mexico at the Louisiana upper continental slope; (d) example of a very large bivalve (35 cm length), Bathymodiolus boomerang, from Barbados Orenoque ridge. © M Sibuet and K Olu-Le Roy (2002)

5.3.2 Dewatering of active margin sediments

At active margins water is extracted from marine sediments by tectonic compaction of subducted and accreted material. Water can migrate laterally and vertically over kilometres, primarily along faults, before being returned to the sea. It may also be released by dehydration reactions in minerals as temperature and pressure increase along the downward path into subduction zones. The outflow at active margins provides the means by which water trapped into sediments returns to the ocean instead of being taken down to facilitate partial melting of the mantle and magma genesis. Large amounts of dissolved substances are thus recirculated (e.g. carbon, sulphur, water, halogens etc.) and released onto the seafloor, especially as methane and hydrogen sulphide. Evidence of fluid escape includes features such as pockmarks, brine pools and volcanoes. Mineral precipitates, together with communities of molluscs and tubeworms living in symbiosis with chemautotrophic bacteria, have been found at discharge locations. The role of fluid pressure build-up within fault zones beneath active margins is of fundamental significance in controlling the initiation and magnitude of earthquakes. For European scientists, the most accessible accretionary wedge systems for research are the Mediterranean Ridge and the Iberian-Moroccan wedge.

5.3.3 Fluid expulsion at passive margins

Fluid discharge also exists along passive margins, in the form of cold water seeps that bring to the ocean a virtually unknown quantity of dissolved solids and gases. The flows that feed these seeps are driven by such diverse factors as hydrostatic overpressure from the adjacent land, compaction of sediments in deltas, and the escape of water and hydrocarbons from deep overpressured and faulted formations. Gas venting, sometimes apparently unrelated to pockmarks, occurs in many hydrocarbon-prone basins along the Thetyan belt, northern Europe and the Gulf of Mexico. Methane, released from hydrocarbon reservoirs, can be temporarily trapped in a dynamic sub-seafloor reservoir of gas hydrates *(see also Section 3.3.3: Geoclimatic hazards along ocean margins).* Climate and sea level-controlled destabilisation of such gas hydrates can release vast quantities of greenhouse gases which rise to the seafloor through fractures in the overlying sedimentary rocks.

At continental margins and in deep ocean sedimentary basins, early diagenetic processes also contribute to diffuse flow and cycling of elements into sea water.

A feature common to all sites of fluid discharge into the sea, as already noted above, is their ubiquitous colonisation by benthic biota. These communities have different characteristics, depending on the tectonic setting (ridge systems, accretionary complexes, cold seeps and groundwater discharges). Their spatial distribution provides indications of the expulsion pattern, while their biomass appears to be a function of the magnitude of fluid flow, and their structure is related to fluid composition.

5.3.4 Key research recommendations

Ridge-flank thermal convection between crust and ocean

- This area of research requires quantification of the transport of material and energy in hydrothermal systems and improved modelling of fluid convection systems. Distinction between fluids originating from heated sea water and those released by fractional crystallisation of underlying magma is required. There is also a requirement to understand and quantify the influence of fluids on sea water composition. Understanding primary generation of hydrocarbons at mid-ocean ridges and considering the volumetric importance of oceanic serpentines, the associated catalytic reactions and the resulting fluxes also requires attention.

Fluids at continental margins

- The thermal structure and fluid regimes in areas of colliding plates should continue to be investigated. Quantification of the contribution of cold vents to the geochemical balance of various elements (i.e. how much carbon, sulphur, water and halogens are introduced into the ocean) with fluids is also required. Research is required to determine transport paths in mass transfer and the respective contributions of focused and diffuse dewatering. Research is necessary on: (i) biological mediation of precipitations at fluid flow sites; (ii) periodicity and transient effects; (iii) integrating early diagenetic material fluxes in models of ocean circulation; and (iv) the relationship between flow, tectonics and earthquakes.

6. Critical technologies

6. Critical technologies

6.1. Introduction

The ability to make new discoveries, understand, forecast and provide management advice on the ocean and its resources is profoundly linked to the availability of appropriate technology. Marine technology provides the means for probing, sampling, viewing, modelling and operating within the ocean, from the stormy surface to the deepest extremities of this blue planet.

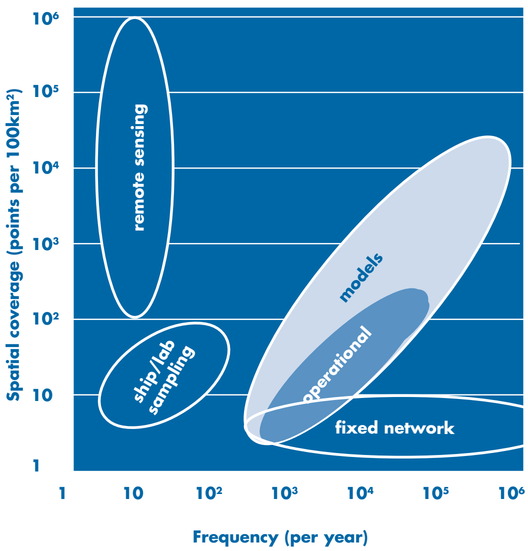
The marine science challenges identified in this Position Paper are multidisciplinary, problem-driven, integrated and strategic in context. Two key issues in marine technology: (i) integrating multidisciplinary observations; and (ii) the importance of timely forecasts, are detailed below.

6.1.1 Integrating multidisciplinary observations

As all key processes in the ocean are interdependent and linked across disciplinary boundaries, observations needed include short-term and long-term, remote (including satellite) and *in situ*, synchronous, physical, chemical, biological and geophysical aspects. The new integrated technologies required to address these challenges should deliver a core suite of critical multidisciplinary parameters and supporting systems, to which additional specialist sensors and experiments can be added. New technologies should incorporate the latest advances in sensors, systems, platforms, communication and propulsion. They must also be robust for deployment at diverse strategic and diagnostic locations on the seafloor, in the water column, and within contrasting biological ecosystems. This is a long-term challenge for European technologists who are enthusiastic to deliver, provided that the necessary resources are in place. International collaboration is also needed to ensure harmonisation and the development of cost-effective technology.

6.1.2 The increasing importance of providing timely forecasts

Forecasts are essential for informing decision makers, marine operators and management of the present and near-future state of the marine environment, thereby providing timely warnings with regard to potential hazards (e.g. storms, floods, algal blooms, geohazards, pollution and climate extremes; *see also Section 3.2.2: Operational oceanography; Section 3.3: Ocean margin processes and geohazards)*. Credible operational forecasts need data streams from remote and/or *in situ* observing systems that can be transmitted ashore in near real time for assimilation into operational models. This requires long-term commitments from policy makers and funding agencies to ensure optimum organisation and reliability to meet these demands of socio-economic importance.



The spatial and temporal resolution of oceanographic data showing the mismatch between resolution of monitoring systems and forecasting models. © D Prandle, Proudman Oceanographic Laboratory, UK

6.2 Technological innovations

The challenges facing marine technologists include:

- development of new sensors: particularly for biological and chemical parameters;
- development of new systems: multiparameter, networking architecture;
- ensuring cost-effectiveness: long-term components and high spatial density deployments;
- appropriate infrastructure: two-way data communication and control.

6.2.1 Novel sensors

Sensors are the basic components of all instrumentation systems and sensor development has to address the requirements of future scientific strategies and research, as well as operational expectations. Measurements of physical, chemical, geological, biological and meteorological parameters that characterise the condition of the marine environment are critical to advance knowledge and understanding of the complex processes occurring within the marine environment, and to enhance the ability to monitor change. Emphasis is needed on the development of new sensors to measure *in situ* nutrients and concentrations of the most widespread and frequent pollutants *(see Table 6.1)*. 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 innovations obtained in disciplines such as medicine and biomolecular technology *(see also Section 3.4.2: Marine taxonomy and genetics; Section 5.1: Marine biotechnology: bioprospecting the planet's largest biotope)*.

Since the 1980s, there has been limited success in the development of new sensors for real-world applications. Future sensors must be operational at the air-sea interface, in the water column and at water-sediment interfaces. Particular limits on the development of *in situ* sensors include:

- complex and varying seawater and sediment matrix;
- limited sensitivity for many trace chemicals;
- fouling of sensor surfaces;
- selectivity and interferences;
- drift and instability in sensor chemistry and material;
- limited depth/pressure precision to match satellite altimeters.

Table 6.1: Key parameters to be monitored in coastal zone and shelf seas

Physical	Chemical	Biological	Geophysical
Temperature	NO_3, PO_4, Si, NH_4	Photosynthetic pigments and activity (chlorophyll)	Seismicity
Conductivity	Trace metals, pH, radionucleides	Bacterial and phyto-plankton cytometry	Bathymetry
Density, pressure	Dissolved gases (O_2, CO_2, DMS)	Viral particles	Gravimetry
Light, bioptics	Volatile organic pollutants	RNA, DNA, proteins key enzymes	Magnetism
Turbidity, particle size distribution	Pesticides	Pelagic animals	Acoustic signals
Velocity, turbulence	PCB, PAH, CFC	Benthic communities	Seafloor characteristics

Recently, there have been reports of promising electrochemical, bioanalytical and optical devices, nanotechnology systems and materials that could find novel applications in marine technology.

6.2.2 Biosensors

Biosensors are powerful tools that combine a recognition surface which is sensitive to ions or molecules with a transducer which transforms the interaction into an analytic signal. The wide variety of reactions, sensing systems (e.g. enzymes, cells, DNA, antigen/antibody etc.) and transducers (e.g. optical, thermal, electrochemical etc.) accounts for the large number of sensors being rapidly developed by the biomedical field in the post-genome era. In particular, biochips based on microarrays of biorecognition elements (e.g. antibodies) will enable simultaneous measurement of a range of parameters (multi-analyte sensing). However, these are generally single-shot devices, and it is not clear whether or not they would survive in the harsh marine environment or be suitable for *in situ* monitoring. Other areas of biosensor technology that are of significance include those based on enzyme inhibition, bioluminescence, and sensors based on living cells. An excellent example of bioptical sensors is the fast repetition rate fluorimetric (FRRF) adaptation of the classical chlorophyll fluorometer which can directly probe in real time and *in situ* the photophysiological state of phytoplankton in the sea.

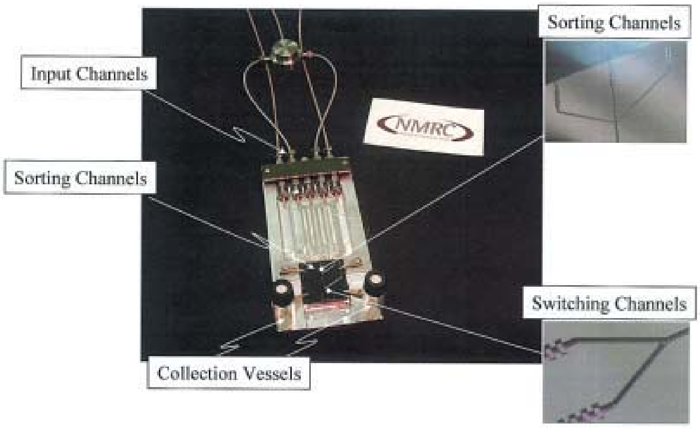
6.2.3 Sensor arrays

Sensor arrays (e.g. microelectrode arrays) for microscale real time and in situ detection of multiple analytes (e.g. O_2, NO_3, NO_2, SiO_2, NH_4, PO_4) show considerable promise (e.g. in benthic landers) compared to the slow response of colourimetric techniques. Recalibration and biofouling control will need to be integrated into sensor array systems. Electronic and optical tongues that detect biogases such as DMS and CH_4 also hold great potential.

6.2.4 Microsystems technology (MST)

Chip microfabrication technology and fluidic chemistry have recently combined to produce what is frequently referred to as a Lab-on-a-Chip, which includes nanofluidic devices (e.g. injectors, valves, mixing lines, LED/CCD detectors), system control, and data processing, all on a silica platform measuring only $4cm^2$. The ability to use proven colourimetric chemistries (e.g. for nutrients), the ultra low power requirements, and the possibility of large-scale low-cost production, implies that microsystems technology (MST) will undoubtedly have a major impact on marine observations. Developments in the area of microfluidic biosensor platforms, in combination with developments of antifouling materials, should facilitate enhanced long-term real time recording and monitoring in the marine environment.

Cytometry Microsystem



Cytometry microsystem: Prototype of a microfluidic device for cell sorting. Hydro-dynamic flow-channels fabricated in silicon (or polymer) provide for single cell flow. An integrated solid state emitter and detector enables sorting and isolation of cells based on LIF (Laser Induced Fluorescence) for further analysis. © P O'Brien, National Microelectronics Research Centre, University College Cork, Ireland

6.2.5 Coupled optical sensors

Spectro-electrochemistry combines the advantages of optical and electrochemical sensing to dramatically improve detection limits for heavy metal ions. Metal ions are first electroconcentrated and then reacted with metal-selective dyes coated on optical sensing fibre. Microspectral imaging, in which flowing cells or particles are detected by chip-embedded lasers, is another promising MST-based device. In other words, microelectronics combined with microfluidics will deliver a chip-based flow cytometer or particle counter weighing a few grams. Infra red lasers (e.g. quantum cascade lasers) can now be tuned for infra red spectrophotometric detection of gases such as gas hydrates and hydrocarbons.

6.2.6 Mass spectrometers (MS)

Mass spectrometers (MS) have already been adapted for *in situ* detection of volatile biogases and hydrocarbons. The depth to which they can make measurements, their weight, size and their sensitivity are rapidly improving and this promises to render *in situ* MS systems ideal as precise multigas monitors.

6.2.7 Smart materials

Smart materials such as molecularly imprinted polymers and enrichment matrices exhibit high stereo selectivity needed to recognise and quantify biomolecules (e.g. algal toxins) and other compounds that cannot be detected by conventional methods. The recognition of these molecules is based on molecularly imprinted luminescent polymers which exhibit significantly enhanced stability (operational and shelf life) compared to enzyme-based sensors. Nanoparticles exhibiting immobilised indicator dyes for pH, ions or oxygen, may soon be inserted into cells or microorganisms to monitor their health. Novel nanomaterials and active coatings are being developed to overcome the problem of biofouling on sensing surfaces.

As with all sensor systems, *in situ* recalibration must be incorporated for quality control of sensor data, particularly for long-term deployments. These methods and techniques have to be continuously improved as they represent a significant part of the monitoring systems operating costs. Tables 6.2 and 6.3 show development times for the application of novel sensor systems in relation to the identified marine science challenges. Industrial partners would accelerate development, sales and usage by marine scientists.

Table 6.2: Biotechnology: sensing the ocean

	Present day	3 Years	5 Years	10 Years	> 10 Years
I. Single use/ spot sample	DNA micro-arrays for genomic analysis		Bioavailable iron using modified cyanobacteria	Automated species identification in simple ecosystems	
	Microbial biomass via DNA analysis		Fluorescent *in situ* hybridisation (FISH)		
II. Medium endurance (week/month)		Biomaterial against biofouling	Probes for biogeochemical functions		Automated species identification in complex ecosystems
III. Long endurance (year)			Biomaterial against biofouling		
IV. Alarm	Detect precursors of harmful algal blooms by immunoassay (*in vitro*)	Detect precursors of harmful algal blooms by immunoassay (*in situ*)			

Table 6.3: Microsystems, smart materials and nanotechnology

	Present day	3 Years	5 Years	10 Years	> 10 Years
I. Single use/ spot sample	Mesoporous material for electrodes (e.g. CO_2, O_2)	Bioarrays based on antibodies or immunoassay *(in situ)*	Gas chromatograph Surface Acoustic Wave mass detector		
	Bioarrays based on antibodies or immunoassay *(in vitro)*		Mass spectrometer for biogenic gases		
II. Medium endurance (weeks/month)		Mesoporous material for electrodes (e.g. CO_2, O_2)	Microfluidic chemical analyser for nutrients	Gas chromatograph Surface Acoustic Wave mass detector *(in situ)*	
			Electronic or optical tongue	Mass spectrometer for biogenic gases	
III. Long endurance (years)	CO_2 partial pressure			Microfluidic chemical analyser for nutrients	
IV. Alarm	Transition to anoxia/hypoxia Radionucleides	Detection of endocrine disrupting compounds	Detection of harmful algae using molecular imprinted membrane electrodes		

Key to Tables 6.2 and 6.3

Ocean climate interactions	Marine life	Coastal zone and shelf seas
New frontiers in marine science	All disciplines	

6.2.8 Acoustics and optics

Observations of marine life are characterised by under-utilisation of advanced acoustic and optic systems. Multifrequency and broad band acoustic systems (e.g. calibrated multibeam systems, parametric sonars) potentially can give quantitative information about density, size and species of marine life from the smallest plankton to the largest fish and mammal. Combining acoustic and visual observation systems with physical sensors could create new powerful instrumentation that will improve reliability, temporal and spatial resolution and reduce the need for biological sampling.

6.2.9 Acoustic tomography and thermometry

One of the legacies of the cold war is the know-how to exploit long-range sound transmission through the ocean for scientific research and, in the future, cost-effective monitoring. Two techniques have been demonstrated successfully by US scientists, and subsequently applied in European seas. The first is acoustic tomography that can monitor the variation of ocean weather (fluctuations in permanent currents such as the Gulf Stream and in transient, quasi-geostrophic eddies – the ocean equivalent of storms.) The second is acoustic thermometry, which can detect small changes (in the order of milliKelvin) in the mean temperature along megametre rays, which is one way to monitor changes in the global heat content of the ocean.

6.3 Key components and systems

The strategic shift by marine scientists from expeditionary or spatial mapping to long-term observations and experimentation creates new challenges, not just in terms of novel microsensors but also with regard to the key components and systems required to support the new sensors.

The idea of observatories, vehicles and instruments operating autonomously in the ocean abyss for extended periods of time with bidirectional communication ashore remains a marine technology frontier. Recent advances in fibre optic cables, robotics, materials, nanotechnology, computers, communication and acoustics have made such measurements and modelling significantly more practical. For example, the pilot Global Ocean Data Assimilation Experiment (GODAE) within GOOS will make use of CTD data from the Argo network of 3000 drifting profiling floats. These could be considered as the first generation of ocean robots.

This section highlights recent developments in key components which promise to revolutionise the deployment, control, data capture and operational range of the next generation of marine observatories.

6.3.1 Energy concepts

Autonomous systems deployed on long-term missions could soon benefit from advanced, modular, renewable, electrochemical cells, reduction of power requirements of systems, and achieve improvement of efficiency through real time remote control to activate systems in response to observed events.

6.3.2 Information technology

Active sensors networked with samplers will be in bidirectional communication with data logging, fusion, interpretation, compression and reporting, with event-driven reprogramming and mission control. Using fibre optics or acoustic modems, deep ocean data will be beamed to low Earth-orbiting or geostationary satellites with Internet capability to shore-based researchers. With data compression and wide bandwidth, video images from abyssal depths of, for example, the Pacific Ocean, could be monitored in real time in Europe. International standardisation of information technology protocols would ensure interoperability and equipment exchange across Europe.

6.3.3 Robotics for long-term operations and maintenance

This includes automated deployment strategies (e.g. ships of opportunity, aircraft), networked robotic sensor systems for adaptive sampling, maintenance, resupply and upgrade of components, and precision navigation for mobile robots.

6.3.4 New materials

Some promising marine applications include:

- novel thermal phase-change materials for buoyancy control;
- biofouling-resistant new materials for sensors, windows and enclosures;
- high-strength, low-weight, corrosion-resistant structural materials;
- biodegradable materials for disposable components.

Installations can be expected to include both coastal and deep water sites. Future installations may be cabled to shore with direct power and high bandwidth data communications. Remote or deep systems may need to produce their own power, and communicate via new low Earth-orbit satellite data links with reduced bandwidth from floating or pop-up buoys. Others may be located in deep water with limitations on power or communication or both. All will need to endure the rigours of marine corrosion and biofouling and still maintain accurate measurements, visible images, adequate power and good communications.

Some underwater robots, when on extended missions such as sub-ice surveys or in response to an environmental event, will require recharging. Alternatively, mini autonomous underwater vehicles (AUVs) may be deployed for refuelling and maintenance of the installations. Some installations may allow networked users direct access to measurements in real time, and some may allow requests for specific measurements to be conducted when needed.

In addition to the potential reduced cost of deployment, operation, maintenance and upgrade of new miniaturised long-term installations, a number of potentially unique applications exist for underwater robots including:

- access to extreme environments (e.g. sub-ice, deep brines);
- repeating spatial or volumetric surveys;
- rapid response, event-driven surveys.

It will be necessary to develop a range of different installations and associated systems to address different applications. A host of hardware, software and sensor standards will be needed to combine the efforts from different nations and installations and convert them into common environmental models.

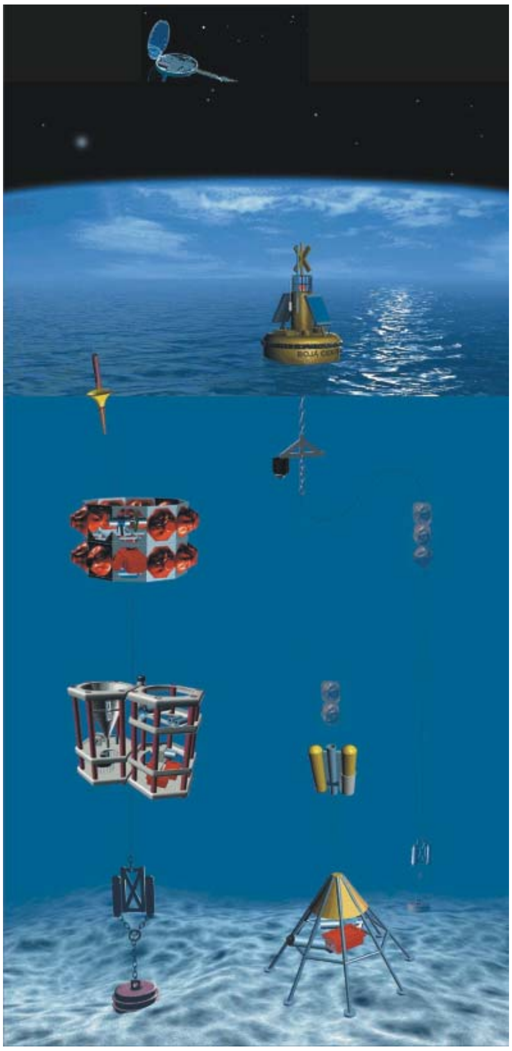
6.4 Systems of the future

6.4.1 General concepts

Marine technological systems of the future will be modular and interchangeable in architecture, incorporating data acquisition, calibration, online transmission and metadata product dissemination. Regardless of the platforms, future observational strategies will become far more interdisciplinary and will capture datasets in real time or near real time with much larger spatial and temporal coverage and resolution and shorter reaction delays in the case of instrument control. Single campaigns will increasingly be seen in the context of a global picture, with outputs assimilated instantly into modelling and forecasting systems.

Future marine networking technology should be compatible with multiple sensor platforms, modular device architecture and improved power supply and management. It is apparent that sensors have to be integrated, exchanged and controlled using a set of standardised interfaces. The management of platforms, vehicles and data should adopt open and accessible LAN (local area network) or WAN (wide area network) standards for communication. For example, by adopting Internet-based networking systems, third party hardware such as interfaces and software products, prototypes or mature components can be flexibly networked. This philosophy is the basis of the Marine Operational Observing System (MOOS) being developed by MBARI (USA), and in emergent European programmes such as ANTARES, DOMEST/DOLAN and the Mediterranean Forecasting System Pilot Project (MFSPP).

The availability of such an infrastructure will open the door to real time information access to installations at remote places, telecontrol of measurement sub-systems and telemaintenance functionality. It will also provide efficient facilities for testing new equipment and allow for the definition and qualification of future operational systems. Such opportunities will in turn influence the strategies of observation and monitoring campaigns themselves.



The DOMEST System for observing material transport at the sea bed includes traps, video, profiling CTD and other sensors, with acoustic and satellite retrieval of data using bi-directional communication. © MARUM, Bremen, Germany

6.4.2 Examples of advanced observatory systems

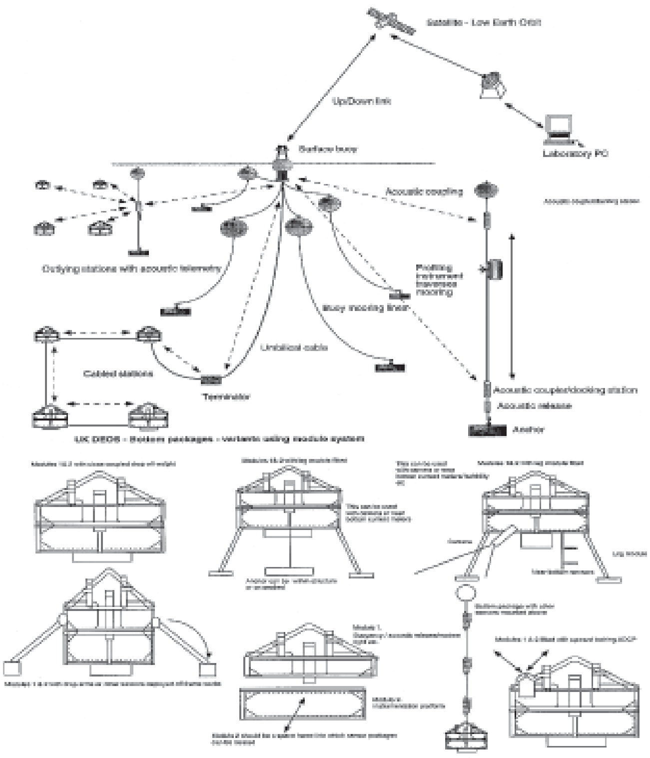
Example 1: Observatory-based networks

Several observatories which take multidisciplinarity and modularity into account are in the planning phase. One example is the B-DEOS project, which aims at long-term (several years) observations of coupled geophysical, sedimentary and hydrodynamic activity at the seafloor. The basic structure consists of a central node that manages bidirectional communication between the system components and the outside world and that delivers reliable, long-term power to the seafloor instruments. The node includes a moored buoy equipped with a diesel powered generator and a satellite communication link. The B-DEOS central node can also be linked to remote (approximately 200km distance) or autonomous platforms, which collect physical and biogeochemical water column data that are acoustically transmitted back to the central node.

Another European example under construction is the Array of Sensors for long-term Seabed Monitoring (ASSEM) of geohazards, such as seismic risks and sedimentary instabilities which occur along oil exploration regions of continental margins and densely populated shallow water areas (*see also Section 3.3.3: Geoclimatic hazards along ocean margins).* The aim is to develop and deploy a permanent set of reliable sensors and their network nodes in a one square kilometre array in 4,000m water depth and 200m boreholes. Key technologies that are needed to establish this kind of infrastructure are reliable long-term (typically two years) sensors, modular data logging and communication nodes, reliable power generation, distribution and management systems, and bidirectional communication systems for underwater and air transmission.

Other concepts make use of existing installations where retired telecommunication cables (e.g. Hawaii Observational Time Series Station, HOT) or observational set-ups for experiments in other scientific fields are employed (e.g. ANTARES or

NEMO). The cost advantage is tremendous compared to dedicated cabled observatories. However, while the locations of these installations are often not ideal for scientific purposes, they are well suited as a test bed for new equipment.



Concept of the B-DEOS mooring system. © D Lampitt, SOC, Southampton, UK

Example 2: Permanent coastal-shelf observing systems

Although many European coastal states operate buoy-based monitoring systems, there are significant gaps in spatial coverage, in addition to technical obstacles hindering data exchange between national networks. To fill these gaps new observational networks linked with ocean forecasting are emerging, for example BOOS (Baltic Ocean Observing System) in the Baltic and MFSPP (Mediterranean Forecasting System Pilot Project) in the Mediterranean. Other concepts such as the FerryBox system for underway physical and water quality measurements using ferries and ships of opportunity will provide a low cost strategy for regular observations of the surface ocean.

Woods Hole's Coastal Observatory at Martha's Vineyard, off the coast of Massachusetts, USA, provides an example of a littoral zone observatory. It is designed for long-term monitoring of the coupled dynamics, sediment transport and biogeochemical processes of the near-shore zone. Multiple sampling nodes are cabled to shore for power and data transmission. Small autonomous underwater vehicles (AUVs), such as floats or gliders, are deployed when needed to characterise and map episodic events such as harmful algal blooms and pollution plumes. Such near-shore observatories are particularly useful for monitoring rapidly eroding coastal zones (e.g. the LOIS programme in North East England) that are already vulnerable, and will be even more so to the extreme weather conditions predicted with future climate change.

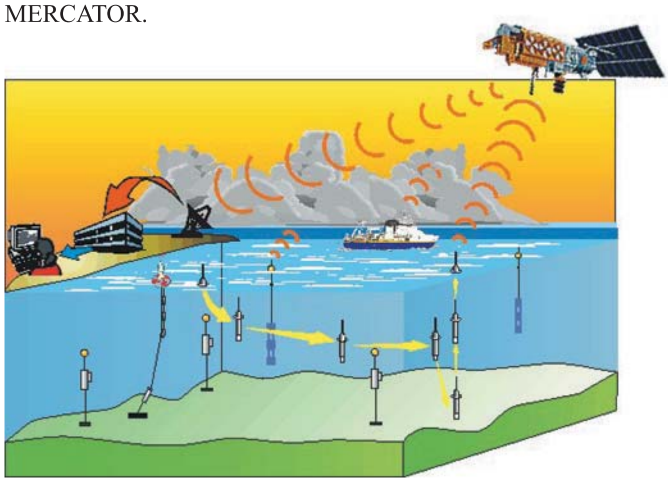
Offshore oil platforms often have their own network of telecommunication cables and infrastructure that could be efficiently adapted for shelf ecosystem and pollution observation. Such collaboration would clearly benefit European marine science, technology and industry.

Martha's Vineyard coastal observatory. © Chief Scientists: J Edson and W McGillis. Artist: J Doucette, Rinehart Coastal Research Center, USA

Example 3: Permanent observing array in the Atlantic Ocean

Oceanic observatories, either moored or mobile, are designed for large-scale long-term time series studies. The success of the TOGA/TAO (Tropical Atmosphere Ocean Project) buoy array system for predicting El Niño events is now being considered as a template for other ocean climate observatories, for example the PIRATA (Pilot Research Moored Array in the Tropical Atlantic) array in the Atlantic. PIRATA is designed to study ocean-atmosphere interactions in the tropical Atlantic that are relevant to regional climate variability on seasonal, interannual and longer time scales.

The use of moored profilers with yo-yoing multisensors, so that one set of sensors produces a high-resolution vertical profile over a selected depth range, is particularly useful. This approach is incorporated into France's Coriolis project input to Argo. It involves the improvement of existing observing systems in operation in the Atlantic Ocean (VOS-XBT lines, drifters and PIRATA array) and the implementation of a new ocean network of profiling floats. The resulting oceanographic (temperature and salinity profiles) and satellite altimetry data will be assimilated into the numerical ocean circulation model MERCATOR.



CORIOLIS: *in situ* measurements for operational oceanography. © Ifremer, France

Example 4: Observatories for fisheries and living resources

There is also considerable scope for applying the above technology for sustainable management of living resources. For example, in an effort to track shelf-wide changes in fish stocks and their migration, the United States and Canada are proposing a series of cabled hydrophones for tracking acoustically tagged fish such as salmon and tuna along the shelf of the North East Pacific. A US Navy network known as the SOSUS array, consisting of military hydrophones situated on the seafloor along the Eastern Atlantic, although deployed for submarine detection, has also recorded cetacean vocalisations, contributing to the knowledge on cetacean population movements, in particular of fin whales.

European marine research and technology are symbiotic and innovative. Only when both are coordinated within a strategic framework such as the European Research Area can the full creative and value-added potential of European marine science be realised for the understanding and sustainable management of Europe's diverse seas and oceans.

6.5 Key technology recommendations

- Marine science and oceanography are critically dependent on advanced technologies to observe and understand ocean ecosystem dynamics and processes. Marine technologists should be encouraged to:
(i) assess, convert and apply novel miniature sensors arising from bioanalytics, nanotechnology and advanced materials science;
(ii) standardise interfaces of system components, and components of novel technologies; and (iii) network national calibration facilities.

- To understand and predict ocean-climate coupling and the sustainable use of marine resources, and to describe the European component of global systems, long-term baseline funding for the development and operation of ocean observatories is required *(see also Section 3.1: Coastal zones)*. These are European responsibilities of profound significance to its citizens, and also to the world, transcending the responsibilities and resources of most national programmes. Thus, a special effort should be made to ensure a visible and effective research contribution by Europe to this domain.

- Development of effective industrial partnerships would accelerate development, sales and use of sensors by marine scientists. Particular priorities for sensor development include:
(i) development of new sensors for biological and chemical parameters;
(ii) development of new systems: multiparameter, networking architecture;
(iii) ensuring cost effectiveness: long-term components and high spatial density deployments; and
(iv) appropriate infrastructure: two-way data communication and control.

- Collaboration with offshore oil and gas platforms, with their own network of telecommunication cables and infrastructure that could be efficiently adapted for shelf ecosystem and pollution observation, would clearly benefit European marine science, technology and industry.

7. Research infrastructures

7. Research infrastructures

7.1 Introduction

An enhanced pan-European large marine infrastructure capacity for monitoring and sustainable management of the ocean would result in operational services which would in turn support new industries, increase employment and protect the environment. The ESF Marine Board, through its membership of the national marine research agencies and institutions, and through its networks with other organisations, provides the forum to develop new knowledge and technology which will contribute to developing the European marine infrastructure needed to complement and add value to existing national infrastructures.

The maritime infrastructure assets based at national and academic institutions are profiled below; industrial and naval assets, also of potential use to European marine scientists, are not included. Up to 50% of the national budgets for marine science is devoted to operating and replacing infrastructure assets, such as large research vessels, underwater vehicles etc. Cost-sharing the replacement of major infrastructures and widening access are a necessary step forward towards integration, in line with the EU Council of Ministers decision of June 2001.

The infrastructures required for marine research include:

- coastal to high seas research vessels and their equipment;
- underwater vehicles;
- sub-sea observation systems (moorings, sediment traps, landers, seafloor observatories);
- satellite and aerial reconnaissance systems;
- testing and calibration facilities and laboratories;
- museum collections, specimens and cultures, taxonomic and genetic databases.

7.2 Marine infrastructure: status and trends

7.2.1 Research vessels

Different size-classes of research vessels are required by different aspects of marine research: large research vessels for global ocean and polar studies, intermediate-sized research vessels for regional and shelf sea studies, and smaller research vessels for coastal and inshore work. Amongst the 15 European Union Member States and Norway, the academic fleet totals about 35 multipurpose research vessels greater than 50m in length. Capabilities differ greatly from country to country; some countries do not own any large research vessels, while others own and operate up to eight. Twenty-three European countries together own more than 190 coastal to high seas research vessels. With construction dates between 1962 and 1995, it is clear that the European research fleet is ageing. Only six new research vessels, all of them in the 60-80m range, are scheduled to come into service on the European Atlantic margin by 2003.

The EC made an assessment of the European research vessels and published a report *EC NatFleet* (National Fleets of Research Vessels in Europe) in December 2000, which concluded that:

- the number of European research ships needed in the near future should remain approximately stable;
- the specification and diversity of shipboard facilities should increase;
- a coordinated replacement programme for Europe's ageing fleet of research vessels should facilitate forward planning, wider access and cost sharing;
- the emergence of new data-gathering systems (remotely operated and automated underwater vehicles, observatories) will enhance the scientific and operational value of research vessels, but will not replace them.

France is building two research vessels in a joint Navy-IFREMER venture, due in 2003 and 2004: one for deep sea exploration and the other for hydrography. Germany is actively consulting with 10 European partners and the ESF Polar Board to promote the concept of a new European Arctic research ice breaker, namely the *Aurora Borealis*, a 23,000 tonne vessel of 132m length with deep ocean drilling capability. The vessel would have the ability to drill in up to 4,000m water depth and 1,000m below the seafloor. It would also have a long sediment coring capacity of up to 50m. The vessel is expected to cost 250 million euros to construct and 15 million euros per year to operate. Proposals are with the UK Government to replace the RV *Charles Darwin* in 2006, involving extensive consultations with European research vessel operators and scientific colleagues who have used the RV *Charles Darwin*. In addition, the scientific community would like to have a ship capable of performing multitrack seismics.

There is an increasing demand for specialised facilities to support onboard experimental biology and tracer chemistries. Multipurpose research vessels that can rapidly accommodate specialised container laboratories are proving increasingly popular with interdisciplinary teams requiring onboard ultra clean, radiochemical, tracer, hyperbaric and physiology facilities, amongst others.

The next phase of the Ocean Drilling Program – the Integrated Ocean Drilling Program (IODP) – due to start in 2003, gives a unique opportunity to the scientific community to tackle new issues of major interest for Europe. A Joint European Ocean Drilling Initiative (JEODI) is actively considering a coordinated participation in IODP by providing access to both alternative drilling platforms with derricks and also to long sediment coring equipment.

The operation, programming and national funding of Europe's research vessels differ significantly between countries and this has largely hampered European-wide coordination.

RV *Thalassa* (France) and RV *Celtic Voyager* (Ireland).
© Marine Institute, Ireland

However, an important start was made in 1996 when a tripartite agreement was signed between the BMBF (Germany), IFREMER (France) and NERC (United Kingdom); this agreement has enabled the exchange of major marine facilities. A three-way build and operating agreement between the French, Spanish and EC European Structural Funds led to the construction of the fisheries RV *Thalassa* in 1996, which is also jointly operated. The RV *Europe* has been built using a similar mechanism and is operated by France and Italy. The proposed *Aurora Borealis* would also be under shared management, in which the European Polar Board would have a role. The recent initiative of the ESF Marine Board to establish a network of operators for European research vessels (ERVO) provides a useful forum in which to exchange information, share problems and improve cooperation. Increasingly, EC funded RTD projects under the EC framework programmes include some financial contribution to research vessels and associated facilities. This facilitates the development of missions covering a range of disciplines and enhances interdisciplinarity and coordination.

Progress is needed towards an integrated ship sharing system, self-managed between major

Research vessel in rough sea. © A Gerdes, MARUM, Bremen, Germany

institutions, as is in operation in the United States. There, the UNOLS, (University-National Oceanography Laboratory System) approach enables US scientists from academic, government and naval institutions to jointly review and allocate ship time and make long-range plans for modernisation and replacement of the US research fleet.

The recently created European Centre for Information on Marine Science and Technology (EurOcean) has focused its initial efforts on making information on the existing marine research infrastructures in Europe, in particular research vessels, and related information (ship time requests and schedules, regulations, ongoing cruises etc.) available on its website *(www.eurocean.org)*.

7.2.2 Ships of opportunity

While future monitoring will include robotic systems in space, in the air and in the sea, ships-of-opportunity have an ongoing role for low-cost monitoring. Merchant ship observations play an important role in weather forecasting, and in monitoring interannual variation in plankton and related environmental variables measured with the continuous plankton recorder. The EuroGOOS FerryBox programme will greatly expand this cost-effective monitoring in European seas. In addition, naval and fisheries patrol vessels are increasingly used as observational platforms by marine biologists whose research endeavours require mapping of vertebrate populations to establish distribution and migration patterns, and tracking impacts of climatic change.

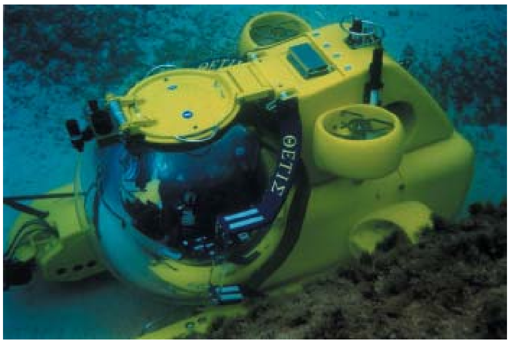
7.2.3 Marine observational systems and underwater vehicles

Oceanographers and those involved in marine resource exploration and exploitation are increasingly in need of advanced tools *(see also Section 6.2: Technological innovations)* allowing them to carry out *in situ* measurements, both in the water column and on the seafloor. Such tools need to be able to adapt to events, in contrast to research vessels that have to follow pre-established routes. Tools include manned submersibles, unmanned underwater vehicles (UUVs), remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs), deep-towed systems, floats and buoys, moored instruments and fixed seafloor observatories. Most of these components of research infrastructure are expensive to develop and to operate. Their deployment generally occurs in difficult, inhospitable and corrosive environments, far removed from logistical bases, requiring dedicated ships and staff to ensure operation and maintenance over long periods of time.

For optimal management of these facilities, a number of conditions have to be fulfilled. They include: robust procedures for maintenance, effective coordination of multidisciplinary and interdisciplinary teams, the potential to set up large multi-institute/multinational networks (e.g. networks of weather floats or of lagrangian profilers, as in the Argo international project); and finally, ensuring that validated data is securely stored and accessible in the minimum time.

Manned submersibles

IFREMER operates two manned deep sea submersibles: *Cyana* and *Nautile*, built in 1971 and 1984 respectively. Extensive studies on hydrothermalism, abyssal biology, microbiology and deep subduction processes have been accomplished using these submersibles. *Cyana* has a long record of international cooperation with teams from the United States, Germany and the United Kingdom but it will be taken out of service in 2003. *Nautile* has recently been refitted with up-to-date capabilities. Greece also owns the manned submersible *Thetis* which has an operational autonomy of nine hours for two persons (1 pilot and 1 scientist) at a maximum depth of 600m. It is owned / operated by the National Centre for Marine Research (NCMR) and it is primarily used for geological and benthic studies as well as for marine archaeology missions.



Greek submersible *THETIS* used for hydrothermal and other studies in the Mediterranean. © K Nittis, NCMR, Athens

Remotely operated vehicles (ROVs)

It is estimated that 10 deep sea ROVs (operating to 6,000m and beyond) exist globally for science and industry, of which only one is European, namely IFREMER's *Victor 6000*. Operational since 1999, *Victor 6000* has important capabilities for prolonged onsite work and the results have been excellent. Even though it is transportable from one vessel to another, its size somewhat constrains its deployment and use since it requires a large support vessel.

The Southampton Oceanographic Centre (UK) has commissioned a new ROV to be delivered in early 2003. It will have a 6500m deep submergence and it is designed as a transportable self-contained system capable of use from any suitable vessel.

Autonomous underwater vehicles (AUVs)

The use of autonomous underwater vehicles (AUVs) is changing scientific research. Because of their combined ability to navigate, survey, measure and return on site, AUVs are invaluable for coastal environments, process studies, geophysical surveys, and oceanic surveys. State-of-the-art developments aim to reduce costs, increase endurance and simplify operations. Data collected by AUVs cost an order of magnitude less than those collected by research ships. Communicating by satellite, these AUVs can make physical measurements (including current profiles) on demand at remote locations where lack of data limits the precision of ocean forecasting models. This method of sampling will complement the sparse observations provided by Argo. Carrying half a tonne of instruments, these AUVs will also monitor chemical and biological properties of the ocean interior that cannot be observed from space.

Recovery of AUTOSUB AUV from trials in Scottish sealoch using the RV *Calanus*. To date, AUTOSUB has achieved 240 autonomous missions with total track of 4600km without support ship control. © SOC Southampton, UK

NERC's AUTOSUB (now in its second version, first tested in 1996) has achieved over 240 successful missions covering over 4,600km in the Atlantic, Mediterranean and sub-ice in the Arctic and Antarctic. Its missions have facilitated wide-ranging research, from duplicating ship-based fish stock surveys, to mapping turbulence in the benthic and sea surface boundary layers. The German science community has applied for funds to build a deep diving and sub-ice AUV.

Deep sea towed systems

SAR (IFREMER) and TOBI (NERC) use side scan technology to carry out deep sea surveys and sub-bottom profiling. In addition, SAR has capabilities for seismic profiling and TOBI for swath bathymetry.

Seafloor observatories

Recent initiatives to develop seafloor stations and observatories have emerged from the growing requirement for marine scientists to monitor processes at or close to the seafloor *(see also Section 6: Critical technologies).* Current observatories predominantly serve geophysics and are at a single location, for example: the ANTARES observatory planned for neutrino detection; and the ASSEM seafloor array of sensors for long-term monitoring of geohazards (e.g. slope instabilities).

It is clear from the scientific issues discussed in this Position Paper that future observatories should be multidisciplinary, modular, reconfigurable and long-term. Examples include the GEOSTAR (Geophysical and Oceanographic Station for Abyssal Research) system being developed by a European consortium. The assured existence of a long-term adequate funding profile is obviously crucial; these long-term observatories, with multiple international partners obviously qualify for funding as Schemes of Shared Use. In addition, a policy to promote international cooperation is needed if Europe is to credibly engage in global ocean research issues with the United States and Japan.

In contrast to the European fleet of research vessels, which is distributed – albeit unevenly – among countries, the marine observational systems and underwater vehicles are unique to a few countries. Since these systems all have the required capabilities to serve the needs of the international science community, arrangements for collaborative use should be actively promoted.

Given the pace of progress with regard to energy supply, data storage and data transfers, and miniaturised technology, the design of new AUVs will be dramatically improved in the coming years.

7.2.4 Satellites and aircraft

Monitoring from space provides the primary data flow for global change research. Orbiting satellites provide global coverage, observing sea-surface elevation, surface temperature, ocean colour, sea-ice cover, surface winds, waves and features relating to ocean circulation. They are used to monitor the environment, for communication and data transfer, and for positioning. Satellite observation was the pre-requisite for the implementation of WOCE (World Ocean Climate Experiment). Global monitoring of the surface pressure field by radar altimeter mapped the open ocean tides and the uneven distribution of storms in the ocean interior, a critical test of circulation models. European operational models such as FOAM and MERCATOR depend on assimilating altimeter data. Radar altimeter is a remarkable instrument that still has more to offer and demands ongoing RTD. Other instruments on ocean observing satellites include radars to monitor waves and sea ice, and radiometers to monitor surface temperature and colour (for sediments and plankton).

Europe is contributing significantly to the development of a new generation of satellites, including the replacement of ERS-1/2 and TOPEX-Poseidon. The launch of ESA's new Earth-observing satellite ENVISAT in March

2002 has been successful; the satellite will, for at least five years, monitor environmentally crucial processes (changes in ocean circulation, ice caps etc.). ESA and EUMETSAT, together with the (US) National Oceanic and Atmospheric Administration (NOAA), are cooperating in the development of a series of polar-orbiting weather satellites (MetOp). Among other tasks, MetOp (expected during 2003) will fulfil European requirements for operational meteorology and climate monitoring, complement the mission of ENVISAT, and contribute to the global surveillance of air, land, sea and ice. The French-American satellite Jason, launched in December 2001 replaced the ageing TOPEX-Poseidon for altimetry measurements and serves the needs of operational oceanography. EUMETSAT recently decided to call for contributions for a follow-on Jason 2 mission, in partnership with NASA, NOAA and CNES, to be launched in 2006.

Some of these satellites will contribute to the objectives of GMES (Global Monitoring for Environment and Security), an initiative that aims to establish by 2008 an autonomous European system for integrated environmental monitoring, based on coordinated use of space tools and *in situ* observing platforms *(see also Section 3.2.3: Ocean monitoring and Global Monitoring for Environment and Security).*

To optimise existing and possible future observational systems, it is important to make best use of current time series, in order to check for trends and to link them with new more precise observations.

Remote sensing from aircraft, its application in marine science, and the application of new technologies, has greatly improved management versatility, for example within the coastal zone. Aircraft complement satellites by making more frequent observations and flying under clouds. They are particularly important for monitoring coastal seas, and feature, for example, in the routine operations of the UK Environment Agency. Airborne instruments include CASI (high resolution spectrometers for mapping sediments and plankton) and LIDAR altimeters (for precision mapping of inshore waters). LIDARs can also provide underwater profiles of plankton pigments and sediments. The development of fast, long-endurance unmanned drones for military reconnaissance promises to revolutionise operational monitoring of the European seas from the air.

7.2.5 Testing and calibration facilities

Marine sensors, platforms and UVs need to be routinely tested and calibrated in dedicated facilities, not only for marine research, but also for fisheries, offshore industry, coastal engineering, ship building and defence. These facilities include hyperbaric tanks for pressure testing and water circulation and wave basins for current meters, nets, and hydrodynamic testing of UVs and towed, floating or anchored platforms.

A European inventory of underwater acoustic test facilities (in 1995) listed 30 atmospheric tanks, 11 pressure vessels and 25 oceanic facilities. Hydrographic test basins in Denmark, France, Germany, the Netherlands, Norway and the United Kingdom have provided intercalibration and testing checks for physical oceanographic systems. A number of these infrastructures received European Commission financial support under the 5^{th} Framework Programme (FP5) to provide new opportunities for research teams to obtain access to the major research infrastructures most appropriate for their work.

In marine biogeochemistry and quantitative biology, European researchers have adopted JGOFS and GLOBEC intercalibration protocols for primary and bacterial production, measurement of chlorophyll, DOC, CO_2, zooplankton, etc. However, there is an urgent need for infrastructural support to assure long-term continuity and quality control of these critical ecological and climatic measurements needed in future climate programmes such as SOLAS, CLIVAR and GOOS.

7.2.6 Data acquisition, management and policy

There is a widespread lack of data relating specifically to the marine and coastal areas of Europe. Wherever data are collected, they are not always categorised, standardised or available in an interoperable format compatible with either assessing relevance to other datasets, or with development of indicators or effective management strategies *(see also Section 2.3.4: Development of indicators).*

Effective data policies are essential to ensure that the right information can be made available to those who need it, in the correct format and at the right time. As yet, data management policies within European countries differ greatly and are poorly adapted to the changing technologies of monitoring and surveying, the changing needs of policy, as well as to technological changes. In the age of the Internet and high-bandwidth connections, a new era of opportunities is expected for the management of marine data.

In its 1998 *Prospectus for an outline of GOOS data management*, GOOS identified the requirement to standardise the international approach to oceanographic and marine data management, and recommended that all data, whether derived from research projects, regional monitoring activities, fisheries research, or military activity, should be made available. The EC FP5 policy-requirement for scientists to deposit their results at accredited database centres is now routinely fulfilled. To progress further, future steps include the need for all marine research results to be deposited in database centres, and for these database centres to provide common metadata front ends to enable any scientist or manager to search and access any data type from any data centre. A start has been made under the EC funded Sea-Search Project, linking 16 national oceanographic data centres and services into a useful online gateway for marine data, information, products and services in Europe. Similar efforts are needed for marine taxonomic and biodiversity studies being set up under the DIVERSITAS programme.

Recent efforts by some agencies and organisations to improve data access (e.g. IODE, ICES, EC FPs) must now be harmonised with the World Meteorological Organization's Resolution 40 of 1995 which states that:

> *"Members shall provide on a free and unrestricted basis essential data and products which are necessary for the provision of services in support of the protection of life and property and the well-being of all nations."*

This resolution has shaped data policies of EuroGOOS and IOC, and should be more widely adopted.

The World Data Centre for Marine Environmental Science (Pangaea) *(www.pangaea.de)* provides one example of the marine scientific community addressing the issue of datasets and archiving. Within GMES, the EC is currently addressing the issue of data management throughout a range of scientific disciplines, including marine science *(see also Section 3.2.3: Operational oceanography and Global Monitoring for Environment and Security).*

7.2.7 E-marine science: a new dimension

The uptake and benefits of e-science for marine research is already evident in the plans for:

- monitoring and observing systems over large geographic areas;
- pooling computing capacities for climate modelling;
- bringing together distributed databases;
- remote operation of sensors and platforms.

The marine community has often been at the forefront of applying e-science to the environment. To illustrate this with one example, plans are already in place to deploy fibre-optic cables on the seafloor for two-way, real time, high-bandwidth video communication via the Internet as the basis for monitoring and controlling seafloor experiments from anywhere in the world. The possibility of beaming live underwater observations and experiments straight into the classroom would be an educationally exciting way of inspiring future generations of marine scientists.

7.3 Importance of long-term commitments

In recent years, marine research has moved away from the traditional expeditionary mode. Subjects such as climate-relevant research, ocean ecology, environmental impacts, and operational forecasting, require that data be collected systematically over periods of at least 10 years or more. Research on new deep sea ecosystems require the installation of deep sea long-term observation stations to be reviewed on a regular basis and to run for at least 15 years.

To cope with this increasingly long-term trend in science, adequate commitments from policy makers and financing authorities are required. The failure to date 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.

7.4 European strategy on marine infrastructures

This Position Paper on Integrating Marine Science in Europe, together with the European Commission policy emphasis on a European Research Area, provide two important drivers for a European strategy on marine infrastructure. Given that up to 50% of national European budgets for marine science are devoted to operating and replacing infrastructure assets such as large research vessels, UVs etc., proposals to widen access and to cost-share the replacement of major infrastructure are starting to attract political support. In June 2001, the Council of Ministers, recognising the benefits of a European approach, asked the EC to draft policies and actions for European research infrastructures.

For any research infrastructure to qualify as truly European, the marine facilities must:

- operate at an international level of excellence;
- demonstrate a substantial, measurable impact on research quality;
- demonstrate significant demand from the European research community;
- provide open access to European researchers under identical criteria;
- demonstrate a European added value in terms of improvement in science quality and in cost savings to partners and European funding agencies.

It is evident that Europe's infrastructure of large research vessels and the priority requirements for long-term multidisciplinary ocean climate observatories both comply with the above criteria.

Ways and means to improve the fabric of European research infrastructures were given prominent consideration by the European countries at two conferences: EurOCEAN 2000, in Hamburg (29th August - 2nd September 2000), and the Research Infrastructures Conference in Strasbourg (18th - 20th September 2000); these issues were also the subject of a temporary working group of six European countries.

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 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 as already initiated in the Internet portal of EurOcean *(www.eurocean.org)*.

7.5 Key recommendations

- Availability of an oceanographic fleet, and associated equipment including underwater vehicles, will continue to be essential for science at sea. There are strategic requirements for a set of European policies and arrangements to maximise the use of these infrastructures on a pan-European scale and to advise the EC and national agencies on new specifications, improved access and cost sharing for these infrastructure investments. The strategic vision exists and the tools for collaboration and coordination are already available, and should be consolidated within the timeframe of EC FP6.

- Europe should widen its support for integrated marine science by incentives for scientific and industrial partnerships and enhanced mobility. Researchers must be encouraged and facilitated to develop industrial links, including Public Private Partnerships (PPPs), to maximise the manufacture and exchange of novel technologies within Europe and to maximise European industrial competitiveness, for the benefit of both marine science and society. Attracting and retaining young researchers into marine science is particularly important to ensure continued development of European capacity and capability.

- A revised effective European data policy should be rapidly elaborated and put into action to ensure: (i) secure storage of appropriate data; (ii) quality control; and (iii) interoperability and open access for science in a timely manner to the petabytes of data and products expected from the next generation of ocean observatories and operational forecasts.

- The establishment of a forum to address the issues of data standards, indexing, transfer and storage is necessary. This forum would provide a focus for increased coordination and cooperation between researchers, agencies and authorities.

- As part of the European enlargement process, investment in regional marine research and infrastructures should be enhanced so as to reduce regional disparity in scientific knowledge, innovation, RTD and competitiveness.

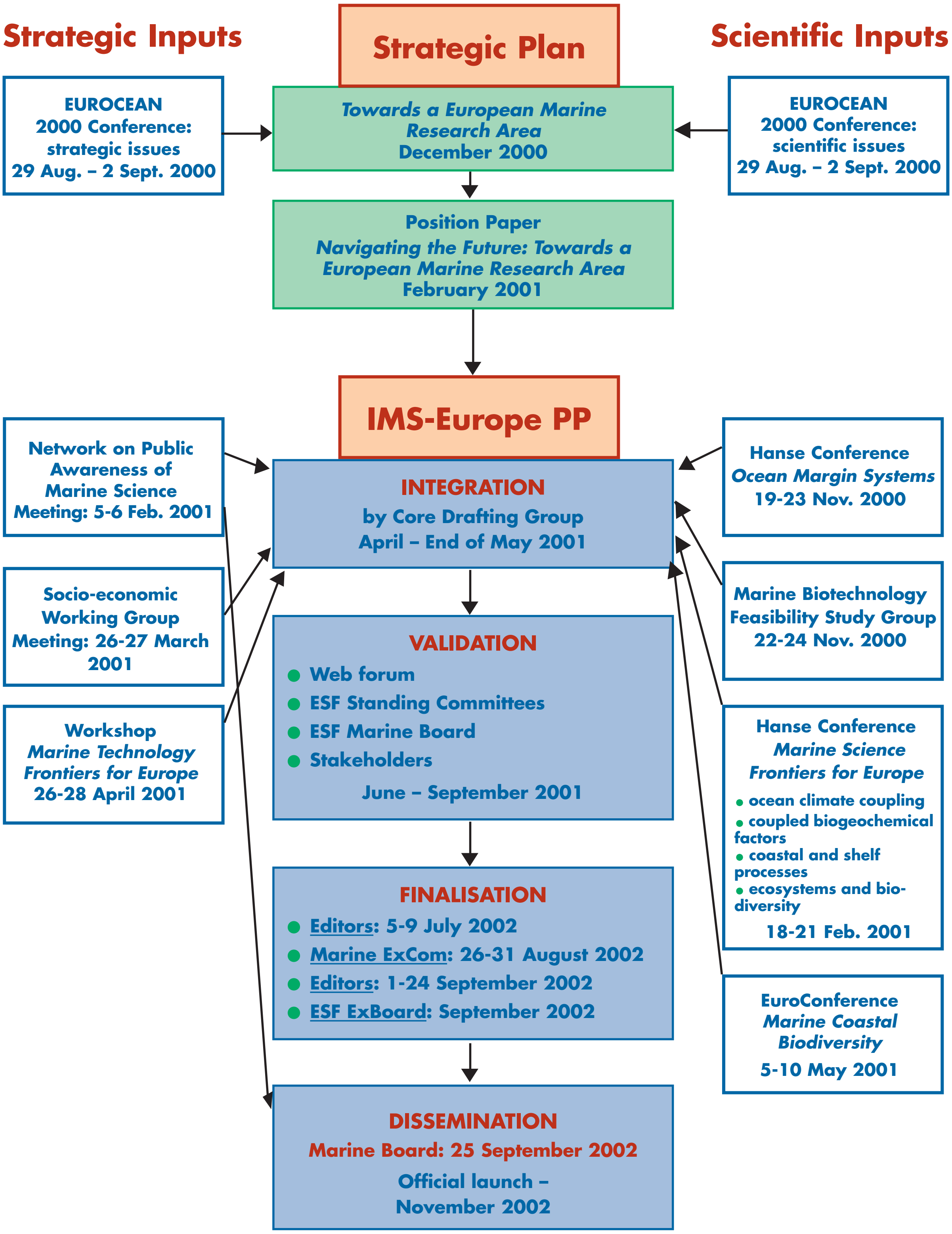
- Europe's capacity for oceanographic monitoring from space should be enhanced, in particular with regard to research satellites for observing new parameters such as thickness of sea ice, surface salinity etc. In addition, there should be further investment in periodic satellites for observing oceanic evidence of climate change.

- Investment priorities for marine research should be agreed across Europe, and should be designed so that they are not constrained by the limited lifecycles of national and EU-funding programmes. This will ensure not only long-term viability of observation networks, but also retention of capacity and capability within Europe.

Appendices

Appendix I

Evolution of *Integrating Marine Science in Europe* Position Paper



Appendix II

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. Climate 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 on fisheries
Ramsar Convention on Wetlands	1971	Global	Protection of wetland habitats for birds
UNESCO World Heritage Convention	1972	Global	
Bonn Convention on the Conservation of Migratory Species	1979	Global	Protection of migrating species
UNCLOS (UN Convention on Law of the sea)	1982	Global	Law of the sea
Convention for the Protection of the Marine Environment of the Northeast Atlantic (OSPAR) Convention	1992	Northeast Atlantic	
New York	1995	Global	Management of migrating species
Washington Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (UNEP)	1995	Global	
Regional Conventions	**Year**	**Area covered**	**Objective**
Barcelona	1975, 2000	Mediterra-nean 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
Fish and shellfish waters	1978, 1979	EU	Water quality for fish and shellfish
Habitat and species	1988	EU	Special areas of conservation, Natura 2000
Integrated coastal zone management	Under prep. in 2000	EU	A European strategy for integrated coastal management
Directive on the Conservation of Wild Birds (97/49/EEC) – Special Protection Areas (SPAs)	1997	EU	Habitats and the environment
Habitats Directive (92/43/EEC) – Special Areas of Conservation (SACs)	1992	EU	Habitats and the environment
Directive on Other Substances: Protection of the Aquatic Environment of the Community (76/464/EEC)	1976	EU	Habitats and the environment
Directive on Waste Disposal (75/442/EEC)	1975	EU	Habitats and the environment
Directive on Disposal of Waste Oil (87/101/EEC)	1987	EU	Habitats and the environment
Directive on Disposal of Polychlorinated Biphenyls and Polychlorinated Terphenyls (96/59/EEC)	1996	EU	Habitats and the environment
Strategic Environmental Assessment (SEA) Directive (pending)		EU	Habitats and the environment
Council Directive 96/82/EC, the Control of Major Accident Hazards Involving Dangerous Substances (COMAH)	1996	EU	Shipping
Council Directive 93/75/EEC, minimum requirements for vessels bound for or leaving community ports and carrying dangerous or polluting goods	1993	EU	Shipping
Directive on Urban Waste Water Treatment (91/271/EEC)(91/271/EEC)	1991	EU	Water quality and management
Directive on the Quality of Shellfish Waters (79/923/EEC)	1979	EU	Water quality and management
Directive on the Quality of Bathing Waters (76/160/EEC)	1976	EU	Water quality and management
Directive on Integrated Pollution Prevention and Control (IPPC) (96/61/EC)	1996	EU	Water quality and management
Directive on Quality of Water for Human Consumption (91/692/EEC)	1991	EU	Water quality and management
Directive on Water suitable for Fish-breeding (78/659/EEC)	1978	EU	Water quality and management
Directive on Surface Freshwater: methods of measurement and analysis (79/869/EEC)	1979	EU	Water quality and management
Directive on Surface Freshwater: quality and control requirements (75/440/EEC)	1975	EU	Water quality and management
Water Framework Directive (2000/60/EC)	2000	EU	Water quality and management

Appendix III

Acronyms and abbreviations cited

AFLP	Amplified Fragment Length Polymorphism
ANTARES	Astronomy with a Neutrino Telescope and Abyss environmental RESearch
AO	Arctic Oscillation
AOGCM	Atmosphere Ocean Global Circulation Models
ARGO	A Global Array of Profiling Floats
ASSEM	Array of Sensors for long-term Seabed Monitoring
AUV	Autonomous Underwater Vehicle
B-DEOS	British Dynamics of Earth and Ocean Systems
BMBF	Bundesministerium für Bildung und Forschung
BOOS	Baltic Ocean Observing System
BSR	Bottom Simulating Reflectors
CASI	Compact Airborne Spectrographic Imager
CBD	Convention on Biological Diversity
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CLIVAR	International Research Programme on Climate Variability and Predictability
CHC	Common Heritage Corporation
CMRC-UCC	Coastal and Marine Resources Centre (University College Cork)
CNES	Centre National d'Etudes Spatiales
CREST	Comité de la REcherche Scientifique et Technique
CoML	Census of Marine Life
CORIOLIS	A French Project for Operational Oceanography
CTD	Conductivity, Temperature, Depth
CVM	Contingency Valuation Methods
DG	Directorate General
DIVERSITAS	International Programme of Biodiversity Science
DKRZ	German Climate Computing Centre
DOMEST	Data Transmission in the Ocean and Sensor Technology
DOLAN	Deep Ocean Lateral Acoustic Network
DPSIR	Driving Force, Pressure, State, Impact and Response
EC	European Commission
EC NatFleet	National Fleets of Research Vessels in Europe
EEA	European Environment Agency
EEZ	Exclusive Economic Zone
EMT	Eastern Mediterranean Transient
ENBI	European Network for Marine Biodiversity
ENSO	El Niño-Southern Oscillation
ENVISAT	ENVIronmental SATellite
EOSIG	European Ocean and Seas Integrated Governance
ERA	European Research Area
ERC	European Research Council
ERMS	European Register of Marine Species
ERS	ESA Remote Sensing Satellite
ERVO	European Research Vessel Operators
ESA	European Space Agency
ESEA	European System for Integrated Environmental and Economic Accounts
ESEPI	European System for Environmental Pressure Indices
ESF EUROCORES	European Science Foundation Collaborative Research Programmes
EU	European Union

EUMETSAT ______ EUropean Organisation for the Exploitation of METeorological SATellites
EuroGOOS _____ European Global Ocean Observing System
EurOcean ______ European Centre for Information in Marine Science and Technology
EUROSTAT ______ The Statistical Office of the European Commission
EUSTAT ________ Empowering USers Through Assistive Technology
FOAM _________ Forecast Ocean Assimilation Model
EC-FP6 ________ EC Sixth Framework Programme
FRRF __________ Fast Repetitive Rate Fluorimetric
GBIF __________ Global Biodiversity Information Facility
GCM __________ General (or Global) Circulation Model
GCOS _________ Global Climate Observing System
GDP ___________ Gross Domestic Product
GEOSTAR ______ Geophysical and Oceanographic Station for Abyssal Research
GIS ____________ Geographical Information System
GLOBEC _______ Global Ocean Ecosystems Dynamics
GMES _________ Global Monitoring for Environment and Security
GNP __________ Gross National Product
GODAE ________ Global Ocean Data Assimilation Experiment
GOOS _________ Global Ocean Observing System
Gtep __________ Billion of tonnes of oil equivalent
GTOS _________ Global Terrestrial Observing System
HNLC _________ High Nutrient Low Chlorophyl
HOT ___________ Hawaii Observational Time Series Station
ICES ___________ International Council for the Exploration of the Sea
ICSU __________ International Council for Science
ICZM __________ Integrated Coastal Zone Management
IFREMER _______ Institut Français de Recherche pour l'Exploitation de la Mer
IGBP __________ International Geosphere Biosphere Programme
IOM ___________ Integrated Ocean Maangement
IHDP __________ International Human Dimensions Programme of Global Environmental Change
IM _____________ Indian Monsoons
IMS ___________ Integrating Marine Science in Europe
IOC ___________ Intergovernmental Oceanographic Commission (of UNESCO)
IODE __________ International Oceanographic Data and Information Exchange
IODP __________ Integrated Ocean Drilling Program
IPCC __________ Intergovernmental Panel on Climate Change
JEODI _________ Joint European Ocean Drilling Initiative
JGOFS ________ Joint Global Ocean Flux Study
LED/CCD ______ Light Emitting Diode/Charge-Coupled Device
LIDAR _________ Light Detection and Ranging Instrument
LOICZ _________ Land Ocean Interactions in the Coastal Zone
LOIS __________ Land Ocean Interaction Study
MAST _________ Marine Science & Technology Programme of the European Commission
MBARI ________ Monterey Bay Aquarium Research Institute
MERCATOR _____ Global ocean modelling, estimation and prediction project
MetOp ________ Meteorological Operational satellites
MFSPP ________ Mediterranean Forecasting System Pilot Project
MOOS ________ Marine Operational Observing System
MPA __________ Marine Protected Areas
MS ____________ Mass Spectrometer

MST	Microsystems Technology
NAO	North-Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NEMO	New Millennium Observatory
NERC	Natural Environment Research Council
NGO	Non Governmental Organisation
NOAA	National Oceanic and Atmospheric Administration
NoCLIM	Norwegian ocean CLIMate project
OBIS	Ocean Biogeographic Information System
OECD	Organisation for Economic Co-operation and Development
OMEX	Ocean Margin EXchange
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic (Oslo-Paris)
OSSE	Observing System Simulation Experiment
PANGAEA	Network for Geological and Environmental Data
PIRATA	Pilot Research Moored Array in the Tropical Atlantic
POL	Proudman Oceanographic Laboratory
PPP	Public Private Partnership
PREP	Public Relations and Education Professional
QSAR	Quantitative Structure Activity Relationship
QTL	Quantitative Trait Loci
ROV	Remotely Operated Vehicle
RTD	Research and Technological Development
RV	Research Vessel
SAC	Special Area of Conservation
SAR	Système Acoustique Remorqué (towed acoustic system)
SNA	System of National Accounts
SOC	Southampton Oceanographic Laboratory
SOLAS	Surface Ocean Lower Atmosphere Study
SOSUS	SOund SUrveillance System
SPA	Special Protection Area
START	Global Change SysTem for Analysis Research and Training
THC	Thermohaline circulation
TOBI	Towed Ocean Bottom Instrument
TOGA/TAO	Tropical Atmosphere Ocean Project
TOPEX/Poseidon	US/French Ocean Topography Satellite Altimeter Experiment
UN	United Nations
UNOLS	University-National Oceanographic Laboratory System
UV	Underwater Vehicles
UUV	Unmanned Underwater Vehicle
VOS	Volunteer Observing Ship
WAN	Wide Area Network
WCRP	World Climate Research Programme
WOCE	World Ocean Climate Experiment
XBT	Expendable Bathythermograph

Chemical symbols and abbreviations

- **AA** — arachidonic acid
- **Cd** — cadmium
- **CFC** — chlorofluorocarbon
- **CH_3Br** — methylbromide
- **CH_3Cl** — methylchloride
- **CH_4** — methane
- **CO_2** — carbon dioxide
- **Cu** — copper
- **DHA** — docosahexaenoic acid
- **DMS** — dimethylsulphide
- **DNA** — deoxyribonucleic acid
- **DOC** — dissolved organic carbon
- **EPA** — eicosapentaenoic acid
- **H_2S** — hydrogen sulphide
- **Hg** — mercury
- **Mn** — manganese
- **mtDNA** — mitochondrial deoxyribonucleic acid
- **N_2O** — nitrous oxide
- **NH_4** — ammonium ion
- **NO_2** — nitrogen dioxide
- **NO_3** — nitrate ion
- **O_2** — molecular oxygen
- **O_3** — ozone
- **PAH** — polycyclic aromatic hydrocarbon
- **Pb** — lead
- **PCB** — polychlorinated biphenyl
- **PCR** — polymerase chain reaction
- **pH** — potency of the hydrogen ion in an aqueous solution
- **PO_4** — phosphate
- **PUFA** — polyunsaturated fatty acids
- **RNA** — ribonucleic acid
- **Si** — silicon
- **SiO_2** — silicon dioxide
- **Sn** — selenium
- **Zn** — zinc

Appendix IV

ESF Marine Board – Member Organisations, Delegates and Observers

Austria

Fonds zur Förderung der Wissenschaftlichen Forschung
Austrian Science Research Fund
and
Österreichische Akademie der Wissenschaften
Austrian Academy of Sciences

Professor Dr Joerg Ott
Universität Wien
Institut für Zoologie
Althanstrasse 14
1090 Wien
Austria
Tel: +43 1 4277 54330
Fax: +43 1 4277 9542
Email: Joerg.ott@univie.ac.at

Belgium

Fonds National de la Recherche Scientifique (FNRS)
National Fund for Scientific Research

Dr. Michel Frankignoulle
Université de Liège
Mécanique des Fluides Géophysiques
Unité d'Océanographie Chimique (B5)
4000 Sart Tilman (Liège 1)
Belgium
Tel: +32 4 366 3326
Fax: +32 4 366 2355 / +32 4 366 4592
Email: michel.frankignoulle@ulg.ac.be

Fonds voor Wetenschappelijk Onderzoek - Vlaanderen (FWO)
Fund for Scientific Research - Flanders

Professor Magda Vincx
Universiteit Ghent
Morfologie en Systematiek
K.L. Ledeganckstraat 35
9000 Ghent
Belgium
Tel: +32 9 264 52 10
Fax: +32 9 264 53 44
Email: magda.vincx@rug.ac.be

Denmark

Statens Naturvidenskabelige Forskningsråd
Danish Natural Science Research Council

Dr. Lars Stemmerik
Geological Survey of Denmark and Greenland
Thoravej 8
2400 Copenhagen
Denmark
Tel: +45 3814 2728
Fax: +45 3814 2050
Email: ls@geus.dk

Finland

Suomen Akatemia / Finlands Akademi
Academy of Finland

Professor Matti Leppäranta
Department of Geophysics
University of Helsinki
Nils Hasselblomin katu 2, P.O. Box 64
00014 Helsinki
Finland
Tel: +358 9 1915 1016
Fax: +358 9 1915 1000
Email: matti.lepparanta@phnet.fi

France

Centre National de la Recherche Scientifique (CNRS)
National Centre for Scientific Research

Dr. Sylvie Joussaume
CNRS-INSU
3 rue Michel-Ange
75766 Paris Cedex 16
France
Tel: +33 1 44 96 43 80
Fax: +33 1 44 96 53 50
Email: sylvie.joussaume@cnrs-dir.fr

Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER)
French Sea Research Institute

(to be confirmed)

France

Professor Jean-François Minster
IFREMER
155 rue Jean-Jacques Rousseau
92138 Issy-les-Moulineaux Cedex
France
Tel: +33 1 46 48 22 87
Fax: +33 1 46 48 22 48
Email: Jean.Francois.Minster@ifremer.fr

Germany

Deutsche Forschungsgemeinschaft (DFG)
German Research Society
and
Hermann-von-Helmholtz-Gemeinschaft Deutscher Forschungszentren (HGF)
Association of National Research Centres

Professor Gerold Wefer
Fachbereich 5 - Geowissenschaften
Universität Bremen
Postfach 33 04 40
28334 Bremen
Germany
Tel: +49 421 218 3389
Fax: +49 421 218 3116
Email: GWefer@zfn.uni-bremen.de

Professor Jens Meincke
Institut für Meereskunde
Universität Hamburg
Troplowitzstrasse 7
22529 Hamburg
Germany
Tel: +49 40 42838 5985
Fax: +49 40 42838 4644
or +49 40 5605724
Email: meincke@ifm.uni-hamburg.de

Greece

National Centre for Marine Research (NCMR)

Dr. George Chronis
National Centre for Marine Research
Institute of Oceanography
46km Athens – Sounion Ave.
P.O. Box 712 Anavyssos
Attica 190 13
Greece
Tel: +30 2910 76 400
Fax: +30 2910 76 323
Email: gchronis@ncmr.gr

Ireland

Marine Institute

Mr. Geoffrey O'Sullivan
Marine Institute
80 Harcourt Street
Dublin 2
Ireland
Tel: +353 1 476 6500
Fax: +353 1 478 4988
Email: gosullivan@marine.ie

Italy

Consiglio Nazionale delle Ricerche (CNR)
National Research Council

Dr. Silvana Vallerga
IMC - International Marine Centre
Lungomare E. d'Arborea 22
09072 Torregrande
Italy
Tel: +39 0783 22027
Fax: +39 0783 22002
Email: Vallerga@nameserver.ge.cnr.it

The Netherlands

Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO)
Netherlands Organisation for Scientific Research
and
Koninklijke Nederlandse Akademie van Wetenschappen
Royal Netherlands Academy of Arts and Sciences

Professor J.W. De Leeuw
Netherlands Institute for Sea Research (NIOZ)
Postbus 59
1790 AB Den Burg
The Netherlands
Tel: +31 222 369 366
Fax: +31 222 319674
Email: deLeeuw@nioz.nl / carmen@nioz.nl

Dr. J. Marks
Council for Earth and Life Sciences
Netherlands Organisation for Scientific Research
PO Box 93510
Laan van Nieuw Oost Indië 300
2509 AM The Hague
The Netherlands
Tel: +31 70 3440 708
Fax: +31 70 335 1005
Email: marks@nwo.nl

Norway

Havforskningsinstituttet
Institute of Marine Research

Dr. Roald Vaage
Institute of Marine Research
P.O. Box 1870, Nordnes
5024 Bergen
Norway
Tel: +47 55 23 85 00
Fax: +47 55 23 85 31
Email: roald.vaage@imr.no

Norges Forskningsråd
The Research Council of Norway

Professor Egil Sakshaug
Norwegian University of Science and Technology
NTNU, Trondheim Biological Station
7034 Trondheim
Norway
Tel: +47 73 591583
Fax: +47 73 591597
Email: egil.sakshaug@vm.ntnu.no

Poland

Polska Akademia Nauk (PAN)
Polish Academy of Sciences

Professor Jerzy Dera
Institute of Oceanology
Polish Academy of Sciences
ul. Postancow Warzawy 55, skr.poczt 68
81-712 Sopot
Poland
Tel: +48 58 550 32 32
Fax: +48 58 551 21 30
Email: dera@iopan.gda.pl

Portugal

Instituto de Cooperação Cîentifica e Tecnológica Internacional (ICCTI)
Institute for International Scientific and Technological Cooperation

Professor Mario Ruivo
Chairman, National Intersectorial Oceanographic Commission
Portuguese Committee for IOC
Av. Infante Santo, 42, 4°
1350 Lisboa
Portugal
Tel: +351 21 390 4330
Fax: +351 21 395 2212
Email: cointersec.presid@fct.mct.pt

Spain

Consejo Superior de Investigaciones Científicas (CSIC)
Council for Scientific Research
and
Instituto Español de Oceanografía (IEO)
Spanish Institute of Oceanography

Dr. Juan José Dañobeitia
Director UTM-CSIC
Centro Mediterráneo de Investigaciones Marinas y Ambientales (CMIMA)
Passeig Maritim de la Barceloneta, 37-49
08003-Barcelona
Spain
Tel: +34 93 230 95 84/83
Fax: +34 93 230 95 55
Email: jjdanobeitia@cmima.csic.es

Dr. Eduardo López-Jamar Martínez
Deputy Director (Research)
Instituto Español de Oceanografía
Avda. de Brasil 31
28020 Madrid
Spain
Tel: +34 91 597 08 41
Fax: +34 91 597 37 70
Email: eduardo.ljamar@md.ieo.es

Sweden

Vetenskapsrådet
Swedish Research Council

Dr. Leif Anderson
Analytical and Marine Chemistry
Göteborg University
41296 Göteborg
Sweden
Tel: +46 31 772 27 74
Fax: +46 31 772 27 85
Email: leif@amc.chalmers.se

Turkey

Türkiye Bilimsel ve Teknik Araştırma Kurumu (TÜBITAK)
The Scientific and Technical Research Council of Turkey

Professor Dr. A. Cemal Saydam
TÜBITAK - The Scientific and Technical Research Council of Turkey
YDABÇAG
Atatürk Bulvari, 221, Kavaklidere
06100 Ankara
Turkey
Tel: +90 312 427 51 95
Fax: +90 312 427 05 36
Email: saydam@rorqual.cc.metu.edu.tr

United Kingdom

Natural Environment Research Council (NERC)

Professor Howard Roe
Southampton Oceanography Centre
University of Southampton
Empress Dock
Southampton SO14 3ZH
United Kingdom
Tel: +44 1703 5106
Fax: +44 1703 596247
Email: howard.roe@soc.soton.ac.uk

Observers

European Commission

Dr. Christian Patermann
European Commission
Research DG, Preserving the Ecosystem I
SDME 7/18
200 rue de la Loi
1049 Brussels
Belgium
Tel: +32 2 295 6481
Fax: +32 2 296 3024
Email: christian.patermann@cec.eu.int

ESF Life and Environmental Sciences Standing Committee (LESC)

Professor Adam Schultz
Head of Department of Earth Sciences
Cardiff University
Cardiff, CF10 3YE
United Kingdom
Tel: +44 029 2087 4284
Fax: +44 029 2087 4991
E-mail: adam@ocean.cf.ac.uk

European Polar Board

Professor Jörn Thiede
Alfred-Wegener-Institut für Polar-und Meeresforschung
Columbusstrasse
27568 Bremerhaven
Germany
Tel: +49 471 4831 100
Fax: +49 471 4831 102
Email: jthiede@awi-bremerhaven.de

IREG Strasbourg - Dépôt légal: novembre 2002 - N° d'ordre 024049