Coastal and Shelf Processes, Science for Integrating Management

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Abstract: A major challenge facing us is to sustain human use of coastal areas and their natural resources within the context of increasing human pressures and uncertainty over the scale and nature of climate changes. To address this challenge, there is an urgent need to more effectively use available scientific knowledge and to fill critical gaps in our understanding of coastal systems. This paper identifies user problems and corresponding scientific opportunities. Critical knowledge gaps which need more or new research include: natural variability in space and time, experimental management, potential role of habitats and species, effects of changing nutrient regimes, preturbations of food web dynamics, and ocean-atmosphere-sea-coast coupling. Safety risks, extreme events-including thinking the unthinkable, food security, sustainable dynamic land-sea boundaries, multiple use, and water quality are other items which demand more attention. Indispensable tools include: permanent integrated coastal oberservational systems,large scale research facilities like mesocosms, marine reintroduction sites and protected areas and a stronger framework to help integrate knowledge. Since in most cases we are dealing with global issues and problems, the need for more co-operation with developing countries and capacity building is stressed.

Introduction

The coastal regions of Europe have been the focus of human settlement and economic activity for many millennia. One of the most important challenges facing the Member States of the European Union (EU) is to maintain the continuity of human use of coastal areas and their natural resources

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within the context of increasing uncertainty over the scale and nature of climatic change and the associated impacts on coastal systems. To address the management challenges facing us in the promotion of wise and durable use of our coasts, there is an urgent need to make more effective use of the available scientific knowledge. Such a strategy would inform and support the formulation and implementation of policy, investment strategies and planning and management systems governing the expansion and diversification of human activities. There is also a need for new scientific information to fill critical gaps in our understanding of how coastal systems will react in response to changes in environmental processes and human management interventions. This is reflected in the findings of the recent EU funded demonstration programme on Integrated Coastal Management and the subsequent formulation of the European Coastal Management Strategy. This is further highlighted in the recent statement on one of the major coastel activities by Margot Wallström, (EU Environmental Commissioner): "What still lies ahead of us is the arduous exercise of defining environmental objectives for fisheries together with a system of indicators for the future monitoring of policy performance, and the adoption of a long-term strategy and legal instruments to achieve policy objectives."

The coastal zone

The term the "Coastal Zone" has been widely adopted to denote a zone of transition between purely terrestrial and purely marine components of the global ecosystem. It contains the crucial boundaries between ocean, coastal systems and land. In the LOICZ (Land Ocean Interactions in the Coastel Zone) definition it is the area between 200 m above and 200 m below sea level. Although other studies may define these boundaries differently, all agree that to understand and manage the coastal zone both the catchment areas and the processes along the continental margins should be included. What makes the management of human activities in this "zone" different from inland or offshore areas is the high concentrations of energy, sediments, and nutrients that stimulate both high biological productivity and a wide diversity of habitats and species. The richness and diversity of resources found in coastal areas has long been recognised by human society and there has been a corresponding concentration of human activities and settlement along shorelines and estuaries throughout Europe. These powerful and dynamic forces that continuously shape our coasts also pose risks to human activities. Poor perceptions of these powerful and dynamic processes increase man's vulnerability to natural hazards.

User problems

The history of the management of Europe's coastal areas and resources has often been characterised by major human interventions in coastal processes. Interventions, such as the reclamation of land from the sea, have been sustained through a massive investment of finance. There has also been a reduction of natural capital represented by the goods and services that would have been generated by the coastal systems if they had not been subjected to human induced changes (Fig. 1). Science has helped to clarify the nature and value of such natural capital. Science has also helped to demonstrate the adverse effects of past management practices in reducing options for longer-term economic and social development and the increasing vulnerability of human activities to sea level rise and other changes in large-scale natural systems affecting coastal regions.

We are faced with a dilemma if we are to maintain the continuity and positive evolution of the human use of coastal areas and resources (Table 1) . We either change the way we manage human interventions in coastal systems or we continue down a path that is leading to a decrease in opportunities for the sustainable economic and social uses of Europe's coastal assets. If we are to achieve a positive change and move towards a stronger form of sustainability and a more diverse and equitable base for economic and social development, we must recognise the powerful and dynamic forces that create coastal ecosystems and maintain the stream of environmental and economic goods and services that sustain human development.

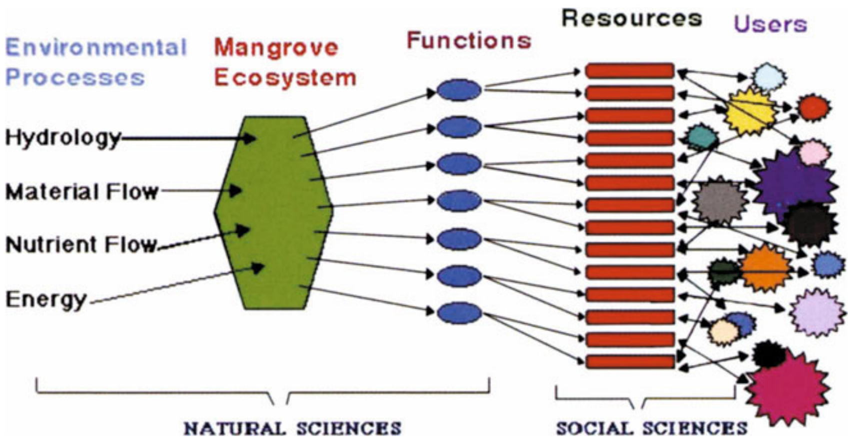

Fig. 1. Understanding the Linkages Among Coastel and Marine Ecosystems and Human Activities.

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

Table 1. Central objectives of research to provide a scientific background for Integrated Coastal Zone Management as proposed by the ESF Marine Board. These topics are addressed in the table.

Science opportunities

Advances in science have helped to explain how ill-advised human interventions in coastal systems and processes have led to less efficient use of both man-made capital and natural resources. These advances have also clearly demonstrated the need for a broader understanding of the linkages between ocean, atmospheric, terrestrial and coastal systems and large-scale environmental processes. For example, increased vulnerability of coastal settlements to flooding is a result of rising sea levels, subsidence, increased storm surges, changes in land cover in river catchments and continued expansion of the coastal settlements themselves. To address such issues of sustainable use of coastal areas, knowledge of the natural and man-induced changes in the surrounding regional marine and terrestrial systems is essential. While the concept of the Coastal Zone remains a useful tool in defining an area within which special planning and management arrangements are required, it is increasingly recognised that such plans and management arrangements must be based on sound scientific knowledge of dynamic environmental processes over a wider geographic scale and longer temporal scale (Lindeboom 2002a).

Sustainability

The concept of "Sustainable Development" was defined in the report of the World Commission on Environment and Development report "Our Common Future" as that which "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987 p8). This concept gained further public recognition as a result of the United Nations Conference on Environment and Development (UNCED) and the production of "Agenda 21" the global plan of action designed to promote more sustainable forms of development. Coastal management was given explicit recognition in Agenda 21 Section 17 dealing with the marine environment. In this section Integrated Coastal Management was given priority as the single most important means of reconciling a number of non-sustainable marine resource development issues. In a recent publication from the Land-Ocean Interchange in the Coastal Zone (LOICZ) programme sustainable coastal development was described as "the proper use and care of the coastal environment borrowed from future generations" (Turner et al. 1998).

The term "Sustainability" is as much an expression of social choice as it is an expression of the ability of the environment to continue to support human needs and aspirations. Throughout history, man has modified coastal systems to suit current needs and aspirations. Reclamation of salt marshes to form sites for agriculture, industry and housing are common examples. However, such changes can seriously undervalue the resources generated by natural systems. For example, the reclamation of wetlands can reduce environmental services that support fisheries where wetlands act as spawning, feeding and nursery grounds for commercially important fish stocks.

Changing these systems to create short-term economic benefits gained by specific activities can foreclose future development options and can create long term costs that are poorly perceived or ignored. Degradation of coastal systems and consequent loss of natural functions such as biological production or stabilisation of sediments means that man has had to spend time, effort and monetary resources to compensate for the loss of environmental and economic goods and services. For example, the need to defend coastal infrastructure such as nuclear power stations located on eroding shorelines could be termed "weak sustainability" because of the need to allocate natural resources (shingle and sand = natural capital) and man made capital (money and machines to move the shingle and sand) to sustain the viability of the power plant. Weak sustainability is also associated with the assumption that there can be unlimited substitution possibilities between different forms of capital via technical progress. For example, the reclamation of intertidal mudflats and marshes has proceeded on the basis that there was little capital value represented by these coastal ecosystems and greater man-made capital could be achieved by their transformation into dry land. However, advances in scientific knowledge have identified highly valuable functions performed by wetlands as well as risks to the sustainable use of reclaimed areas resulting from both the destruction of the functions of wetlands and other coastal systems, and rising sea level. "Strong sustainability" is associated in economic thinking with the conservation of different forms of capital (man-made, human, natural, and social/moral) in respect to meeting the needs of human populations over time. Strong sustainability applied to marine and coastal systems would mean that their natural capital expressed in terms of biological diversity, generation or renewable resources, and maintenance of natural processes and functions would remain constant or increase.

Programmes for future scientific research:

In addressing the challenge of meeting the social and economic development needs of European society it is imperative that the Marine Science Plan for Europe addresses two critical coastal management and scientific investment issues, namely:

- filling critical gaps in available scientific information required to reduce uncertainty in dealing with predicted changes in large-scale environmental processes affecting coastal systems.
- investment to improve the utility of existing scientific knowledge from a wide array of social and natural science disciplines in the formulation of coastal policy, development strategies, investment and natural resources management practices.

Filling critical gaps

Natural variability of the coastal zone in space and time

Before discussing the sustainable use of coastal and shelf ecosystems implying acceptable, i.e. reversible human-induced perturbations of these ecosystems, we first have to establish the natural variability of these ecosystems.

Natural variability in (European) coastal zones (and to some extent in land-locked or inland seas like the Baltic, the Mediterranean and the Black Sea) is a long recognised phenomenon. However, the time scales, the amplitudes and the nature of this variability is far from understood.

Over the last decade it has become increasingly clear that the Northern Atlantic Oscillation (NAO) determines to a large extent the natural variability of the coastal ecosystems in Europe and that the time scales involved vary from seasonal to annual to decadal to centennial (Fig. 2). Moreover, the NAO as such interacts with other oceanic phenomena such as the THC variability, the Tropical Atlantic Variability (TAV) and the Arctic Variability (AV) and is possibly influenced by global warming. Apart from the NAO, other factors that influence natural variability have to be taken into consideration. For example the variability in tidal current strengths is partly caused by the so-called moon cycle of 18.6 years (Oost et al.1993) and there are strong indications based on high-resolution lake sediment analyses that several decadal and centennial solar activity cycles are important as well.

Consequently, coastal ecosystems are confronted by cold or warm winters, frequent or sporadic storms, low or high average wave heights, low or high run off and by more or less erosion, sedimentation and resuspension. Such natural variability substantially affects the physical and morphological boundaries of coastal ecosystems and inland seas and, as a consequence of that, their chemistry and biology (Lindeboom 2002b).

Hence, before we can determine to what extent humans can explore coastal ecosystems in a sustainable way we first have to define the physical, chemical and biological bandwidths of the natural ecosystem.

This is a difficult task since presently there are few pristine European coastal ecosystems anymore. Thus, we have to rely on historical data, long-term data series and high-resolution analyses of sedimentary archives (to reconstruct the past and predict the potential future). To establish the natural variability of European coastal ecosystems is a major scientific task in itself, which can only be accomplished by intense European collaboration of (palaeo)-climatologists, meteorologists, oceanographers and "coastal scientists" critically analysing their historical data and long-term data series, pooling such data and contemporary data and careful interpretation of these huge data sets. Once the natural variability has been established the second major line of research can start focussing on the sustainable use of coastal ecosystems (and inland seas). Hence, what are the limits of physical, chemical and biological perturbations without irreversibly changing the variable natural ecosystem?

Experimental management

Applied research in general is retrospective, addressing issues that have arisen as a result of human activities in the marine environment. The outcome of such research provides the basis for formulating potential new management regimes. Of-

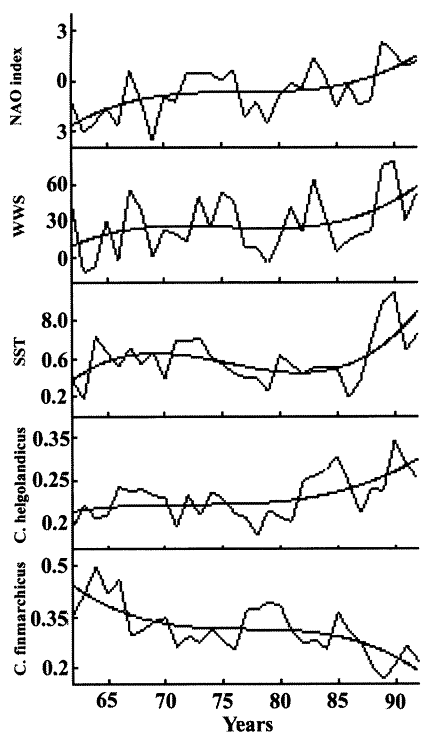

Fig. 2. Year-to-year fluctuations and long-term trends in the North Atlantic Oscillation index (NAO), West Wind Stress (WWS) in m^2/s^2, Sea Surface Temperature (SST) in °C, and abundance of *Calanus finmarchicus* and *C. helgolandicus* (log-transformed) from 1962 to 1992 over the northeast Atlantic and the North Sea. Supplied by J.-M. Fromentin and B. Planque, adapted from Fromentin and Planque (1996). Polynomial fits were used to provide a visual indication of the long-term trends of these series. The NAO index is the difference in normalized sea level pressures between the Azores and Iceland calculated on the December-April period. WWS and SST values are the mean of December-April monthly data over the eastern-north Atlantic and the North Sea. Calanus values are the annual mean of log-abundance (log-number of organisms per sample) of copepodite V and adults of each species calculated over the eastern-north Atlantic and the North Sea. Calanus species are collected in near-surface water and each sample has a volume of about $3m^3$ (each annual value is calculated from about 2300 samples).

ten there is resistance to the initiation of novel management regimes because of the uncertainty associated with their outcome. Yet there is a need for research outcomes to be implemented, otherwise our endeavours are wasted. Consequently, there is an urgent need for managers to adopt experimental management regimes to enable us to test the predictions that have arisen from experimental studies. Generically, such regimes would include different levels of human interference ranging from no removal to partial removal and on to complete removal. An example of such a system may be the exclusion of bottom fishing activities from certain areas of the seabed to remove the effect of anthropogenic physical disturbance to the seabed and its biological components. An experimental management regime that permitted varying levels of disturbance would permit a rigorous examination of community responses to human disturbance. The outcome of such experiments may conclude that intermediate levels of disturbance result in a more productive system that may have benefits for the wider fishery and may result in a more diverse range of habitats and communities. In some cases, unexpected findings may occur. For example, 17 000 km^2 of the seabed off the eastern coast of the US was closed to all forms of towed bottom fishing gear to protect stocks of yellowtail flounder.

Not only did this closure protect this fish stock; it also permitted development of a more diverse seabed assemblage and resulted in a 14-fold increase in the biomass of commercially important scallops within the area (Fig. 3). Such findings enable us to continue to use the marine environment in a manner that is both sustainable but that is also not entirely prohibitive.

If parts of the coastal seas will be filled with fields of windturbines, the chance should be taken to explore experimentally new trajectories for a multiple and sustainable use in these area. 'Wind Parks' may be developed into 'Marine Parks' where fisheries with towed gear are excluded. On the other hand, there is a wide potential for other uses in addition to generating electricity. This particularly applies to aquacultures typically practiced inshore where they cause an array of environmental problems. Within offshore wind parks such

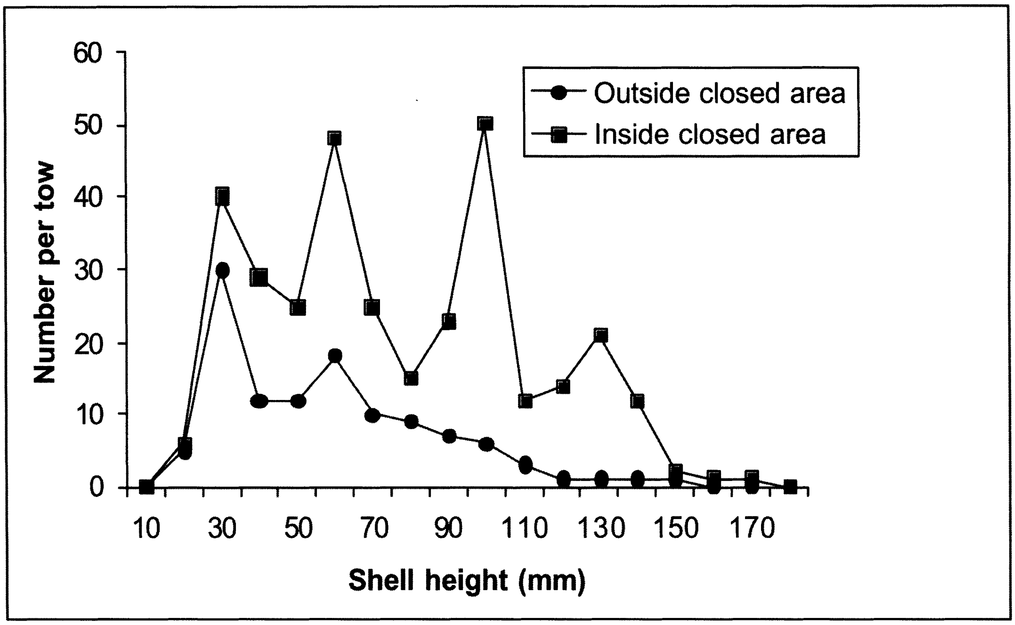

Fig. 3. Standardised abundance of sea scallops (numbers per dredge tow) by shell height, taken in the July National Marine Fisheries Service dredge survey on Georges Bank. Data are presented separately for the areas closed and those open to scallop dredging (adapted from Murawski et al. 2000).

problems may be mitigated by the larger water bodies passing through such an area. As examples, mussels may be raised on longlines, lobsters in crabs pots, attached oysters and macroalgae may be grown on rafts, etc. Performing these activities offshore needs partially new methods, and the consequences on the marine ecosystem need careful evaluation. However, coastal management may shift aqua-cultures from inshore to offshore to unburden shoreline habitats.

Another example where an experimental approach would have a wide potential for stimulating management practices are sand nourishments at coasts where erosion prevails. Where these coasts have been armoured by coastal protection to prevent shoreline retreat, natural habitats have been lost, there dynamics ceased and biodiversity decreased. Sand replenishments offer a chance to restore lost habitats and their dynamics. Particularly, experiments should be conducted with different designs of the supplied sand deposits. These may be arranged as sandy spits in front of seawals or dikes. In the shelter of such a sand bar, mud may accumulate and salt marshes may develop. Another option would be arcs of sandy isles and sand bars, providing shelter and at the same time offering coastal birds sites for undisturbed breeding colonies. Depending on sea level rise and the resulting sand hunger at a particular shoreline, such deposits may last for decades or centuries but continuously will change morphologically 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 are not compromised in their use of the coastal zone.

Potential role of habitats and species

Habitat fragmentation and distribution of habitats of shoreline organisms entailed a loss of species along European coasts. Consequences are:

• Impaired ecosystem functions such as missing biotic filters between land and sea.

• A truncation of the coastal food web at its upper meshes.

• A degraded aesthetic and recreational value.

Species played and partially still play an important role in the biogenic morphodynamics of the shore. Other species directly or indirectly support essential coastal functions such as storage of organic carbon and nutrients, nurseries for offshore adult populations, food supply for flocks of birds, fisheries and human welfare. Based on deletion and addition experiments as well as observations on wider scales, science has to demonstrate the cascading effects species have on the integrity of the coastal system. The main emphasis will have to be on restoring sizeable habitats, mostly for spontaneous and self-organising recolonization of the coastal species assemblages. The target is not to achieve fixed species associations or habitat structures. Instead, the abiotic prerequisites for coastal life to unfold need to be supplied on European wide scales. To achieve this, research is requested to reconstruct the role of lost habitats and species in the coastal ecosystems at their time. In a second step, predictions are needed on the role of these elements in the context of the modern coast. In selected cases, individual species may be reintroduced which have an ecological flagship role such as sturgeons or the European flat oyster.

Effects of changing nutrient regimes

Human activities in the catchment area are often visible in higher nutrient concentrations, increased plankton growth and blooms and oxygen deficient conditions. However, more subtle long term changes are also occurring in the catchment area and coastal zones which are related to changes in the relative contribution of different nutrient elements. Nutrient concentrations in the coastal zones are mainly affected by the riverine inputs reflecting changing human activities in the catchment area. In addition to an increase in the concentrations and fluxes of nutrient elements such as N, P and Si, there is also a change in their ratios between the different elements compared to those in pristine or natural coastal systems. This change in ratio has been reinforced in the industrialised western countries by a sharp drop in phosphate but nearly no reduction in nitrogen. Retention of nutrients in lakes and reservoirs behind dams has been found to retain besides N and P also Si.

The changing nutrient ratios in turn has an effect on the species composition of phytoplankton and consequently on the food web structure in the catchment area and in the coastal zone.

Perturbations of food web dynamics

Physical interventions (for example, constructions, land reclamation, dikes, beam trawling), withdrawal of material (fishing, sand and gravel mining, gas and oil exploration), changes in the input of matter and energy (oil spills, sediments, changes in storm surges, wave action, currents and the introduction of alien species) affect the coastal marine food web structure both directly and indirectly by habitat modification and selective removal or addition of biota. In many cases these changes are taking place unnoticed during a certain time span, since they can also be attributed to the natural variability before the actual causes suddenly become manifest.

There have been several instances in the past where scientists were not equipped to respond or were not able to respond rapidly to environmental events, perceived by the public and policy makers as catastrophes, which occurred in European Seas such as algal blooms or a decline in populations of several species. For instance, the decline in the Wadden Sea of the Eider duck populations in the past few years which appeared to be related to events that had their beginnings at least 10 years earlier. These and other events such as oil spills require that adequate institutional structures with a continuity in basic research are in place to respond to them.

To anticipate food web changes due to the above reasons at an early stage much more detailed insight into the microbial and macro food web structure is required.

Optimal design of observing networks

To establish a permanent coastal ocean observing system, optimal design of the observing system is required to reach cost-effective performance. This means a fordable observing system with the capability to provide data for the diagnosis and prognosis of coastal/shelf oceans and to support decision-making in coastal zone management and marine industry.

The scientific issues concerned include quality of existing and optimal design of future coastal ocean monitoring networks.The first objective is to evaluate scientific quality of the current existing coastal observing systems by developing suitable indicators and methods to assess the quality of existing systems. Methods to estimate reconstruction error and effective information need to be developed and applied to identify data redundancy and insufficiency. Observing System Simulation Experiments via data assimilation should be used to evaluate the significance of the observing system. The second objective is to optimally integrate existing observing systems and state-of- the-art monitoring technology and determine a cost-effective monitoring strategy for European coastal oceans, i.e. where to put our limited resources. Cost-benefit analysis and optimisation methods should be combined with approaches used in observing system evaluation. Pilot field experiments may be needed to demonstrate the quality of optimally designed coastal observing systems.

Ocean-atmosphere-sea-coast coupling

Global Climate Change concerns focus attention directly on this issue. How might changes in Atlantic circulation impact on coastal climate and related dynamics to ecology? How will this impact be conveyed through shelf-edge exchanges, internal circulations, atmospheric coupling? Noting the vastly reduced inertial lag of the shelf seas – are there first signs of Global Climate Change in shelf seas. Such scientific questions are foremost world wide, the integrated communications provided within the Operational Oceanographic approach allows individual, specialist scientists to interact with and impact on these issues.

The models by which such integration can be facilitated need to be explored along with the needs for infrastructure investment in Very High Performance Computers, High Performance Data Networks etc. The success of the ECMWF in stimulating European research into meteorological, climate and oceanographic is noted.

Improve the utility of existing scientific knowledge

There is an urgent need to invest time, effort and funds in gaining additional value from the scientific knowledge that exists. To do this we propose to identify critical management issues affecting the sustainable use of European coastal regions and then to undertake a series of meta-analyses of existing studies. Such an analysis should more clearly represent the mosaic of coastal ecosystems, the key environmental processes that govern the health and productivity of individual coastal ecosystems, and to assess the effect of current management policies on the sustainable use of those systems and their renewable resources. The major issues identified so far are:

- Risk to life, property public and private investment
- Food security relating to both fisheries and aquaculture.
- Sustainability of the land-sea boundary.
- Optimisation of the use of the coastal zone which would include multiple uses.
- Water quality in catchment and coastal areas.

A meta-analysis approach adds value to existing science by identifying where we appear to have reasonably complete scientific information. Perhaps more importantly this approach identifies critical gaps in our knowledge permitting us to identify those areas of research that need to be addressed. Finally, meta-analysis may yield new knowledge enabling us to better understand how our coastal systems function.

Risks

To address the challenge to protect coastal marine biodiversity and ecosystems from damage caused by human activity, it is a pre-requisite that we must appreciate the relative influence of human activities in comparison with natural processes. For example, human sources of physical disturbance to the marine environment must be assessed against the background of natural physical perturbations (wave action, seabed currents) that occur. It is important to realise that even without the influence of human activities coastal ecosystems and biodiversity will evolve through time. Hence we would caution the use of the word "protect" as this suggests that we would attempt to maintain a system in a condition that may not be appropriate (i.e. it may have changed even without human influences acting upon it). Such efforts would be scientifically flawed and extremely costly. In order to assess the natural variability within the coastal system, we urgently require areas that remain free from interference. Such a goal is achievable when considering activities that directly impinge upon coastal systems (e.g. fishing, dredging, land-reclamation) but is perhaps unattainable with respect to the chemical composition of the seawater.

Extreme events – thinking the unthinkable

Earlier EU studies have both advanced individual aspects of marine science (models, technology, process studies) and linked some components of these in COHERENS, PROMISE, ERSEM etc. Comprehensive 'risk analysis' makes it now opportune to examine extreme, extraordinary events that may occur due to:

- Unsustainable, accelerating rates of change in meteorological forcing associated global response (mean sea level) and localised conditions (supply of sediments, river flow etc).
- Exception events - seismic, accidental spillage.
- Peculiar interactions between physical, sedimentary, chemical and biological parameters.

The scientific issues concerned include:

- Extension from linear to non-linear systems and from 'primitive equations' to 'group dynamics'.
- Cross-spectral exchanges in physical – biological parameters, across temporal and spatial scales under exceptional circumstances.
- Time variability of extreme events in different time scales and its reasons.
- Value-added prediction for extreme events to reduce the risk.

Food security relating to both fisheries and aquaculture

The decline of marine fish resources in the European coastal zone is primarily caused by over-fishing and the lack of political will to implement the measures required to halt this decline. This is a fisheries management issue. However, fishing activities have wider ecosystem effects on both the biota and habitat, these include:

- Disturbance of the upper 1 cm – 20 cm of the substratum causing short-term resuspension of sediments, remineralisation of nutrients and contaminants, and re-sorting of sediment particles.
- Direct removal, damage, displacement or death of a proportion of the infaunal and epifaunal biota.
- A short-term (0-72 hrs) aggregation of scavenging species.
- The alteration of habitat structure (e.g. flattening of wave forms, removal of rock and biogenic structures).

From an ecological perspective, fishing removes specific components of the marine community that perform different functions within that community (e.g. fish may be important predators whilst bivalves are important filter feeders transporting energy from the water column to the seabed). Because of the complex number of interactions within the fish community of the North Sea, it is unlikely that even the total extirpation of one species (e.g. cod) would lead to dramatic 'cascading' effects within the system. However, the removal of species that are important habitat engineers (e.g. bivalves that form reefs, bioturbating sea urchins etc) may alter the habitat such that it becomes less suitable for the maintenance of some species, whilst other species may benefit. Thus the degradation of seabed surface topography by bottom fishing may reduce the suitability of the habitat for roundfish (e.g. cod) but may favour flatfish populations (e.g. plaice and sole). While the physical disturbance of soft-sediment communities by fishing gears may elevate productivity and promote the smaller body-sized biota (e.g. worms that provide food for fishes), excessive levels of disturbance will ultimately reduce overall production. Whilst the benefits of extra food might be easy to measure in terms of population benefits (e.g. increased growth rate of plaice in the North Sea) the unknown benefits of habitat composition and structure require further research.

Aquaculture is an effective method for increasing the provision of dietary protein when it is based on species that convert organisms at low trophic levels (e.g. plankton and plants) into protein. Hence, bivalve mariculture and the production of herbivorous and omnivorous fishes such as carps and tilapias is one of the most efficient methods of generating protein for human consumption. The cultivation of piscivorous species typically consumed by western societies is less efficient because of the use of other fish species in the production of fish-feed. Research to identify plant-derived feeds that can be used to rear piscivorous fishes is of the utmost priority. In addition, the activities associated with intensive aquaculture can have deleterious effects upon the marine environment, these include:

- The use of anti-biotics to suppress disease may lead to disease resistance and changes in the microbial community in the vicinity of fish cages.
- The build up of organic matter in proximity to aquaculture sites alters benthic community structure.
- Poor management may lead to the production of toxic algal blooms.
- Escaping fish may lead to loss of genetic diversity.

Towards more sustainability of dynamic land-sea boundaries in Europe

Most developed coastlines in Europe lost their morphodynamic flexibility and biotic diversity. Adaptability to a gradual rise in sea level and to exceptional meteorological events such as storm tides ceased. Maintaining these shorelines in their present form will require an increasing effort in structural as well as financial terms. There is a lack of sustainability which asks for scientific innovations and guidelines to initiate an integrated management allowing self-sustaining processes to unfold to the benefit of continued human use of the coast.

The dynamics of the land-sea boundary must be given more room. To achieve this, geomorphological and ecological scenarios need to be elaborated. These may be worked out along a continuum. At one end there would be managed retreat by deconstructing and abandoning unsustainable portions of the coast. At the other are attempts to supplement structurally defended coastlines with a buffer of sand borrowed from offshore bottoms. The aim is to find solutions, which offer a wide potential for multiple uses but no longer are based on a permanency of infrastructure compromising future generations.

Optimisation of the use of the coastal zone which would include multiple uses

A feature of complex coastal ecosystems is the wide array of physical, biological and chemical functions they perform. Primary and secondary biological production are examples. These functions generate environmental resources such as fish, which have tangible social and economic value. Other valuable functions and resources are common to coastal ecosystems. For example, seagrass beds help to reduce wave energy that otherwise would erode soft coastlines. The value of such environmental services is often poorly perceived by policy makers, planners and coastal managers with the result that they are afforded little protection and can be degraded. With mounting population pressures on coastal areas and increasing demands for resources, we can ill afford to degrade or lose either the economic or environmental goods and services provided by coastal systems (Fig. 4).

A solution is to promote multiple-use of complex coastal systems and to seek to optimise the stream of economic, social and environmental benefits to society. To do this requires sound knowledge of what form of human activity are dependent on the functions and resources created by coastal systems and how such activities can be integrated in time or space as part of coastal management.

This is an example of where science needs to be used to better inform management and is also an example where cross-disciplinary science can help to define management options for wise and sustainable coastal development.

Water quality in catchment and coastal areas

From hazard to risk assessment Billions of EUROs are spent each year during the last 30years to assess the water quality in rivers and coastal zones. Office shelfs, books and data bases are piled up with data with concentrations of certain priority substances. They are assessed in national annual reports and international Quality Status Reports of different coastal seas. However, it is still difficult to say if water quality is getting better or worse. We are data rich and information poor.

To assess the water quality, objectives or quality values, based on toxicological data, have been set by different national authorities. To be absolute sure to prevent organisms from hazardous effects, all kind of safety factors were introduced, lowering the quality objectives, sometimes below the natural background values.

However, more and more it is recognised that this substance-oriented assessment with these quality values is not possible anymore. First of all this assessment method is just an identification of a possible potential effect, not a real effect in the environment it self. Also, it is not possible to assess the toxic effects of all 150000 substances separately and in combination with each other, because it will take too long time and is too expensive. The ultimate effect of the last 10 years is that the quality values differ enormously (factor of at least 1000) between different countries. It is beginning to be recognised that the monitoring programmes do not always include the substances, which cause the real effects.

So, more and more, real effects in the lab and field are determined with bioassays and rapid screening methods.

With these bio-effect tools it is possible with the Toxicity Identification Evaluation (TIE) procedures, to determine the substances causing the real effects.

These developments will have an impact on the monitoring strategy to assess water quality. Policy measures to reduce the input of substances and to meet their quality values, are taken nowadays at an international level. However, the monitoring strategies are still at a local or national level. International harmonisation and standardisation in monitoring strategies in catchment areas and coastal zones will be necessary in the near future to fulfil the information needs of policy makers and the general public.

Tools

Permanent Integrated Coastal Observational System

European requirements for developing and assessing science and informing management include permanent *in situ* integrated observation systems in the coastal areas and the Atlantic equipped with automated physical, chemical and biological sensors.

There is a need to optimise investments by:
- co-ordinating existing observational networks.
- adding (European value) to on-going/proposed. observational missions (sea/ground truth; proxy relationships etc.
- maximizing synergy between satellite-aircraft-ship-buoy-radar-lander platforms.
- determining key indices, critical positions, appropriate sampling intervals.
- standardisation/harmonisation of instrumentation/analytical procedures.
- delegated responsibilities for data analyses, dissemination and archiving.
- establishing links with terrestrial, atmospheric, oceanic monitoring programmes.
- interfacing with modelling requirements (set up bathymetry), initialisation, forcing, assimilation, assessment) and utilising developing modelling capacities.

The scientific issues concerned include quality of existing and optimal design of future coastal ocean monitoring networks.

The objective is to evaluate scientific quality of the current existing coastal observing system. Developing suitable indicators and methods to assess the quality of the existing coastal observing system; Developing and applying theories estimate reconstruction error and effective information in order to identify data redundancy and insufficiency. Observing System Simulation Experiment via data assimilation should be used to evaluate the significance of the observing system on improving prediction.

Another objective is to optimally integrate existing observing system and state-of-art monitoring technology and determine a cost-effective monitoring strategy for European coastal ocean, i.e. where to put our limited resources. Cost-benefit analysis and optimisation methods are combined with approaches used in observing system evaluation. Pilot field experiments may be needed to demonstrate the quality of optimally designed coastal observing systems.

Large scale facilities, e.g. mesocosms

To understand the different processes in the complex coastal systems and to execute experiments with different management options, both laboratory and outdoor experiments are necessary. Experiments in which the impact of different boundary conditions or different management regimes can be tested need large-scale facilities like mesocosms, both to ensure realistic scaling and to enable sufficient replicates. Although a co-operation among several existing facilities has been established within the EU, we urge for a further organisational effort. This should lead to a better co-ordination of experiments, prevent duplication and provide additional funding for these expensive facilities.

Marine reintroduction sites

Habitat loss, fisheries and pollution have led to local extinction's of many species. The urge for protection of biodiversity and sustainability has started the discussion on reintroduction of several species like sturgeons, flat oysters, sabellaria reefs, seagrasses and rays.

We recommend to establish marine reintroduction sites for species that were common in the past but have now disappeared from large parts of the coastal zones. Apart from sites in the field, which will need special protection such that the original causes of disappearance have been taken away, facilities were viable specimen for reintroduction can be bred are urgently needed.

Need for stronger framework to help integrate knowledge

There is a need for a stronger framework to bridge the gap between science and management. The dynamic tension between real user needs and the perception of scientists often leads to miscommunication and frustration on both sides.

To overcome this problem we should identify user needs and balance fundamental and applied science taking into account integration and application. Scientist more often have to ask the question WHY?, and will have to indicate and propagate the relevance of science to management.

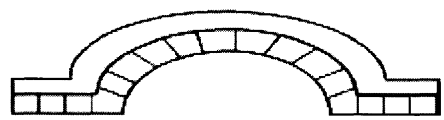

Fig. 4. a) Coastel Land and Ocean systems are Interdependent like the stones in a bridge: Bridge is strong because elements are linked and mutually supporting.

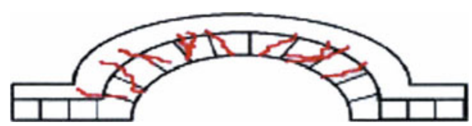

Fig. 4. b) If you damage 1 or more ecosystems you weaken the carrying capacity of the coast and coastal seas.

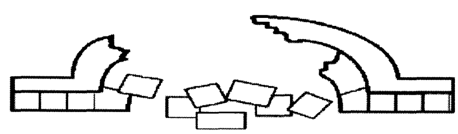

Fig. 4. c) Extreme damage can severely reduce capacity of coastal systems to sustain human needs.

On the other hand, managers have to set priorities of what is really important and what options are realistic, also in a social and economical context. Furthermore, there will always be a mismatch between the managers needs of to-day, and the results of freshly started research.

Partly this may be overcome by a better integration of the natural and social sciences, and also elaborate GIS and MSS systems may help to bridge the gap. But to do so, there is a need to back up science with investment in infrastructure. Europe has a task to influence broader international science and management agendas.

A major problem in coastal and shelf seas management is the invisibility of the underwater world. Out of sight, out of mind. For protection of habitats and species, public and political awareness and support is indispensable. In order to attain this, we will have to develop ways and tools so that the public can enjoy and appreciate the underwater world.

Co-operation with developing countries

The cooperation with developing countries in the field of marine sciences should take place in the form of long-term co-operative exercises with a strong capacity building component. These co-operative efforts will also entail the transfer of European expertise and tools in the form of environmental packages for application in the coastal zones of developing countries. Suggested are additional initiatives to establish regional centres of excellence in developing countries, which will further contribute to ensuring the international role of European science. From the scientific point of view Co-operation with developing countries in several regions such as S and SE Asia will help to obtain valuable data sets on marine and atmospheric processes that are interlinked and of a global nature (global teleconnections).

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