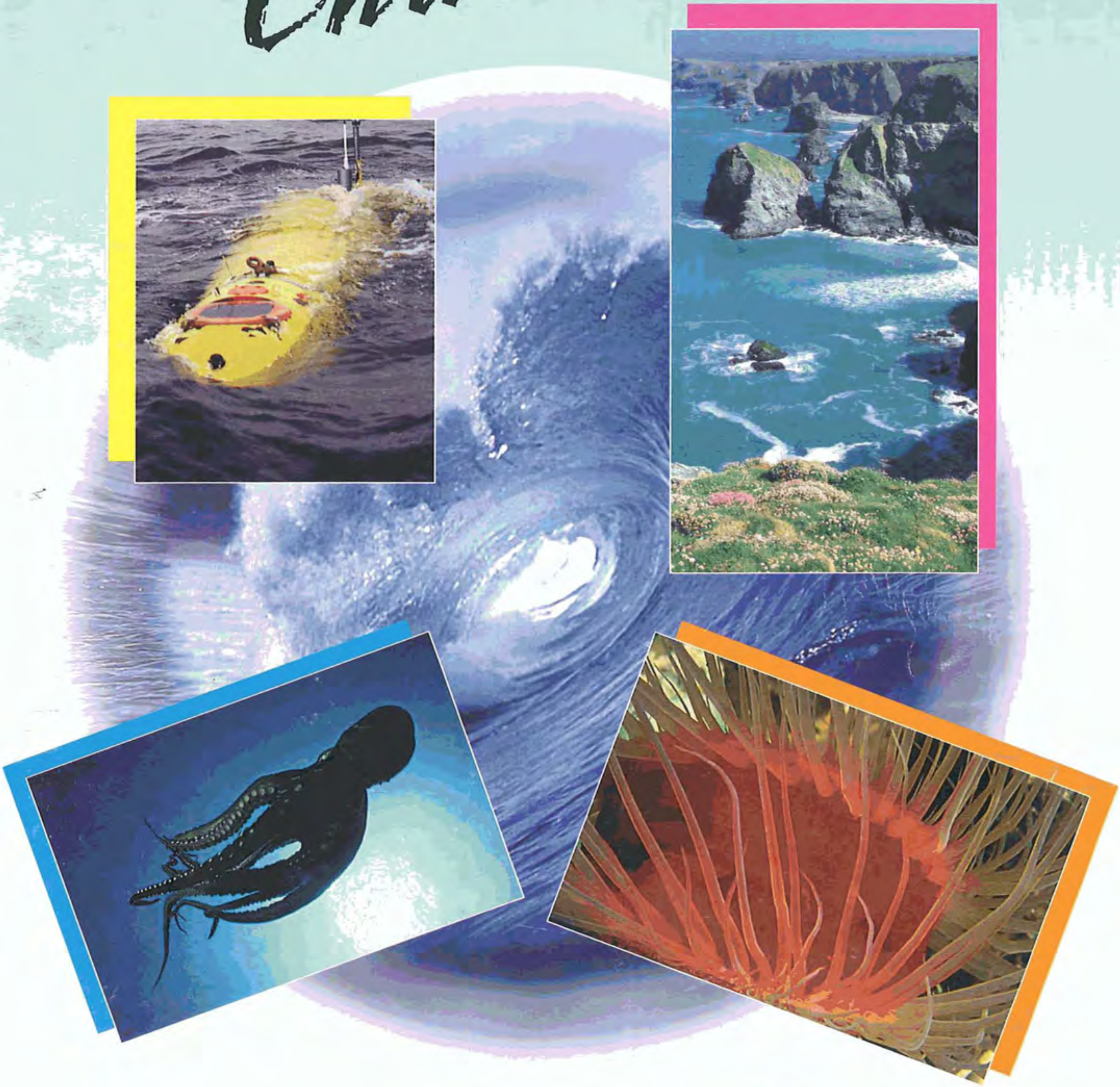
OCEAN Challenge



Special European Issue

Volume 12, No. 1, 2002

EFMS

The Challenger Society for Marine Science

Volume 12, No. 1, 2002

OCEAN Challenge

EFMS

Special European Issue, published for the EFMS

The **European Federation of Marine Science and Technology Societies** was founded in December 1998 in Paris. It consists of European non-governmental scientific associations specialising in research and education pertaining to the marine environment.

The EFMS Secretariat is at Institut océanographique, 195 rue Saint-Jaques, F-75005 Paris, France.

The objectives of the EFMS are:

- To contribute to the advancement of research and education in marine science and technology.
- To disseminate information to promote the advancement of marine science and technology in Europe.

The EFMS website is: www.efmsts.org

Welcome to all our readers

It is a great pleasure to welcome all new readers to this special European issue of *Ocean Challenge*, the regular magazine of the Challenger Society for Marine Science. This issue, published on behalf of the EFMS and with its collaboration, has long been planned, and I am delighted to see it come to fruition. Marine science is naturally an international endeavour, and this is clearly evident in the articles assembled for this issue.

It is also appropriate that many of the articles deal with environmental issues, and relate to public policies for the future. Much of national and international funding of science is now driven by the primary objective of wealth creation, but science (and especially marine science) is also vitally necessary for understanding and so ultimately protecting our environment. This is one of the most important factors determining our quality of life, and it is imperative that it is given equal weight in setting the research agenda and the allocation of funds, in Europe and elsewhere.

This magazine, and especially this special issue, would not exist without the dedication and hard work of our editors, Angela Colling and John Wright, ably assisted on this occasion by Karl Hesse for the EFMS, and Hjalmar Thiel, and I thank them sincerely for their good work on our behalf. Thanks also to all our contributors, and finally to Tim Jickells and Graham Shimmield for finding a way to make it happen at last! I hope you enjoy the magazine, and that we shall be able to have further special issues of this sort in the future.

John Shepherd,
President, Challenger Society for Marine Science

Ocean Challenge is the magazine of the Challenger Society for Marine Science (see inside back cover). The views expressed in *Ocean Challenge* are those of the authors and do not necessarily reflect those of the Challenger Society or the Editor.

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The cover was designed by Ann Aldred Associates.

Maps and illustrations: John Taylor and Sara Hack

A Message from the President of the EFMS

May I invite you to enjoy reading this European issue of *Ocean Challenge*, which is the first to be planned and put together under the auspices of the EFMS. The EFMS is a new body, created by statute in Paris in December 1998, and now representing 11 member marine science and technology societies, and one affiliate, spanning the length and breadth of Europe. The creation of the Society is a tribute to the vision and energy of Michael Whitfield, Thomas Hoepner and Lucien Laubier. Over the past two years, I have had the privilege of acting as the Society's President, and thus presiding over this innovative publication. I will also have the pleasure of introducing the first international conference of the Society to be held in Athens in September on the subject of sustainability in the Mediterranean Sea. These two events mark the developing maturity of the organization and the potential for its future growth and influence on behalf of national bodies across Europe.

The EFMS has two important objectives: (1) to contribute to the advancement of research and education in marine science and technology, and (2) to disseminate information to promote the advancement of marine science and technology in Europe. This year also marks a fundamental change in the way science is funded across Europe, with the introduction of the 6th Framework Programme. The development of Centres of Excellence and of Integrated Projects will change working relationships, placing the institutional structures closer to the co-ordination and operation of the programmes. Such devolution of responsibility is a key component of the European Research Area (ERA) and will mark greater involvement of the national funding agencies in meeting the overall European objectives. However, not all creative and innovative research can be carried out through the institutional mechanisms – there will always be scope for individual thematic groups, the members of which represent a broad cross-section of academia, research and industry. I believe this is an area where the EFMS and other related organizations have a very important, non-governmental role to play in shaping the new collaborations across Europe. The articles contained within this issue represent some of the variety of thought-provoking and relevant scientific issues being studied across Europe. Many have relevance to the new emerging policies and Directives.

Within the ERA, marine science is no longer an individual discipline existing as one of a number of discrete subjects. Most of us who carry out research with European funding will be active within the new Priority 6: Sustainable Development, Global Change and Ecosystems. The challenge for the EFMS, and each of us individually, is to place the marine realm at the core of developments within this priority. Nevertheless, there remain glaring inconsistencies in the EC's attempts to provide a more unified approach to sustainable development. I refer to the contrast between the objectives of the Common Fisheries Policy and the increasing concern for the future of marine habitats and ecosystems in European and adjacent waters. Into this mix of policy and sustainability is introduced the rapidly growing aquaculture industry. Public debate has risen to the extent that in several countries there are currently enquiries and reviews into the future of marine aquaculture. Issues like this require dedicated, visionary research objectives with appropriate funding and coordination to provide the sound principles on which safe, sustainable fisheries policies may be developed. Arguably, Europe can lead the world in integrated marine science and technology research through this approach. At the forthcoming Rio+10 world summit in Johannesburg, the state of the oceans will be a key element for political consideration.

EFMS is an embryonic organization with a bright future. Its voice needs to be heard in the corridors of Brussels, and this publication provides the first tangible evidence of its presence. I would encourage all of you to rally your national marine scientists and technologists, advocate the objectives of the Society, and enjoy the union created by our membership.

With best wishes from myself, and EFMS Vice-Presidents Lucien Laubier and Manos Dassenakis.

Graham Shimmield
EFMS President

Who Owns the Ocean's Resources?

Cornelius Hammer

In 2001, the Directorate General for Fisheries of the European Commission published a 'Green Book', which was an extremely critical analysis of what the Commission's Common Fishery Policy (CFP) had so far achieved, and also of how it intended to proceed. In light of the state of many fish stocks in European waters the achievements do not appear at all impressive, and the EU 'Green Book' agrees with this assessment. One of the conclusions drawn is that any future CFP – details of which need to be formulated and agreed – *must* be much more effective at managing fish stocks in a precautionary context.

It is acknowledged by the Commission that the overcapacity of fishing fleets is about 40%, and cuts need to be drastic. To achieve this, it is intended that, amongst other measures, the fishing effort of the entire European fishing fleet be cut by about 30–60%, depending on the region concerned and the state of the targeted stocks. This would eventually result in a withdrawal of some 8600 vessels, which represent 8.5% of the number of EU fishing vessels and about 350 000 GT or 8.5% in tonnage.

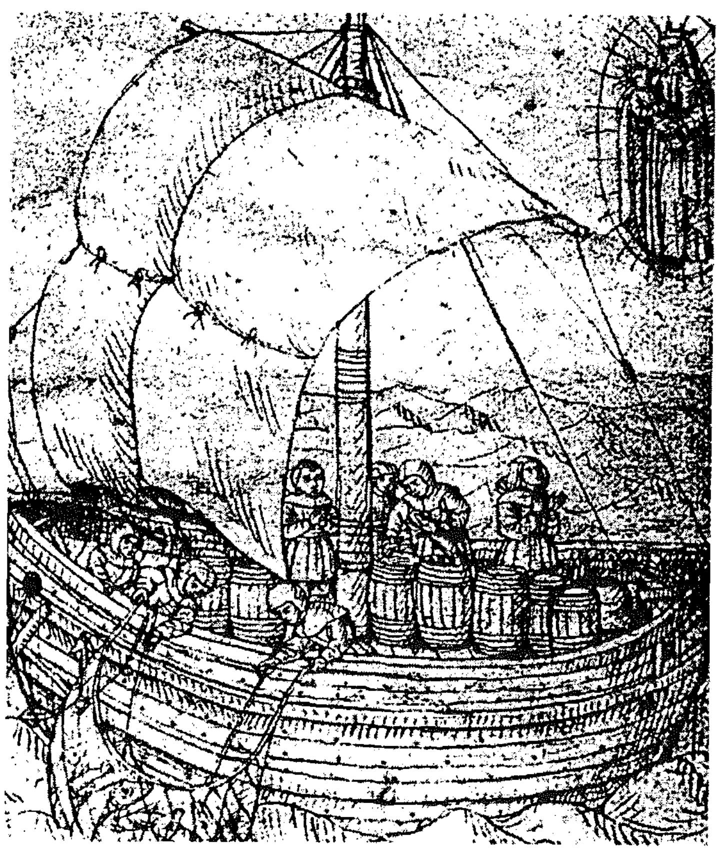
When this proposal became public, the fishing industry reacted less vociferously than expected. The reason may have been that this particular prospect is not new to the fishermen, and also that the fishing industry reluctantly concedes that the overcapacity of the national fleets is detrimental to the development of the stocks and will eventually and inevitably cause their decline.

Individual fishermen would no doubt enthusiastically support the idea of reducing the fleet by 40%, if they were guaranteed that their own vessel would be spared and the burden would be carried by others, preferably by fishermen of other nations, rather than by their neighbour along the jetty. This is the core of the dilemma. Free access to common resources, which in principle means that everyone has the right to harvest the seas, is a paradigm as old as fishing itself and is deeply rooted in the consciousness of fishermen. Throughout the centuries, fishermen have faced the perils of the sea and paid a high price for the fish they took – a hard existence, and in all too many cases, their lives. In other words, even though the resource was accessible to all, it was not free, and harvesting it was anything but easy.

In some Polynesian cultures the fishermen pray to a certain god for permission to go to sea and fish. Although this permission is never denied, and the fish always end up in the net, this ritual is a symptom of a different attitude. Fishermen do not own the resource – they ask for permission to fish, even if only symbolically.

The attitude of European fishermen is different, however. To their way of thinking, there is no problem as long as there is a balance between catch on the one hand and effort on the other. Since the end of the 19th century, however, rapid technological development and mechanization of fishing vessels has disrupted the balance in favour of a tremendous and still ongoing increase in efficiency, and a substantial decrease in perils and hardship encountered. However, the attitudes of fishermen have not changed accordingly. The 'catch as catch can' mentality is fed by the (correct) assumption that if one vessel does not catch the fish, another will, and not even the flood of detailed regulations has changed this attitude.

Fisheries biologists have analyzed the situation and estimated the state of fish stocks throughout the 20th century. Their international organizations have formulated advice for most sensible harvesting strategies of the stocks in the context of precautionary management, and they see themselves as advocates of the voiceless fish. At the same time, non-governmental organizations have accused them of being influenced, or even 'remotely controlled' by the (by no means voiceless) fishing industry. Political bodies translate the scientific advice into legally binding total allowable catches of the stocks (TACs), which are broken down into national quotas. Sometimes the TACs are close to those advised by the fisheries biologists, sometimes not. In most cases, the attitude of the fishing industry towards this is clear: If there is such a thing as depletion of stocks, it is the fault of exploding populations of seals, or other predators, but otherwise there are so many fish in the sea that they practically jump into



In mediaeval times, fishing was so hazardous that fishermen prayed to the Virgin Mary to protect them. Even though the dangers are now greatly reduced, fishermen still feel that they have a right to the rewards of fishing

the boats. Only reluctantly will they admit that the fishery also plays a part in the overall decline of fish stocks.

Of course, this is an oversimplified picture, but it does portray the two extreme positions. Fishermen are not aware that – despite all imperfections – it is only because of 100 years of well organized international co-operation in fisheries biology that there are still any fish left in the sea to exploit. Many fishermen refuse to understand that all the efforts undertaken by national laboratories, including expensive fishery surveys, analyses of samples and statistical evaluation of stock levels, have been made to ensure fishing income for future years. This effectively amounts to an enormous subsidy of approximately 100 million euros per year Europe-wide.

Nonetheless, the underlying – and often barely concealed – hostility of the fishing industry towards science remains. This, however, seems to be not only a result of being unable to adapt to rapid changes in economic and biological circumstances, but also a reaction towards growing demands on marine resources from other industries. There are also increasing demands from biologists and environmentalists to establish extensive Marine Protected Areas (MPAs) for certain species or entire habitats. In many European countries, environmentalists have formed powerful pressure groups, representing a great number of voters. As a result, environmental conservation ranks highly for politicians, and there is growing agreement and understanding that species need protection: whales and dolphins as well as seabirds need prey to forage on, biodiversity needs to be maintained. As a consequence, fishing must be restricted if it imperils environmental goals. Whereas fishermen are still convinced that the fish belong to them and to no-one else, environmentalists are of the opinion that the fish in the sea belong to the natural system. They see themselves as the advocates for all the inarticulate inhabitants of the ecosystem, and feel that it is their role to decide what belongs to the ecosystem and what may be shared with the fishing industry. In more abstract terms, this means that a paradigm shift has occurred (or is in the process of occurring) from a fishery-dominated sea, with more or less badly managed stocks, to an environmentally determined system, where fishing is just one variable amongst many others.

Fontispiece of Mare Librum by Hugo Grotius, published in 1609. Grotius appealed to 'the civilized world' for the complete freedom of the high seas for the innocent use and mutual benefit of all. He could never have foreseen the conflicts facing us in the twenty-first century.

At the same time, new claims on the sea are coming from other industries. While there is some reluctant coexistence between the oil industry and the fishing industry, there is unlikely to be much cooperation when it comes to offshore wind and ocean-current energy parks. Large areas have been claimed for wind generators by the industry in the North and Baltic Seas, and a new wind park is currently being erected off the Danish coast (see pp.40–43). However, it is still not finally decided whether, or to what degree, fishing activities will be prohibited in such areas. In the case of the wind generators, this is an ongoing dispute, and the outcome may be a compromise, but there is no doubt that submerged propellers in 'ocean-current-parks' will be surrounded by a strict ban on all kinds of fishing. The first submerged ocean-current generator is presently being installed in the Channel off the coast of Cornwall.

The paradigm of fisheries science throughout the 60s, 70s and into the 80s was that the annual catch could continually be increased by improvements in catching methods and by developing new fisheries for hitherto unexploited stocks. On the basis of this fundamental assumption, the availability of fish was regulated as if it were a technological question, in the belief that if there were new resources discovered, the fishery would have access to them. Things have now changed. For one thing, it is known for sure that there are no more big resources to be discovered. And even if there were, the question would be raised as to whether other species depended directly on the resource, and how much should be left in the ecosystem to keep it in a healthy and productive state.

In such circumstances, fishermen in many countries are feeling cornered. Having faced a mountain of often incomprehensible regulations on the technological side (often becoming heavily indebted to banks for loans for technological improvement), and having half-heartedly obeyed the TAC restrictions imposed on them, they now find that increasing and widespread demands are being made on the whole ocean, the sea-bed, the water and even the air above.

On top of this, the marine realm is also being claimed by the environmentalists to protect biodiversity. Although this again oversimplifies the situation, it characterizes the impression fishermen these days may have. It shows that there has been a massive change in the overall public perception of the use of the ocean, and that the concept of open access to its resources is an old fashioned and probably out-dated concept.

Cornelius Hammer is the Director of the Institute for Baltic Sea Fisheries (IOR), Rostock, Germany.

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Planning to take an MSc. course in a marine-related area?
See pp.10 and 48.

Interested in antiquarian and second-hand books on marine biology and oceanography?
See advert on p.32.

In need of translation services?
See advert on p.43.

The European Environment Agency

Anita Künitzer

What is the EEA?

The European Environment Agency was established by the European Union in 1990 and became operational in 1994, following a decision to locate it in Copenhagen. Although our name could suggest we that are Europe's equivalent of the US Environmental Protection Agency, with its wide-ranging powers of regulation and enforcement, the EEA – as our mission statement shows – is an actually an information-provider.

In broad terms, the EEA's core task is to provide objective, reliable and comparable information to support the protection and improvement of the environment and the achievement of sustainable development. Our primary target audience is government decision-makers at European and national level, but the Agency's mandate also requires it to ensure the broad dissemination of environmental information to the public, and to maintain a public reference centre of such information.

The EEA is currently unique among the EU agencies in having as members not only EU Member States but any other country that shares its objectives and is able to participate in its activities. The Agency's membership, which previously comprised the 15 EU Member States plus the three other European Economic Area countries (Norway, Iceland and Liechtenstein), grew in 2001 with the addition of 13 countries seeking accession to the EU. This makes us the first EU institution to 'enlarge' to the east and south, making a membership of 31 countries. The four Balkan countries cooperate with the EEA, and membership negotiations with Switzerland and Yugoslavia are also underway (Figure 1).

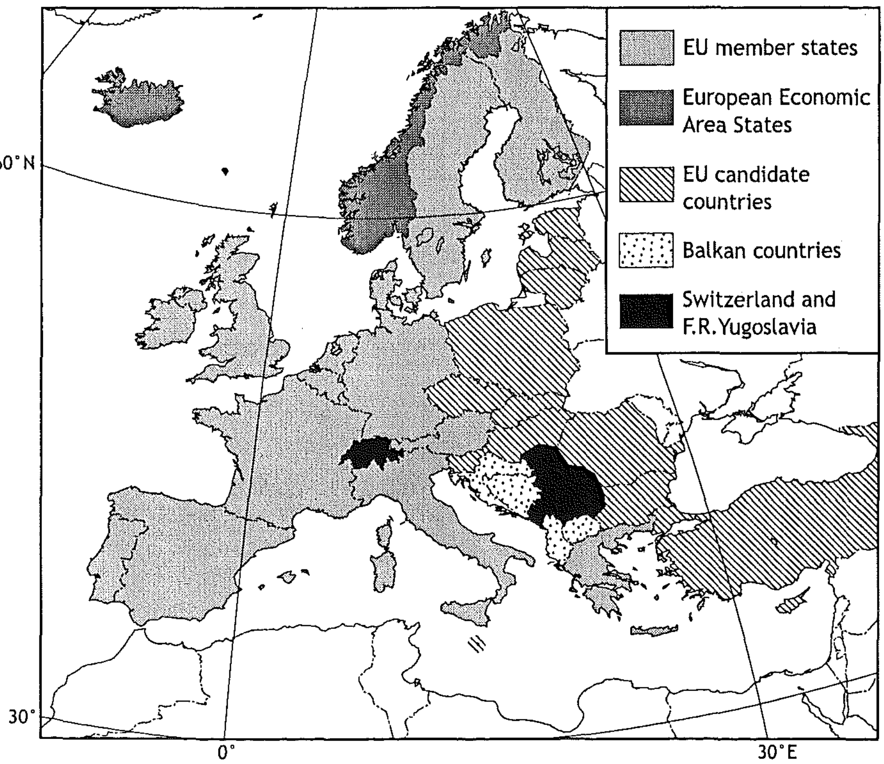
About 80 people work in the EEA headquarters in Copenhagen. The EEA could be compared with the secretariat of a Marine Convention, managing the activities of the Agency and its network, EIONET. Most EEA employees work on short-term contracts and this creates a high turnover rate of staff and an atmosphere like in a university rather than an administration. The Agency organization comprises three operational departments, plus an administration and an IT service unit (Figure 2, overleaf). EEA staff work in cross-cutting teams, which means that staff from different programme areas work together in teams of 5 to 8 members, each focussing on a certain subject or topic. Examples are the teams on Water, on Biodiversity, on particular scenarios, on GIS etc. One of the staff members leads the team. The Executive Director oversees the functioning of the Agency as a whole, and the work of Programme and Project Managers. The Executive Director answers to the Management Board, which is appointed for a four-year term and consists of one representative from each of the 31 member countries, two representatives of the European Commission, and two scientific personnel nominated by the European Parliament. The Scientific Committee, also appointed for a four-year term, advises the Management Board on scientific matters and advises the Director's Office on appointments. In this way, member countries control the EEA via the Management Board; and all major decisions and agreements need approval by the Management Board, which meets three times a year.

> **The EEA Mission Statement**
>
> *'The EEA aims to support sustainable development and to help achieve significant and measurable improvement in Europe's environment, through the provision of timely, targeted, relevant and reliable information to policy-making agents and the public.'*

What is the Environment Information and Observation Network (EIONET)?

The EEA's work is based on the input of the European Environment Information and Observation Network (EIONET). This is an information network of over 600 environmental bodies and agencies, and public and private research centres across Europe. The EEA's role is to help build the network and support it in its work. The major contributors and actors within this network are the five European Topic Centres (ETCs), the National Focal Points (NFPs), and the National Reference Centres (NRCs).

Figure 1 EEA member countries: EU Member States, EU Economic Area countries (Norway, Iceland and Liechtenstein), thirteen EU Candidate countries, and the four Balkan countries. Negotiations are underway with Switzerland and the countries formerly part of Yugoslavia.



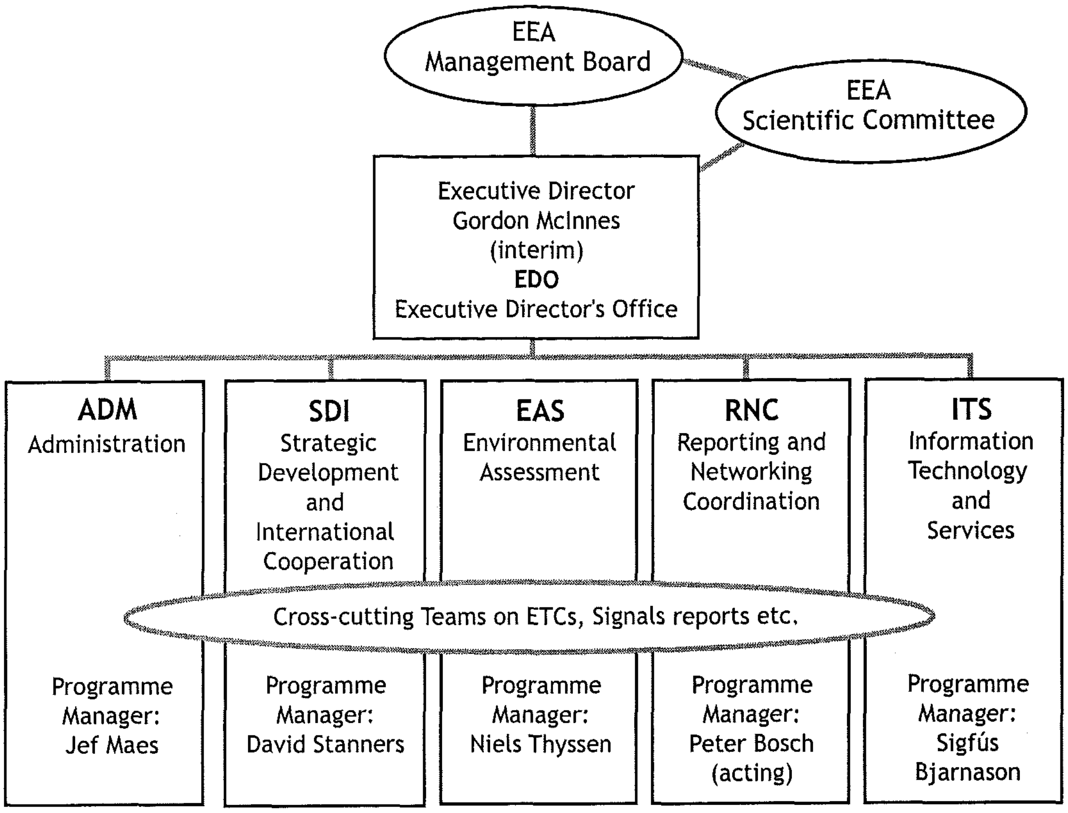


Figure 2 *EEA organizational chart.*

European Topic Centres (ETCs)
ETCs undertake the bulk of the EEA's work in the thematic areas of: water (including seas); air and climate change; nature and biodiversity; waste and material flow; and the terrestrial environment. Each of the five ETCs is a consortium of about 10 European specialist partner organizations from the environmental research and information community, which pools resources in its particular area of expertise. The organizations in the ETC for Water are shown in Box 1.

ETCs collect data from member countries, built databases, develop indicators and assessments and produce draft versions of reports.

National Focal Points (NFPs)
NFPs are people who coordinate EEA activities at national level across all environmental themes and related sectors. They are typically governmental people in ministries or national environment agencies, and have to co-ordinate national interests and data-provision with EEA activities in all fields. Their role is to assist in preparation, implementation and follow-up of the EEA work programme and the development of the EIONET. For example, the NFP of Germany is Barbara Clark and her boss in the Federal Environmental Agency in Berlin, and the NFP of Bulgaria is Svetlana Zhekova in the Ministry of

Box 1: Organizations within the European Topic Centre for Water

Lead organizations

WRc plc, UK Topic Centre Manager, Tim Lack

WRc plc, UK Topic Centre Technical Manger, Steve Nixon

WRc plc, UK Topic Centre Data Manager, Ruth Cullingford

Partner organizations

Austrian Working Group on Water (AWW), Johannes Grath *(Austria)*

Centre for Ecology & Hydrology (CEH) Dick Bradford (*UK)*

Centro de Estudios y Experimentacion de Obras Publicas (CEDEX), Teodoro Estrela (*Spain)*

Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (ENEA), Marcello Peronaci (*Italy)*

Geological Survey of Denmark and Greenland (GEUS), Peter Gravesen *(Denmark)*

Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), Michel Joanny (*France)*

Institute of Meteorology and Water Management (IMGW), Waldemar Jarosinski *(Poland)*

http://water.eionet.eu.int/Consortium/IOW International Office for Water (IOW), Dominique Preux (*France)*

National Centre for Marine Research (NCMR), Argyro Zenetos *(Greece)*

Norwegian Institute for Water Research (NIVA), Kari Nygaard (*Norway)*

National Environmental Research Institute (NERI), Jens Bogestrand (*Denmark)*

http://water.eionet.eu.int/Consortium/VITUKI Vituki Consult Rt, Janos Feher *(Hungary)*

Environment and Water. Increasingly, the 31 NFPs are in touch with the various national elements electronically and are also active in developing information policy. Many NFPs produce reports on their activities, distribute newsletters and offer free access to their national databases. As a group, the NFP/EIONET Group meets three times a year at the EEA in Copenhagen.

National Reference Centres (NRCs)
NRCs are established at national level in various areas of environmental and sectoral activity, usually corresponding to the expertise needed in ETC areas of work. They coordinate national topic-specific data and information flow to the EEA, check the quality of national data and of data products produced by ETCs, such as indicators (explained later) and assessment reports. In the Thematic Topic Area of Water, NRCs have been nominated for the following areas: river quality, lake quality, groundwater quality, coastal water quality, marine water quality, water quantity and use, water emissions, hydrobiology, marine biology, fisheries, and Integrated Coastal Zone Management. Some countries have nominated a different person for each area, others have nominated fewer experts who cover a wider range of topics. If you are interested in getting involved with EEA work, please contact your national NRC. The web address list is constantly being updated.

What does the EEA report on?

The EEA distributes information about developments in environmental issues and sectoral activities in relation to environmental integration. The following environmental issues are addressed: air quality, acidification, biodiversity change, chemicals, climate change, human health, natural resources, noise, waste, nature, soil, water, coasts and seas, the urban environment. The following sectors are addressed: agriculture, energy, fisheries, households, industry, population, tourism and transport.

The activities of the EEA relating to these issues and sectors are specified in the **Annual Work Programme**. This includes everything from monitoring, data-collection, development of databases and their web publication, to data analysis and presentation of data as indicators and maps, production of assessments, and publication of reports, both printed and on the web.

The major **reports** produced by the EEA are:

1. State and Outlook Reports, published every five years, covering all environmental issues and having a focus on integrated environmental assessments and scenarios (*see reference* EEA (1998) *at the end*).

2. Environmental Signals Reports, published on an annual basis, covering all environmental issues and being indicator-based (*references* EEA, (2002c); EEA (2001c)).

3. Sector and environment integration reports, on an annual or biannual basis, focussing on an indicator for one specific sector. Already published are reports are on transport, *TERM* (EEA (2001b)) and on energy, *EERM* (EEA (2002a)). There are plans for reports on agriculture *(AERM)*, on tourism *(TouERM)*, and probably in future, fisheries *(FERM)*.

4. Environmental issue reports, published on an irregular basis, e.g. *Europe's Biodiversity* (EEA (2002b)), *Eutrophication in Europe's Coastal Waters* (EEA (2001a)), *State and Pressures of the Marine and Coastal Mediterranean Environment* (EEA (1999) or the planned *Water Indicator Report*.

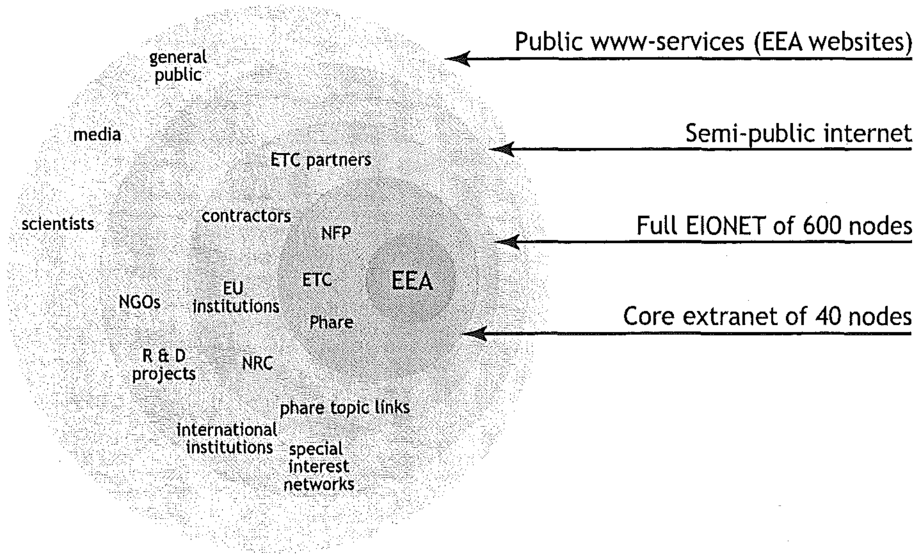
5. Pan-European assessments like the *Dobris Assessment* (EEA (1995)) and the *Kiev Report* for 2003, which is currently being compiled.

Besides these major reports, the EEA is producing several more technical and detailed reports in the series of *EEA Topic Reports* and *EEA Technical Reports*, all of which can be downloaded from the web.

As basis for these reports, the EEA is producing **indicators**. These are graphs or maps showing information about trends over time, at aggregated European level and at inter-country comparison level. They are grouped into Driving Force indicators, Pressure indicators, State indicators, Impact indicators and Response indicators (these are thought of as a 'DPSIR' chain). The data for the maps and figures are collected from international organizations such as Eurostat, FAO, Marine Conventions, etc., or from EEA member countries, through regular annual data submissions according to agreed formats and guidelines. The indicators are presented in factsheets, which contain the graph or map, the policy relevance of the indicator, its environmental relevance, an assessment of the information, a judgement of the quality of the data, and the key message coming out of the assessment. These indicator factsheets are published on the web and updated annually. Starting this year, they will form the basis for all EEA reports.

The **data** collected from member countries are stored in working databases, which are maintained by partner organizations of the ETCs. The various national formats and units of these data are harmonized before they are published on the web. Access to the data used for indicators is in the process of development, and at present access is available for air quality ('airbase'), air emission, waste ('wastebase') and nature data (EUNIS). Access to water data ('waterbase') is under development, and datasets on rivers, lakes and groundwater will be available through the EEA data service by the end of this year.

Zones of the EIONET Telematics Network.



Datasets on transitional, coastal and marine waters, water quantity and emissions will follow next year. Visualization tools for the content of the databases are under development, and for the 'wastebase' data, GIS maps can already be produced online.

What is the EEA doing on Water and Seas?

The EEA has a topic team on Water with eight staff members, which I lead. It deals with all waters, inland and marine, and I am also responsible for fisheries and marine biodiversity. The topic team comprises project managers in the following areas of expertise: marine and coastal environments, inland waters, agriculture, emissions, reporting, integrated environmental assessment and data. This team defines the activities relating to water, ensuring the link to the longer-term work programme of the EEA, keeping in contact with the European Commission in connection with activities like the Water Framework Directive, networking with countries, and Marine Conventions, and linking to other activities in the EEA such as scenario development etc. The team leader is responsible for the work programme of the European Topic Centre on Water (ETC/WTR), which is defined in a so-called Technical Annex every year and is the basis for the annual subvention from the EEA to ETC/WTR under a three-year agreement with the consortium. The annual subvention of about 1000 kEuro is split among the different partners depending on their tasks.

Some marine activities are also undertaken by other ETCs:

- The ETC for Nature Protection and Biodiversity (ETC/NPB) is developing indicators for coastal and marine ecosystems, which are related to habitats, larger species and nature protection. The EUNIS habitat classification also covers coastal and marine habitats. This year, a special workshop will be held jointly with ICES, HELCOM and Baltic Marine Biologists to further develop the habitat classification for the Baltic Sea. The EUNIS species inventory includes larger marine species.
- The ETC on Air and Climate change (ETC/ACC) is developing indicators on climate change in relation to the marine environment. Indicators on atmospheric deposition of nitrogen and hazardous substances are also relevant for the seas.

It is difficult to include research in EEA activity on indicator development. I have been invited to several presentations of DG Research-funded projects on clusters, such as IMPACT, ELOISE and the BIOMARE COST activity, and have established useful contacts. Few research projects provide European-wide results and/or long time-series. But this is just what we need for our reports: maps of the whole of Europe, or time trends for the whole of Europe's seas.

The EEA urgently needs integrated environmental models, which combine sector or socio-economic development with environmental changes. The development of the agricultural sector, and scenarios on emissions from that sector in relation to the development of eutrophication in inland waters and coastal waters, are needed urgently. Scenarios on the fisheries sector under the new fisheries policy, and developments in fish stocks and the marine ecosystem would be another challenging area of research and development. Models of such scenarios could be run and kept operational by universities or research institutes, while the EEA, Eurostat, FAO, ICES or the European Commission could provide the data for such quantitative models. The upcoming *State and Outlook report 2004/5* will focus on scenarios. For water and fisheries we are considering scenarios on water quantity, eutrophication and organic pollution, hazardous substances, and fish stocks. A first 'scoping' study on available models has been compiled by ETC/WTR (as an internal document). There is obviously a need for more quantitative models based on the data EEA are collecting for its set of indicators, and for linking environmental and socio-economic models. We will specify our needs in the Water area more fully during coming weeks by linking to scenario development in the Air topic. This will enable us to define our research needs more clearly.

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EEA organization
http://org.eea.eu.int/organisation/

European Environment Information and Observation Network (EIONET)
http://eionet.eu.int/

European Topic Centres (ETCs)
http://eionet.eu.int/Topic_Areas/New_Topic_Centres

National Focal Points (NFPs)
http://eea.eionet.eu.int:8980/Members/irc/eionet-circle/Home/central_dir_admin?fn=roles&v=eionet-nfp&rd=1&ud=1&od=1

National Reference Centres (NRCs)
http://eea.eionet.eu.int:8980/Public/irc/eionet-circle/Home/central_dir_admin?fn=roles&v=eionet-nrc&rd=1&ud=1&od=1

EEA reports can be downloaded from: http://reports.eea.eu.int/

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Envisat

A new marine environmental satellite that observes the ocean from all perspectives

Samantha Lavender and Jim Aiken

The first images of the ocean seen from space were obtained through hand-held cameras on the manned space missions in the 1960s. These stunning photographs clearly demonstrated the potential of satellites for monitoring suspended sediment along coasts, and colour variations due to phytoplankton. Satellite monitoring was made possible by the Earth Resources Technology Satellite (later renamed *Landsat*), and the first dedicated marine sensor was the Coastal Zone Color Scanner (CZCS), launched in October 1978.

On 1 March 2002, a major new environmental satellite, *Envisat*, was launched onboard the Ariane 5 rocket by the European Space Agency (ESA). *Envisat*, which weighs 8200 kg and is as big as a bus, carries a suite of ten instruments:

- Advanced along-track scanning radiometer (AATSR).
- Advanced synthetic aperture radar (ASAR).
- Doppler orbitography and radio positioning integrated by Satellite (DORIS).
- Global ozone monitoring by occultation of stars (GOMOS).
- Laser retro-reflector (LRR).
- Medium-resolution imaging spectrometer (MERIS) (cf. Figure 1).
- Michelson interferometer for passive atmospheric sounding (MIPAS).
- Microwave radiometer (MWR).
- Radar altimeter (RA-2).
- Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY).

For marine scientists, MERIS, AATSR, ASAR and RA-2 will measure the ocean's colour, sea-surface temperature, roughness and height, respectively. No other satellite combines all the instruments on one platform, and together, they will provide scientists with a new and exciting dataset.

Figure 1 shows a preliminary uncorrected MERIS image of Sicily, taken on 21 March 2002, that highlights the sensor's potential for monitoring the ocean. MERIS has 15 wavebands in the visible and near-infra-red. The level 2 processing (atmospheric correction of the top of atmosphere radiances and application of models/ algorithms) will provide a combined dataset of water, land and atmospheric products where the pixels have been classified prior to the level 2 processing. Over the water, this will include the water-leaving reflectance in 13 wavebands, chlorophyll concentration, sediment-specific backscattering, and absorption due to Coloured Dissolved Organic Matter (CDOM). It will have a spatial resolution of 300 m for coastal areas and a reduced resolution of 1.2 km over the open ocean, and will provide a global coverage every 2–3 days.

The sensors are currently undergoing a 6-month commissioning phase and the first data will be released to the community in October 2002. The conditions of data distribution for *Envisat* data are directly related to Category use as defined by the *Envisat* Data Policy. For this purpose two different categories of use have been defined:

- Category 1: Research and applications development in support of the mission objectives, including research on long-term issues of Earth System science, research and development in preparation for future operational use, certification of receiving stations as part of the ESA functions, and ESA internal use.
- Category 2: All other uses, including operational and commercial use.

Researchers can submit Category 1 proposal submissions at any time, see ESA Earth Observation (EO) Exploitation Projects website in the further reading below.

The data from *Envisat* will be used together with ocean colour imagery from satellite sensors such as the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), operational since September 1997, and Moderate Resolution Imaging Spectrometer (MODIS), which was launched on the *Terra* satellite in December 1999 and *Aqua* satellite in May 2002. The combined dataset will be used to answer fundamental questions about how the growth of phytoplankton in response to physical and chemical factors is changing globally on short (annual) and long-term (>5 year) scales.

Figure 1 *Uncorrected MERIS image of south-eastern Sicily taken on 21 March 2002. The image shows suspended material produced by coastal erosion being carried along the coast, and forming plumes in the direction of prevailing current flow. MERIS has been designed to look at colour in the oceans and coastal waters, and can produce 300 m resolution imagery from 15 spectral bands.*
© ESA.

The Envisat website is at http://envisat.esa.int/ and the ESA EO Exploitation Projects website is at http://projects.esa-ao.org/

See also the MERIS Special Issue of the *International Journal of Remote Sensing*, **20**, No.9 (15 June 1999).

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Samantha Lavender is a Lecturer with the Institute of Marine Studies at the University of Plymouth, and runs the CSMS Ocean Colour SIG: http://www.ims.plymouth.ac.uk/geomatics/csms_ocolour/index.html
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ERASMUS: Joint Masters in Water and Coastal Management

ERASMUS is the European Community programme in the field of higher education. It supports student and lecturer exchanges, joint development of study programmes, dissemination and implementation of results of CD projects, thematic networks between departments/faculties across Europe, language courses and intensive programmes, and the European credit transfer system.

A recent call (15 June) for proposals for Joint Masters Programmes resulted in the selection of a Joint Masters Network Programme in Water and Coastal Management. The proposal was selected for presentation at the European Universities Association in Brussels in September. The Masters is designed to train managers for the Water Framework Directive and implementation of Integrated Coastal Zone Management (ICZM). It is based on an existing and expanding network of bilateral agreements in oceanography between 17 universities in 12 countries. Students will register with a home university that is part of the network (maximum of five per institution, at present), and will attend a short course (October to December) on the Water Framework Directive and ICZM in their country of origin. In the case of land-locked countries, the focus will be on lake/freshwater resources management. There will be limited provision for students from countries not at present represented in the network, but it is the aim of the network eventually to include members from all EU countries (including candidate countries).

After the end-of-year break, the students will travel to the host university chosen for that year (this will rotate through the members). Students will attend modules of lectures contributed by guest speakers from the European Union Directorate, the European Environment Agency and the Joint Research Council, as well as by lecturers from member universities.

The exact content of the modules will evolve according to the changing needs of the EU Water Framework Directive and implementation of ICZM. The relationship with the European Union Directorate, the European Environment Agency, the JRC, and the European Association for Environmental Management Education (EAEME) will be especially important to ensure that the Masters programme is up-to-date.

Assessment will be through continual assessment of submitted work, and presentations by the students on topics set by the lecturers. The first assessment will be a presentation of an aspect of water and/or coastal management from the student's country of origin, thus allowing the students to get to know one another, and learn about the problems faced in other member countries, at the start of the course.

Students will participate in research projects supervised by a lecturer from a third country (neither country of origin nor host country). Participating universities will be asked to provide the same number of possible research projects as there are students registered with that university as part of the network (maximum of five per institution, at present). In this way, there will be the same number of research projects as there are students. Universities will be asked to involve students in EU-funded projects whenever possible.

One of the aims of the Joint Masters is to promote better cross-cultural understanding. The host university will be encouraged to provide basic language training in the language(s) of the host country as well as a short socio-cultural course. Universities providing this kind of course will be chosen preferentially as host universities. Students will be encouraged to use materials in different languages and submit reports or make presentations in a language other than their own.

Lecturers will also be encouraged to provide material in more than one language. The possibility of supplying translation services at each successive host university is being investigated, with the aim of producing a fully multilingual website by the end of the project. At present, the limitation appears to be the need for updating the material in different languages, but funding opportunities are being explored.

The network is actively seeking partners with expertise in distance learning techniques. Students will also be provided with notes and study material through the internet, and will be encouraged to use internet sources.

Objectives include a diploma issued by the EAEME and endorsed by all participating universities, as well as participation in the existing European thematic network, ETNET.

For information on the Masters or on joining the network, contact Alice Newton (anewton@ualg.pt).

For information on ERASMUS consult: http://europa.eu.int/comm/education/erasmus.html

For further information on the European Universities Association consult: http://www.unige.ch/eua/

For further information on EAEME consult: http://hosting.jrc.cec.eu.int/asso-eaeme/

For further information on ETNET consult: http://etnet.vub.ac.be/etnet21.asp

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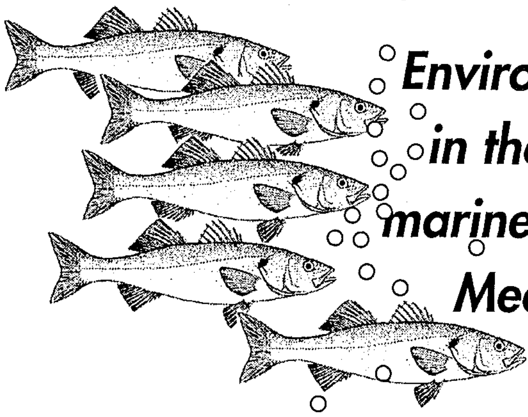
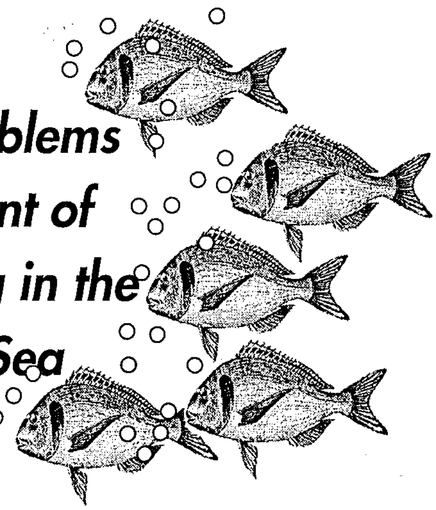


Environmental problems in the development of marine fish-farming in the Mediterranean Sea



Christos Belias and Manos Dassenakis

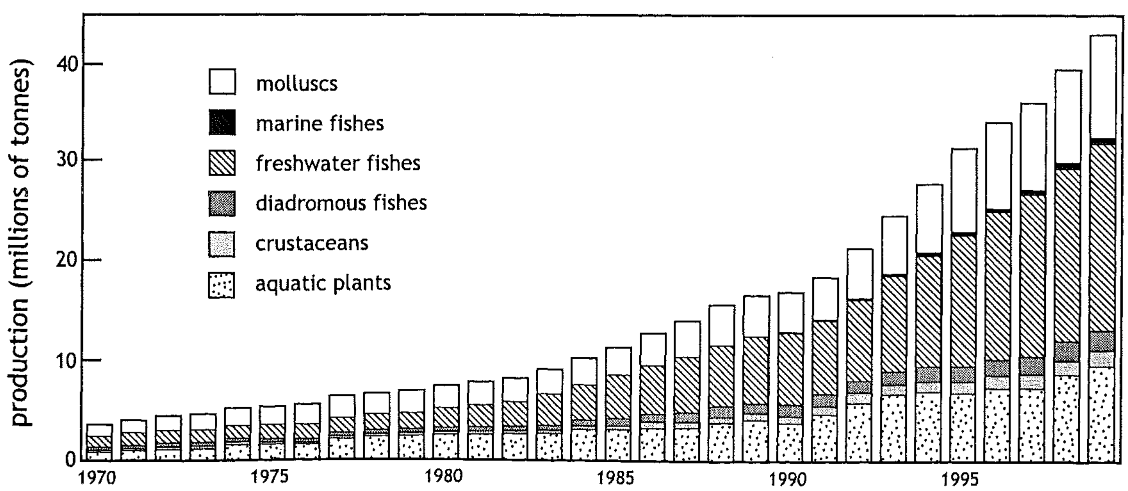
Aquaculture – the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants – has great potential for the production of food, alleviation of poverty and generation of wealth for people living in coastal areas. Worldwide, aquaculture production is growing at more than 10% per year (Figure 1), compared with 3% for terrestrial livestock and 1.5% for capture fisheries. This growth is expected to continue. The rapid growth of aquaculture in recent years has been consistent across sub-sectors, from low-input systems generating low-value products, to medium- and high-value products for national and international markets, which are important for improved living standards. A wide range of diverse coastal aquaculture systems has developed at different intensities and varying scales of production. The great diversity of the sector encompasses enterprises ranging from very small-scale to very large-scale, suggesting that aquaculture can contribute significantly to a wide range of development needs.

However, coastal aquaculture projects have faced significant difficulties, including unsuccessful development, marketing problems, social problems, diseases and vulnerability to poor water quality, as well as aquatic pollution caused by industrial, domestic, agricultural and aquacultural wastes. Aquaculture may also add to the many other development pressures on the coastal zone. These cumulative and additive problems can only be addressed through better planning and management of the sector in collaboration with producer associations or industry organizations. In practice, these aims are unlikely to be achieved without effective integration with planning and management of other sectors. The use of Integrated Coastal Management methodology is necessary for sustainability in areas with aquaculture.

Aquaculture development in the Mediterranean

During the period of development of intensive marine aquaculture, the rapid evolution of aquaculture technologies has been helped by government policies of pushing aquaculture development as a way of reducing the gap between supply and demand for fisheries products. Also, because farmed fish are high-value species, the prospect of large profits has

Figure 1 *Global aquaculture trends since 1970. (Diadromous fish are those that migrate between fresh and salt water.)*



Farming of marine fish is still a small part of global aquaculture, but is increasing along with other sectors

In the Mediterranean, the production of farmed marine fish has been growing by nearly 30% per year

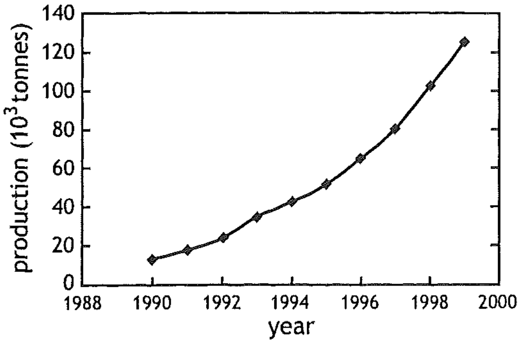


Figure 2 *Total fish-farming production in the Mediterranean Sea.*

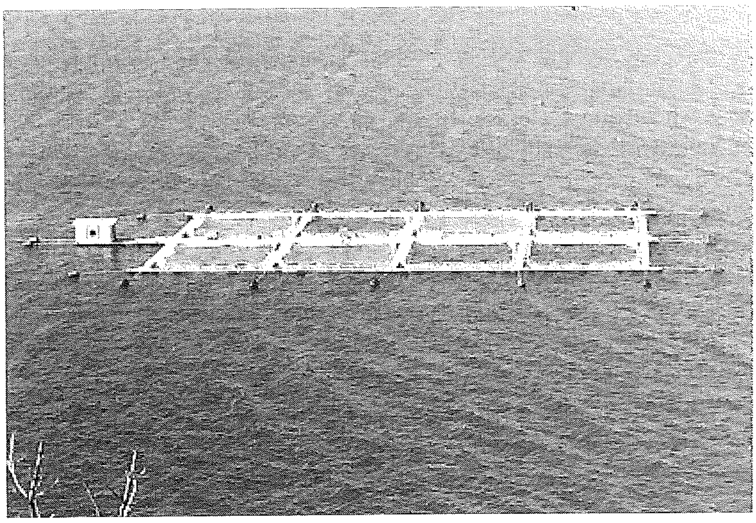


Figure 3 *Typical fish cages off the Mediterranean coast.*

Two species dominate marine fish-farming in the Mediterranean

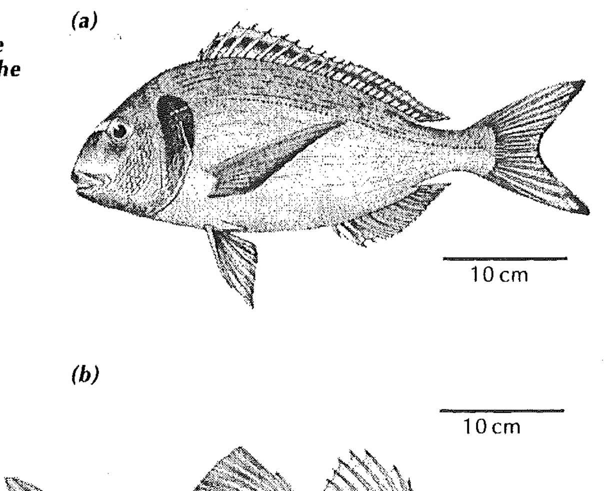


Figure 4(a) *Gilthead seabream (*Sparus aurata*) and **(b)** European seabass (*Dicentrarchus labrax*).*

attracted investors. In the Mediterranean region over the last decade, the marine fish-farming sector of aquaculture has shown a potential growth of around 29% per year, reaching 124 000 tonnes in 1999, which is nearly ten times more than the 1990 value of 12 500 tonnes (Figure 2).

For a many years, marine fish rearing in the Mediterranean region was exclusively based on collection of wild juveniles from the sea. This has been practiced in various extensive culture systems, taking advantage of the natural migration of juveniles from the sea into coastal lagoons to feed. The fish are trapped in the lagoons by placing fish barriers along the channels that link the lagoons to the sea. The special design of these barriers allows fish to enter the lagoon but impedes their reverse migration to the sea. This culture system requires highly skilled personnel for lagoon management, and an intensive use of juveniles from the sea. During recent decades, wild fry stocks have drastically decreased for several reasons: over-fishing, change of coastal environmental conditions, and pollution of freshwater sources flowing into the sea.

Marine aquaculture involves two separate phases. The first is the growth of fish larvae in hatcheries near the coast. The larvae are kept in tanks under controlled conditions and fed with phytoplankton until they have attained the proper length to be transferred to cages in the sea (Figure 3). The first hatcheries had to deal with a number of problems, including determining adequate larval diets, the setting up of mass culture units for synchronized production of live feed, the training of specialized personnel, and the control of diseases and of larval quality. Optimization and control of the major environmental parameters were among the early improvements. Studies of early larval stages have been carried out to determine the effects of different temperatures and salinities, dissolved oxygen requirements, and preferred levels of light intensity and photoperiod.

The hatchery is proportionately the most expensive component of a marine fish farm. Hatcheries (using eggs from farmed fish) are usually integrated in the production cycle of marine fish farms, but they also exist as economically viable autonomous entities. Production targets in the hatcheries are now established according to the needs of the associated farm or farms. More than a hundred breeding centres are distributed around the coasts of Cyprus, France, Greece, Israel, Italy, Malta, Morocco, Spain, Tunisia, Turkey and Croatia.

Large-scale production of gilthead seabream juveniles was achieved in 1988–89 in Spain, Italy and Greece. This success largely determined the model for modern intensive marine fish-farming in the Mediterranean. Gilthead seabream (*Sparus aurata*) (Figure 4(a)) and European seabass (*Dicentrarchus labrax*) (Figure 4(b)) are now the two most important species produced in the Mediterranean in intensive farming conditions (Figure 5). Both species are carnivorous. Their life-cycle from larvae (2 g) to harvestable size (about 350 g) takes 14–18 months for gilthead seabream, and 18–24 months for European seabass. At present, seabream is still farmed under both intensive and extensive conditions, while seabass is mainly produced in intensive farms, because of its strong predatory behaviour. In 1999, these two species represented 92% of the value of the entire fish production from marine areas in the region (50% and 42% respectively), together reaching 115 500 tonnes. In economic terms, in 1998 these two species contributed more than US$ 330 million and US$ 324 million, respectively.

Over the last decade, many attempts have been made to cultivate new species. Sharpsnout seabream (*Puntazzo puntazzo*) in Greece, Cyprus and Italy, white seabream (*Diplotus sargus*) in Greece and France, and flathead grey mullet (*Mugil cefalus*) in Greece, Israel and Cyprus, have all produced promising results and are now raised by farming. In Egypt, flathead grey mullet has experienced a faster growth than seabass and gilthead seabream. Several other interesting species have also recently been considered, including the thinlip grey mullet (*Liza ramada*) in Tunisia, the common dentex (*Dentex dentex*) in Spain, and the shi drum (*Umbrina cirrosa*). In contrast, efforts to develop farming of common two-banded seabream (*Diplotus vulgaris*) in Turkey, red seabream (*Crysophrys major*) in Italy and Croatia, striped seabream (*Lithognathus mormyrus*) and sole (*Solea vulgaris*), have been abandoned.

It is obvious from Figure 5 that production of all other species is still very low in comparison with those of gilthead seabream and seabass, and efforts to improve the diversity of farmed species have not had the expected results. Although a considerable decrease in price (due to the fast growth in production) was observed for the two major species, no real alternative has been found. Many of the efforts for new species are focussed on sparid species (i.e. types of bream) and it is doubtful whether these could be considered real replacements from a marketing point of view. The problems that have not allowed any significant introduction of new species into aquaculture production are both biological and economic. The biological reasons relate to the life-cycle of the new species, their environmental needs, the rates at which they grow, the production of their food, their susceptibility to diseases, etc. The economic reasons relate to the total cost of production (including research and advertisement) and the pricing of the new species.

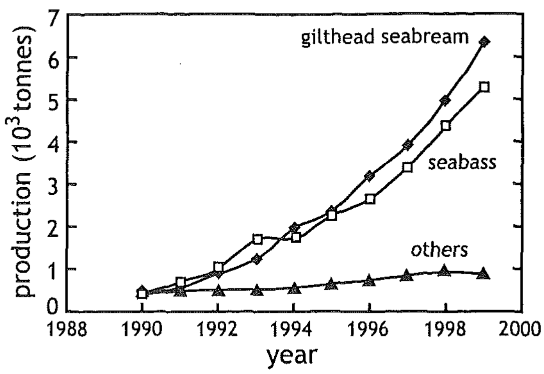
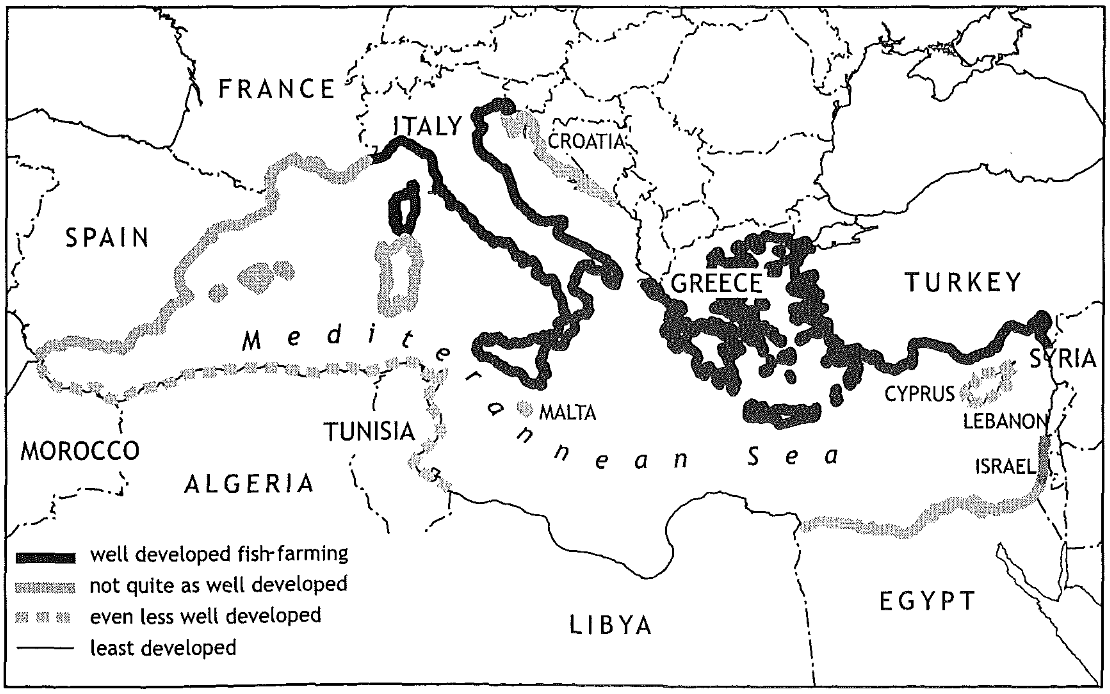


Figure 5 *Growth in production of gilthead bream, European seabass and other species by intensive aquaculture, since 1990.*

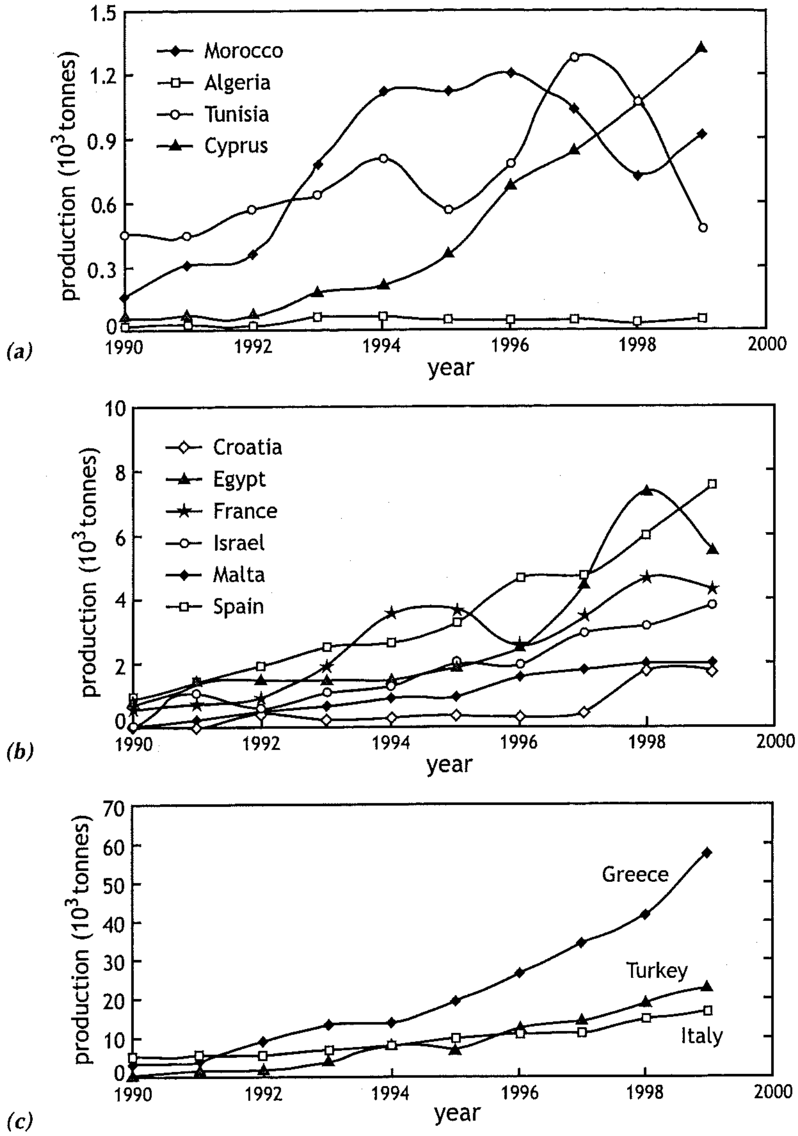
While cage farming of gilthead bream and sea bass have grown dramatically, production of other marine fish has remained relatively constant

Marine fish farms are located all around the Mediterranean Sea (Figure 6). In alphabetical order, countries that report fish-farming production are: Algeria, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Morocco, Spain, Syria, Tunisia, and Turkey. As far as their annual production is

Figure 6 *Degree of development of fish-farming by country, around the Mediterranean.*



Marine fish-farming is best developed around the eastern Mediterranean and Italy



Greece, Italy and Turkey together produce 78% of the fish intensively farmed in the Mediterranean

Figure 7 Trends in intensive fish-farming in the Mediterranean: ***(a)*** *for those countries each producing less than 1500 tonnes annually,* ***(b)*** *for those countries producing between 1500 and 10 000 tonnes annually, and* ***(c)*** *for Greece, Italy and Turkey, which each produce more than 10 000 tonnes, about 78% per cent of the total.*

concerned, these countries fall into four different groups. The first group did not begin reporting production until 1999, and includes Lebanon, Libya and Syria. The second group (Figure 7(a)) contributes a limited amount (less than 1500 tonnes per country) and includes Algeria, Cyprus, Morocco and Tunisia. As shown in Figure 7(a), significant fluctuations are observed in the production by Morocco and Tunisia, whereas the production by Algeria remains low. The production by Cyprus has shown fast steady growth over the last decade.

The third group includes Croatia, Egypt, France, Israel, Malta and Spain, which have all production between 1500 and 10 000 tonnes per year. As shown in Figure 7(b), there is an increasing trend in all cases, which is most marked for Egypt and Spain. The fourth group includes Greece, Italy and Turkey, which have had impressive growth rates over the last few years, with annual productions of over 10 000 tonnes. In 1999, Greece contributed almost half the production (46%) of marine fish-farming in the Mediterranean (with 269 units), while Italy contributed 13% and Turkey 19% (Figure 7(c)).

Environmental problems

The rapid and impressive development of aquaculture, mainly in the eastern Mediterranean, was not fully planned in terms of the sites selected, and development was not followed up with rigorous environmental monitoring. As a result, conflicts were created between the fast-growing aquaculture industry and other users of aquatic resources, generating a considerable degree of public concern about the potential effects of fish-farming on the environment and the way in which the industry is regulated and monitored.

The main conflict is between fish-farmers and operators of tourist activities (hotels, rooms for rent, restaurants, marinas etc.). It is well known that in most Mediterranean coastal areas income from tourism is very important for the local population. Most people in these areas are afraid that the establishment of fish cages near the coast and the possible influence on water quality, as well as on the beauty of the coast, will reduce the amount of tourism and hence their profit. Another conflict is between fish-farmers and coastal fishermen, who blame aquaculture for reducing their catches through the pollution they cause. On the other hand, fish-farmers blame the authorities of coastal cities for not controlling pollution that affects fish in cages, and also cannot prevent marine accidents or oil spills which may harm aquaculture. Although arguments on both sides may not be at all strong, the existing mistrust hinders efforts for sustainability through the amicable coexistence of various coastal activities.

The main consequences of fish-farming for the marine environment are physical, chemical and ecological: they include the dispersal of various substances (mainly nutrients and organic carbon) in seawater, their dilution, degradation, adsorption in sediments, and their assimilation by plants and animals. There is established knowledge about the environmental effects of feeding fish and the operation of fish farms in the marine environment of the countries of northern Europe. However, information relating to the consequences of fish-farming in the Mediterranean, which is characterized by higher salinity and temperature, lower eutrophic levels and different coastal activities, has only begun to emerge in the last five years.

Determining the environmental capacity of coastal areas, that is, the ability of the environment to accommodate a particular activity without unacceptable impact, has required a major effort. In practice, and in relation to aquaculture, 'environmental capacity' may be interpreted as the rate at which nutrients can be added to the water column without triggering eutrophication, or at which organic material can be supplied to the benthos without major disruption of natural benthic processes.

Currently, a significant effort is being made to estimate of the amounts of organic carbon, nitrogen and phosphorus entering the sea from aquaculture operations. Although this input is small compared with the total anthropogenic waste production in Mediterranean coastal waters – only at about 0.3–1% for nitrogen and 0.4–1.4% for phosphorus – locally the effects can be dangerous. In many cases, a significant increase in the concentrations of phosphates, ammonium and organic carbon has been observed near fish cages, but for the time being *no serious eutrophication incidents* have been reported, probably due to the relatively low background nutrient levels in the Mediterranean. The lack of adequate knowledge about the environmental capacity of coastal waters, combined with the increase in the number of fish farms, means that any predictions will be unreliable.

The primary undesirable effects of fish-farming on the marine environment are well known, and consist of the addition of organic matter via food remains and the metabolic products of the fish. Part of the organic particulate material contributes to the enrichment of dissolved and particulate organic carbon in the water column, but most of it accumulates under the cages. It leads to the formation of a loose flocculent black sediment layer that covers the sea bed (Figure 8), and varies in thickness and composition according to the distance from the cages, the season and the local currents. This marked enrichment of the sediment in organic matter results in the creation of anoxic conditions in near-bottom seawater that lead to the formation of substances like methane, ammonia and hydrogen sulfide, with devastating consequences for the benthic fauna. The problems are most serious in the case of small enclosed bays without adequate water renewal. Moreover this 'fish farm sediment' constitutes a secondary source of pollution via a continuous release of nutrients and dangerous compounds, even long after the removal of the fish farm.

An interesting study relating to the recovery of the benthic system after the cessation of fish-farming, involved a *Posidonia* (seagrass) meadow that had been badly affected by excessive growth of phytoplankton, which reduced the light available for the seagrass. This meadow took about three years to recover after the cessation of the fish-farming operation.

Another interesting phenomenon associated with 'fish farm sediment' is significantly elevated concentrations of non-lattice-held heavy metals, such as Cd, Fe, Cu and Zn. This seems to be largely connected to the trace elements present in the fish food. The increased mobility of these metals through the food chain may be dangerous for the whole ecosystem. Other toxic substances produced by the operation of fish farms are antifouling paints and petroleum hydrocarbons from the vessels used on the farm, and drugs used against fish diseases.

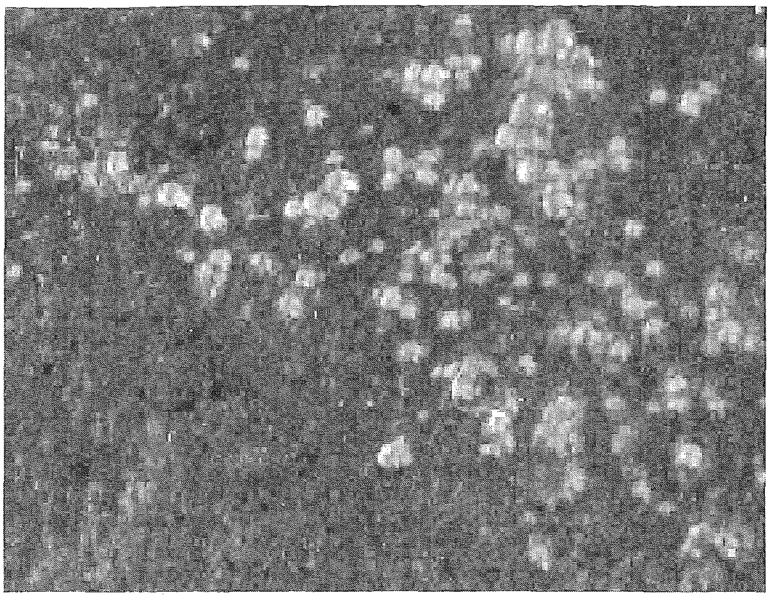


Figure 8 *Example of the flocculent black sediment that accumulates under fish cages.*

'Fish farm sediment' can be a secondary source of pollution long after the fish farm has stopped operating

Moving towards sustainable coastal aquaculture

The main cause for concern in the Mediterranean region is the over-rapid development of the fish-farming sector. Coastal aquaculture has brought significant benefits to both national economies and coastal inhabitants, but is vulnerable to pollution caused by other sources, and if poorly designed or managed it may cause:

- Environmental problems, such as overwhelming of the ecosystem's natural carrying capacity, loss of natural habitat, pollution of local waters, and spread of disease into wild fish populations.
- Social problems, such as nuisance in tourist areas, and disputes with local fishermen.
- Marketing problems, such as low market value due to excessive supply.

The rationale for a more integrated approach to aquaculture development is powerful. Basic criteria for economic and ecological success of best management practice are:

- High survival rate of the farmed fish.
- Low FCR (feed conversion ratio).
- Low waste-discharge into the wider environment.
- High rate of return or profitability.

Crucial elements in a more planned approach include:

- Improvements in design, technology, and monitoring at the farm level.
- Better location and spatial distribution of fish farms.
- Better water supply.
- Better management of fish health, including disease and stock control.
- Improved communication and information exchange between fish farm operators.

• Improved access to markets and better trade opportunities.

• A more equitable distribution of the benefits derived from the development of aquaculture.

The successful co-existence of increased fish production from coastal aquaculture and a high quality neighbouring marine environment will be hard to achieve, but it is vital for the Mediterranean. It requires collaboration between scientists, citizens, institutions, local authorities, NGOs etc. As their contribution, marine scientists must participate in relevant research, monitoring and management. Without scientific guidance, success will be impossible.

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Sessile benthic invertebrates as indicators of climate change

– mass mortalities in the north-west Mediterranean in summer 1999

Joaquin Garrabou, Lucien Laubier and Thierry Pérez

Biogeography, the study of the distribution of animals and plants, has for some time been considered a useful tool for the study of long time-scale climatic changes. For instance, to monitor temperature changes precisely, it is necessary to know the upper and lower limits that a particular animal can tolerate. Natural events may help us to determine those limits. This was the case during summer 1999 in the north-western Mediterranean: a mass mortality of large sessile invertebrates living on rocky substrates and coralligenous assemblages was recorded along the Ligurian and Provence coasts of Italy and France respectively. In the Marseilles–Port-Cros area, available data showed that a temperature increase of up to 5 °C occurred in the topmost 40 m over periods of at least a month (August or September). High temperatures lasting for such a long period could well have produced physiological stresses in sessile invertebrates and led to their death, associated with proliferation of opportunistic microorganisms (protozoans, fungi, etc.).

The geographical distribution of living organisms ultimately depends upon their adaptation to climatic conditions. Gradual change in climatic conditions will induce a corresponding drift in an organism's distribution, while dramatic climatic change can lead to their dying out. For a given ecological factor, the range of tolerance varies according to each species, its evolutionary history, and its origin.

As far as temperature is concerned, a number of physiological mechanisms are controlled by a combination of both the actual temperature value and the exposure time. Slight changes in seawater temperature can generate considerable drift in the distribution of mobile marine species. In the Mediterranean, a number of observations have been made of this phenomenon. For example, southern species, such as the fishes *Thalassoma pavo* and *Sphyraena sphyraena,* have been recorded in the north-western Mediterranean. The latter is now currently sold as sea-pike along the coast of Provence. Evidence of temperature increase in the deep water of the Mediterranean during the last forty years partially supports these biological indications of a rise in temperature.

The situation is completely different for sessile animal species: they cannot move from their location to search for deeper and cooler waters.

Outbreaks of sponge diseases have been reported in the Mediterranean since the beginning of the 20th century, although they appear not to have been virulent and did not significantly affect bath-sponge production. Bath sponges belong to the family Spongiidae; they are dictyoceratid sponges, a group which is devoid of siliceous spicules and has skeletons made up of interconnecting fibres of spongin (a type of collagen with large fibres).

Then in 1986 there was a Mediterranean sponge disease which strongly affected bath-sponges. It was suggested that bacteria that normally degrade dead spongin skeletons could become virulent and digest the spongin fibres inside living tissues. The virulence of the disease appeared to be related to relatively high seawater temperatures, as sponges were less affected in the northern part of the Mediterranean and below 40 m depth. Several episodes of local mortality of gorgonians (sea-fans), sponges and other sessile invertebrates have been recorded during the last decade in the north-western Mediterranean.

None of these outbreaks was anywhere near as widespread or as serious as the mass mortality crisis in the summer of 1999. A number of different causes were hypothesized for them – natural and human-induced mechanical damage; chemical pollutants carried in the North Mediterranean Current; increased temperature-related vulnerability; and a local drop in salinity and a high density of suspended sediment stirred up by violent storms. Another possibility was a nutrient-rich water mass warmed as a result of abnormal meteorological conditions, enhancing the growth of mucilage-producing phytoplankton. (Mucilage aggregates are moss-like associations charaterized by the presence of *Tribonemales* and *Ectocarpales* algae, together with heterogeneous assemblages of macroalgae fragments, cyanobacteria, diatoms, dinoflagellates and inorganic sediment.) Apart from the possibility of mechanical damage caused by fishing or by divers, none of these hypotheses could be experimentally tested. Moreover, these local mortality episodes were recorded in very limited areas and differed markedly from the summer 1999 event.

Outside the Mediterranean, the most important and probably the best known example of the effects of climatic fluctuations have been seen in tropical coral reef communities. Several diseases have been described over the last thirty years, although a disease pathogen has been identified for only three coral diseases, and for only two of these has the pathogen been shown in the laboratory to be the disease agent. Along with the diseases, the role of the El Niño–Southern Oscillation (ENSO) phenomenon in producing increased water temperatures and hence coral bleaching (expulsion of symbiotic algae) was dramatically verified during the 1998 El Niño event.

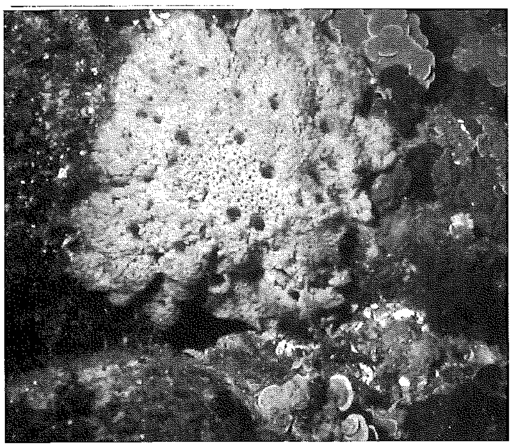
An apparent link between ENSO and marine disease has recently been suggested in the case of 'dermo', a disease of the oyster *Crassostrea virginica* caused by the protozoan parasite *Perkinsus marinus* in the Caribbean. Outbreaks of *P. marinus* seem to be triggered by the warm and dry conditions in the Gulf of Mexico which occur during La Niña events, the opposite climatic extreme to El Niño. El Niño events, by contrast, produce cold and wet conditions in the Gulf, which reduce the number and intensity of *P. marinus* outbreaks. Similar causes have been suggested for the bleaching of Eastern Mediterranean colonies of the reef-building coral, *Oculina patagonica,* infected by *Vibrio shiloi.* Obviously, it is very difficult to demonstrate whether increased seawater temperature induces the microbial virulence or reduces the host's defence, or a combination of the two.

The mass mortality of summer 1999

Towards the end of summer 1999, an unprecedented mass mortality of sessile marine invertebrates was observed along the coasts of Provence (France) and Liguria (Italy). Mortalities severely affected a wide array of sessile filter-feeding invertebrates from hard substratum communities (either rocky bottoms or coralligenous concretions), notably sponges (particularly the bath-sponges *Hippospongia* and *Spongia*, cf. Figure 1(a)), and cnidarians* (particularly anthozoans – sea-anemones and corals – including *Corallium, Paramuricea, Eunicella* and *Cladocora,* cf. Figure 1(b),(c)); bivalves, bryozoans and ascidians were also affected.

The outbreak seemed to spread from east to west along the Provence coast between mid-August and mid-October. The taxa most affected were sponges and cnidarians. Among sponges, the commercial sponges were dramatically affected in most of the area hit by the mass mortality. Among cnidarians, the gorgonians, *Paramuricea clavata* (Figure 1(c)) and *Eunicella singularis* were the most affected species, with the mortality rate reaching 90% at some sites. Other gorgonian species, such as *Eunicella cavolinii,* and the red coral *Corallium rubrum*, showed less extensive damage.

Sponges, corals and sea-fans were the sessile benthic organisms most severely affected by the summer 1999 mass mortality



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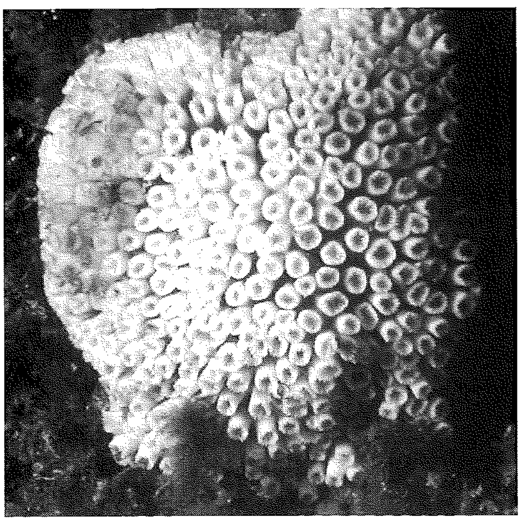

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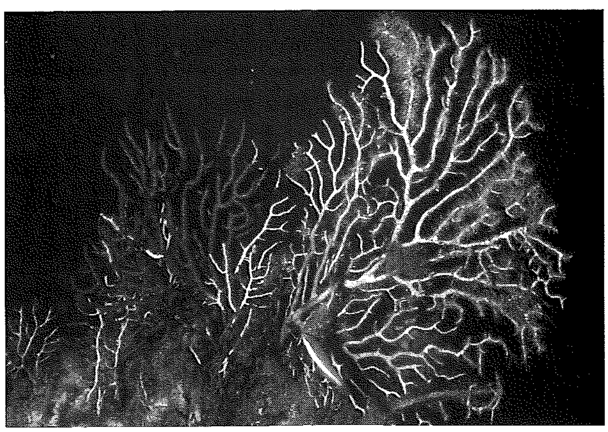
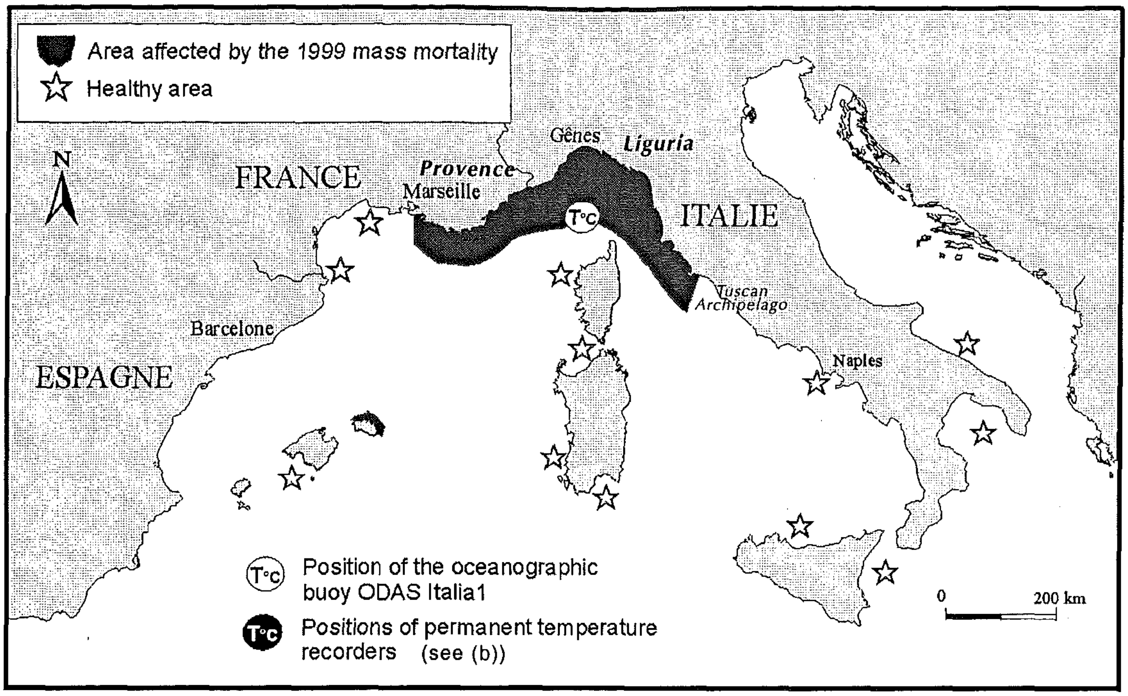


(c)

Figure 1 *Dead and dying benthic animals collected off the coast of Provence during summer 1999.* ***(a)*** *Skeleton of a dead bath-sponge,* Spongia officinalis. ***(b)*** *Bleaching of the coral* Cladocora caespitosa. ***(c)*** *Two gorgonians (sea-fans)* Paramuricea clavata *exhibiting different degrees of necrosis. Dead branches of the fan in the foreground have been colonized by epiphytic algae.*

(Photo (a) by courtesy of T. Pérez; Photos (c) and (d) by courtesy of J.G.Harmelin)

*Cnidarians are characterized by having special stinging cells, the cnidocysts.



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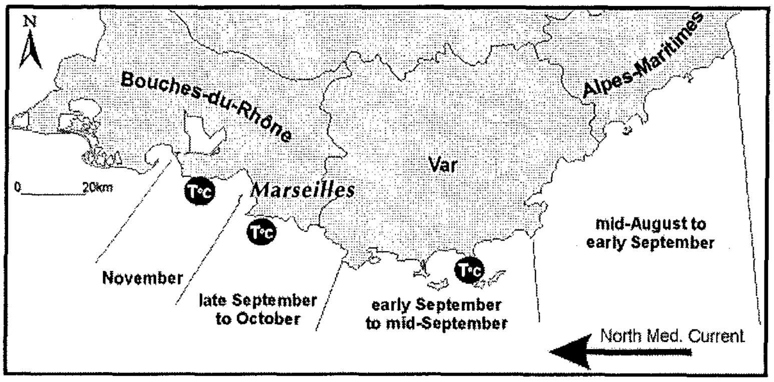


(b)

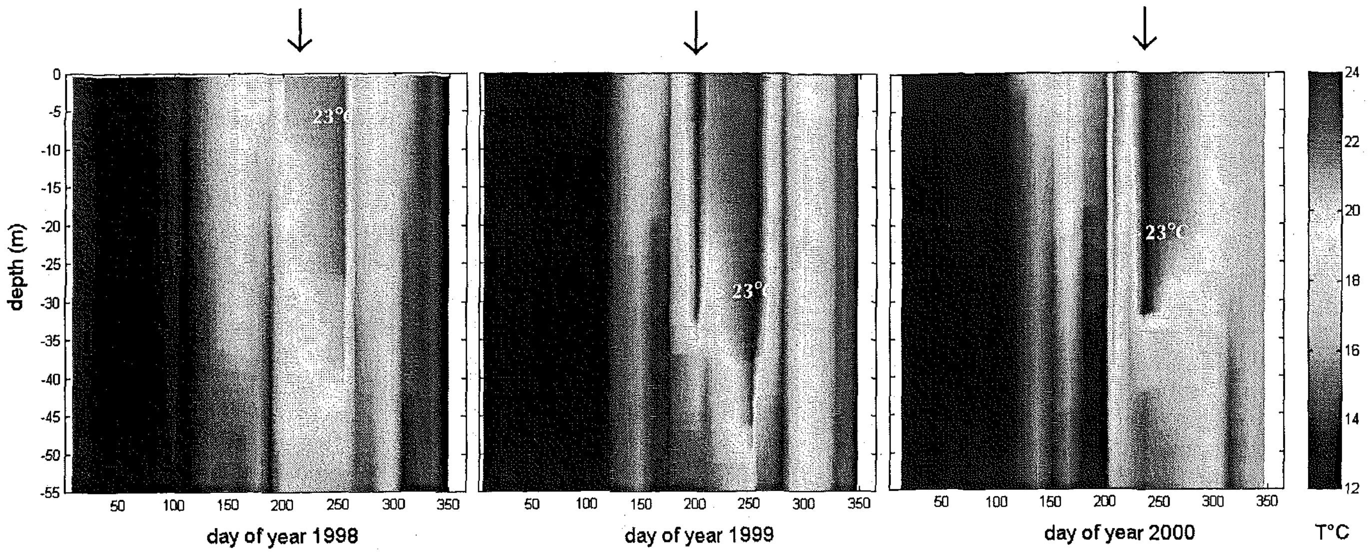
Figure 2 *Maps of the sites where data were collected relating to the 1999 thermal anomaly and the associated mass mortalities.*
(a) *The north-west Mediterranean coast. Portofino Promontory is just east of Genoa (Gênes), and Tino Island is further east round the coast of the Gulf of Genoa.*
(b) *Chronology of the disease outbreak along the coast of Provence (France). From east to west, the sites for the permanent temperature recorders (autonomous thermographs) are Port-Cros Island, Marseilles and Carry-le-Rouet.*

Although the mortalities spread from east to west, the timings off Liguria and Provence were generally sufficiently similar for pollution carried in the North Mediterranean Current to be an unlikely cause

Along the Ligurian coast, extensive mortality of gorgonians and other epibenthic organisms was observed from the Tuscan Archipelago to the French border (Figure 2). Quantitative data from Tino Island and Portofino Promontory indicated that the proportion of affected gorgonians ranged from 60% to 10% in populations with a density of 9–28 colonies per square metre. Extrapolating these figures to other parts of the Ligurian coast (which could in fact not be considered due to the lack of field data) led to the conclusion that millions of sea fans probably died along the Ligurian coast. At Tino Island, the early signs of mortality were seen in late August, first at 10 m depth, then down to 27 m. At Portofino Promontory, mortality was observed at the beginning of September. The chronology of these observations off Liguria does not differ very much from those off Provence – late August to mid-September in both cases (with the exception of the western part of the area, in the Bay of Marseilles).

Although there is not a lot of information from other parts of the Mediterranean, it is apparent that the mortality event mainly affected the coasts of Liguria and Provence, and possibly the northern part of Tunisia. Different hypotheses have been suggested to explain the geographical extent of the event. Although water masses in the north of the western Mediterranean generally flow anticlockwise along the continental slope from east to west, an early hypothesis of a plume of pollution carried westward by the North Mediterranean Current was quickly rejected: the affected invertebrates did not contain abnormal levels of contaminants, and the event began during the same fortnight whatever the location, as emphasized above. Moreover, the impact was identical whether in confined areas (small bays) or in open situations off major capes, even though dilution and diffusion of a hypothetical pollutant over several hundreds of kilometres should have drastically reduced its toxicity. In fact, this mortality event appeared to be affecting the whole region.

The bathymetric range of the mortality crisis extended from the surface down to 35–40 m depth, with a high local variability between populations of impacted species. So could it be the result of abiotic parameters such as temperature or salinity? It soon became obvious that the salinity was similar to that in previous summers (e.g. between 37.85 and 38.20), but that temperature records showed vertical homogeneity from 0 to 40 m depth, and high temperatures of 23–24 °C.



In summer 1999, water warmer than 23 °C extended from the surface down to ~40 m depth for more than 50 days

Figure 3 *Observations collected in the Bay of Marseilles (cf. Figure 2). The water depth at the station in question is 65 m. The vertical arrow indicates the start of the summer warming period.*

A careful analysis of available meteorological data in the Marseilles area for wind velocity and direction over a period of ten years (1990–1999) showed that summer 1999 was characterized by a marked drop in the relative frequency of north-west winds during July–October (for September, this figure was 13–27%, instead of 42%, the mean value for the previous 12 years). Although the winds were of similar velocity to previous years, the windy periods were shorter. Furthermore, there were a large number of 'no wind' periods (a mean of 125–250 hours per month) during this period. The significance of this is that in average years, sea-surface temperature during summer falls to 17–19 °C for two or three days after a north-west wind; this sometimes occurs several times during the summer months, but never happened at all in summer 1999.

Records of seawater temperature in the Marseilles area between 0 and 50 m depth, showed another feature directly related to the weakness of north-west winds in summer 1999: the summer thermocline never came to the surface, but progressively sank down to 35–40 m depth (middle part of Figure 3). In the meantime, the temperature of surface layers went up to 23–24 °C and remained at these high values for at least two months.

Autonomous thermographs were also deployed from the end of August to the beginning of October in three locations: Port-Cros Island, Marseilles and Carry-le-Rouet (black circles in Figure 2(b)). The records obtained showed that, for a depth of 24 m, average temperatures in the three locations were 23.3 °C, 22 °C and 23.1 °C, with a small variation coefficient (4–10%).

In the Ligurian Sea, computer-logged dive data for September 1999 show that temperatures remained above 20 °C (up to 24 °C) throughout the whole water column down to 40 m. In the central part of the Ligurian Sea, a meteorological buoy recorded a sudden rise of temperature from 17.5 to 22 °C at 35 m depth during the month of September, approximately at the same time as in the Marseilles area. This observation underlines the large-scale character of this hydrographic event. From the Tuscan Archipelago to the Bay of Marseilles, the combination of high temperatures and an abnormally long time of exposure was directly or indirectly responsible for the deaths of tens to hundreds of millions of sessile invertebrates unable to move into deeper and colder waters.

The sessile invertebrates affected were probably already living at the upper limit of their thermal tolerance, which is not surprising given that they used to live in much lower temperatures some 20 000 years ago. Their low metabolic rate (purple gorgonians 0.5 m high are some 50 years old) compared with a rapid rise in temperature might explain why these invertebrates reached their upper limit of thermal tolerance; in such cases, a small increase in temperature or in exposure time could have lethal consequences, either directly, or by triggering the virulence of micro-organisms. The case mentioned earlier, of a *Vibrio* living in the tissues of *Oculina patagonica* (introduced into the Mediterranean some 40 years ago), has recently been shown to be such an example of an indirect effect of temperature.

These observations can only partially explain the mass mortality phenomenon. The vertical extent of the temperature increase explains why all affected populations were observed above 40 m depth. The high within-site variability in the mortality rate and degree of necrosis (e.g. Figure 1(c)) could point to the existence of individuals resistant to pathogens or to thermal stress, or both. Of course, local variability in the level of the thermocline resulting from the interaction of winds and currents with the topography of the coast, as well as the bathymetry, may also contribute to within-site variability, although actual data at the relevant space- and time-scale are not available.

In the face of such a complicated challenge, an autoecological approach (i.e. studying individual species) suggests interesting guidelines for interpreting not only recent observations but also the results of future research.

Shelford's Law of Tolerance

More than eighty years ago, the British ecologist Victor Shelford proposed an ecological law still known as Shelford's Law of Tolerance. It states that, for each ecological parameter such as temperature or light intensity, there is a range of values within which the physiological activity of a given animal species is possible, with an optimum value near the mid-range; the higher and lower limits of this interval of tolerance vary according to the species. On the basis of the width of this interval, it is possible to distinguish between stenoecious species with a narrow range of tolerance, and euryoecious species with a wide range of tolerance. In the case of temperature, animal species can be stenothermic or eurythermic; they are also either thermophilic or psychrophilic (preferring either warm or cool conditions), with all possible combinations with the preceding categories.

Initially, Shelford's Law was restricted to temperature values, with no reference to the exposure time. However, it soon became obvious that temperature value and exposure time are both important. A key example is given by the ecological control of the end of diapause (resting stage) in insects: both temperature and time of exposure are significant. A thermal constant K has been defined using the following formula:

$$K \text{ (in degree days)} = y\,(t_0 - t)$$

where y is the exposure time in days needed to achieve diapause, t_0 the critical temperature value above which the diapause will never end, and t the temperature value in question. K takes its lower limit for an optimal combination of temperature and time. Following on from this, one can assume that, if temperature is the main parameter responsible for the mass mortality event, critical exposure times may be determined for different temperature values.

One of the problems that marine ecologists are facing is that until very recently, continuous records of temperature at several tens of metres depth were not available, because of the lack of appropriate instruments. This is the reason why ecological publications generally refer to temperature values and completely neglect the second thermal parameter, the time of exposure. A few years ago, autonomous electronic marine thermographs were developed (cf. Figure 2(b)). They can operate for several months and record as many as 20 000 individual temperature measurements. With such instruments it becomes possible to fully investigate the effect of temperature on sessile invertebrates.

Another problem has been that because many marine invertebrates, and all fish, are able to move from one area to another, or from shallow to deeper waters, it is difficult to determine their ecological range. Information about the effect of temperature on animals such as sponges and cnidarians that are sessile (except during the larval stage) is therefore very useful.

Similar questions about time of exposure to a given temperature are currently being considered by land ecologists and plant physiologists trying to predict the effects of climate and atmospheric change on species and community structure. In this context, four categories of effects have been suggested:

- Effects on physiology of changes in atmospheric CO_2 concentration, temperature and precipitation;
- Effects on distribution, in both latitude and elevation;
- Effects on phenology (the timings of different stages of the life cycle); life-cycle events triggered by environmental cues (degree days) could be altered, leading to different relationships between species;
- Adaptation, especially for species with short generation times and high population growth rates.

The most recent example of the use of a 'degree days' indicator in marine animals involves the bleaching phenomenon in tropical reef-building corals.

Coral reef bleaching and ocean 'hot spots'

The so-called bleaching process in tropical reef-building corals is an example of a recently understood temperature-controlled phenomenon. Most reef-building corals can tolerate a range of temperature between 18 °C and 29–30 °C. Bleaching occurs when water temperatures rise above 29–30 °C for several weeks; the corals expel from their tissues the symbiotic dinoflagellates (*Symbiodinium*) on which they rely for their nutrition. Following this rejection, the coral tissues appear transparent, and the calcium carbonate skeleton can be seen within as a whitish surface. In most cases, this rejection is shortly followed by the death of the coral colony, although some recoveries have been observed. In response to the recent strong El Niño (1997–98), when sea-surface temperatures were as much as 4 °C higher than average for several years, new methods were introduced to forecast such events. The so-called 'HotSpot' technique was employed to identify and map areas of the global tropical ocean where satellite-derived surface temperatures (SSTs) have exceeded a threshold of 1 °C above the warm season monthly mean temperature. This technique has been highly successful in providing early warnings of coral reef bleaching linked to thermal stress. In 1997 and 1998, HotSpot mapping identified all areas of the tropics that were subjected to intense and prolonged warming, coral bleaching and subsequent mortality.

A new treatment of the HotSpot data has been recently suggested to help study thermal stress as a primary cause of coral bleaching. The overlapping of ninety-day HotSpot accumulation maps creates a Degree Heating Weeks (DHWs) Index relating the duration and magnitude of HotSpots to the timing of coral bleaching. One DHW is equivalent to one week of SSTs one degree warmer than the expected summertime maximum. DHWs determine the time and degree of accumulated thermal stress that leads to bleaching (although concurrent environmental factors such as weak winds, low water levels due to high atmospheric pressure, and direct sunlight may be essential to force bleaching). Retrospective DHW-accumulation maps also highlight those areas which experienced the most prolonged thermal stress in 1998, and clearly implicate temperature in the widespread extent of coral bleaching and mortality. For example, significant bleaching occurred in the southern Great Barrier Reef, where 4–7 DHWs accumulated between 1 February and 30 April 1998. Also, the northern Indian Ocean accumulated 4–8 DHWs near India, accounting for the mass bleaching that occurred in the Maldives. More field data are needed to relate the timing of HotSpots to the onset of the bleaching.

Experimental ecophysiology

To better understand the summer 1999 Mediterranean mass mortality event, we need to investigate the precise thermal tolerance of each of the sessile species that were strongly affected, including their tolerance to high temperatures, combining temperature values and time of exposure in a a number of realistic combinations (e.g. 20 °C over two months, 24 °C for a fortnight, and other combinations in between); short drops of temperature within each of the experimental periods may also be necessary, in light of the high local variability that was observed during the event (e.g. a few hours at 18 °C at mid-experiment). Several individual specimens would need to be tested, in order to get some idea of the variability between individuals. Lethal combinations of experimental variables would also help our understanding of the degenerative sequences in different species. Any physiological mechanism that is easy to measure could be chosen to quantify the response of the organisms.

So how feasible would such an experimental research programme be? It is clear that laboratory experiments would introduce artificial effects. Some variability could in theory be avoided, such as in the case of light (intensity, spectrum, photoperiod, etc.) and temperature; in practice, it is very difficult to strictly control experiments lasting several months. Moreover, some ecological parameters, such as the size and chemical composition of suspended organic particles on which gorgonians and red coral feed, cannot be reproduced in the laboratory.

Another possibility would be the use of special laboratory chambers that have been developed to determine physiological responses of plants to changes in atmospheric CO_2 concentration, temperature and humidity. Even here, it would be necessary to use closed seawater circulation, so it would not be possible to reproduce the density, size and biochemical composition of the particulate matter on which these filter-feeding invertebrates feed in the sea, or the water mass movements along submarine cliffs.

It would be much more rigorous to operate in the sea, using large transparent chambers or bells with a heating device, a temperature control and an electrical pump to ensure seawater circulation within the enclosure; the pump could also maintain a slight pressure over the hydrostatic pressure, to allow the deployment of the transparent membrane. Nevertheless, laboratory experiments using respirometers could be used to determine the optimum, sublethal and lethal limits of each of the species affected. Some technical experience could be derived from ecophysiological studies on sediment respiration, and exchange of CO_2 between tropical reef-building corals and seawater.

Such data would enable us to develop different scenarios for population survival. For example, we could investigate why the bathymetric ranges of species such as *Corallium rubrum* are rather large, between 20 and 120 m depth. If increased summer temperatures altered the reproductive process in shallower populations of the species, then the survival of these populations would rely on propagules (planulae) produced by deeper populations. These propagules might well not be adapted to survive high summer temperatures in the shallower part of the species' bathymetric range. The long-term consequence would be that shallow-water populations would become unable to reproduce (i.e. become 'pseudo-populations') and would completely disappear if the increase in temperature continued.

At present, it is quite impossible to identify the origin of shallow-water populations: do they come from deeper propagules, or do they originate from *in situ* reproduction? Interestingly, production of planulae was recorded in Ligurian waters during the high-temperature period, but it was not possible to determine whether they were viable and able to settle, or had been already stressed by the high temperature.

The example of *Corallium rubrum* underlines the need for genetic analyses of populations of sessile invertebrates from various depths at a given site, and in different locations. One of the key tasks is to distinguish between phenotypic plasticity (individual capability for acclimatisation) and genetically controlled variability (resulting of the selection of mutations).

Also, as mentioned earlier, it should be borne in mind that 20 000 years ago, the Mediterranean had temperatures 8–10 °C lower than today. Since that time, animals have had to adjust themselves through selection to post-glacial conditions. During the summer months, they could well be living very near their lethal upper temperature limit, and have become vulnerable to a longer period of warm summer water.

Suitable observing networks

Most of the existing observing networks of physico-chemical parameters in the ocean are designed for the continental shelf and open ocean; they are not suitable for the space- and time-scales appropriate to the littoral fringe of a few kilometers out from the coast and a depth up to 80 m. The Mediterranean mass mortality event of summer 1999 highlights the need to monitor the summer thermocline in a continuous way, and at several locations. As suggested earlier, coastal relief may locally modify the wind direction, and submarine topography may induce changes in current direction and velocity. These small-scale mechanisms could well be responsible for at least part of the local variability that was recorded during the mass mortality event. Numerical models taking into account the subaerial and submarine topography at a relevant space-scale (50 to 100 m) have yet to be developed and tested. They could be a great help in achieving a complete understanding of the mass mortality event. Moreover, they could help to identify areas at risk along the coast.

It is also necessary to establish a network of coastal observatories, not only for physico-chemical parameters, but also to monitor characteristic Mediterranean benthic communities, e.g. the *Posidonia oceanica* (seagrass) meadows and deeper coralligenous assemblages.

What next?

The scarcity of previous mass mortality events in the Mediterranean makes it difficult to determine whether the apparently increasing frequency of such events during recent decades is real or simply reflects the increase in observations as a result of the intensification of scientific studies and surveys, and the increase in sport diving. Nevertheless, the effect of such events on invertebrate populations, and more generally on the structure and functioning of littoral marine benthic ecosystems, should not be underestimated. Clearly, phenomena with such large geographical extents have to be studied through international cooperation between Mediterranean countries. The socio-economic importance of such mass mortalities on subaquatic tourism should also be emphasized: the rocky seascapes of the Mediterranean, particularly those along the Italian, French and Spanish coasts in the western Mediterranean, are visited yearly by hundreds of thousands of scuba divers. Given the continued evidence of global warming, monitoring of physico-chemical parameters as well as of vulnerable invertebrate populations should clearly be implemented, particularly in areas at risk in the north-western Mediterranean.

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This is a revised and adapted version of an article first published in the journal Atti dell'Associazione Italiana di Oceanologia e Limnologia*; see Laubier (2001) in the Further Reading list for full details.*

Joaquin Garrabou* is a young marine ecologist interested in sessile cnidarians and responses to environmental change.

Thierry Perez* is a marine ecologist working on sponge biology and ecotoxicology.

Lucien Laubier* is a senior marine ecologist who has been working on Mediterranean corillagenous assemblages.

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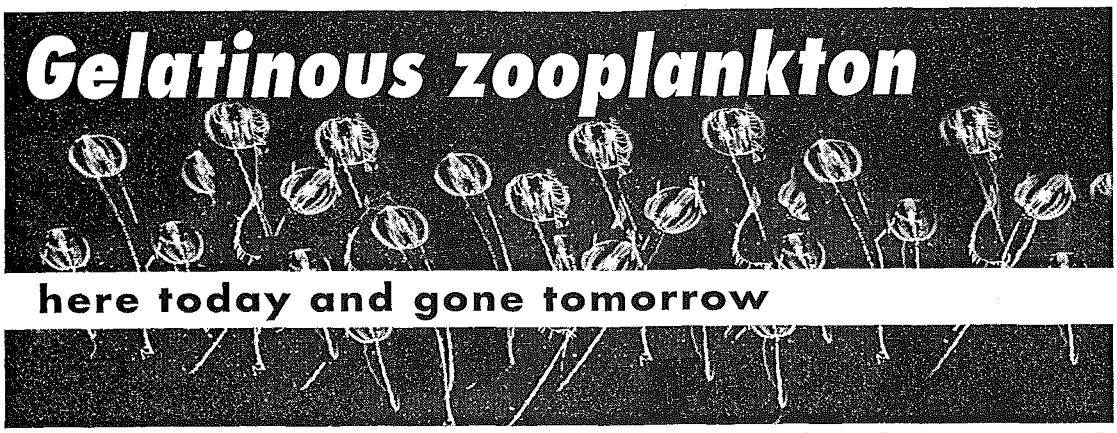
Gelatinous zooplankton

here today and gone tomorrow



... BUT IGNORED AT OUR PERIL

Ferdinando Boero

The word 'zooplankton' very often conjures up thoughts of crustaceans – copepods and euphausids. Indeed, the term is often explained to non-biologists as 'little shrimps which whales feed on', or something similar. Furthermore, it is generally assumed that zooplankton are all small, and are fed upon by bigger animals, usually vertebrates. But jellyfish are plankton too, and although everyone knows what jellyfish are, they are rarely cited as examples of zooplankton. Why is that? Some answers to this question emerged during two meetings organized on the shores of the Mediterranean Sea.

The first of these meetings was a workshop organized by the International Commission for the Scientific Exploration of the Mediterranean Sea (CIESM) at the Zoological Station of Naples (Italy), to explore the lesser known side of the zooplankton coin – gelatinous zooplankton. Nineteen scientists from 13 countries gathered to discuss this topic, and to highlight research priorities for future studies on marine systems. Participants presented their personal contributions, but the most profitable part of the workshop consisted of discussions about 'hot topics' that emerged informally, within working groups and brainstorming sessions.

Shortly after the Naples meeting, the Regional Activity Centre for Specially Protected Areas of the United Nations Environment Programme at Tunis organized a more focussed meeting to discuss possible causes of the enormous populations of jellyfish in Tunisian waters in the last few years, and possible remedies. The present burst of interest in gelatinous zooplankton is part of a recurrent pattern in the history of plankton research, and is related to the episodic nature of population explosions in these animals.

What follows is a synthesis of the Naples workshop, with some material integrated from the meeting at Tunis.

What should we call explosions of gelatinous zooplankton?

Population explosions of gelatinous zooplankton are often referred to as 'blooms'. This issue of terminology caused a lot of argument. Some participants maintained that the term 'bloom' is associated with plants rather than animals, and that it is only appropriate for describing increases in phytoplankton. However, others felt that the term 'jellyfish bloom' is found in the literature, that everyone knows what it means – and that, in any case, many common 'phytoplankton' (e.g. many species of dinoflagellates) are not strictly plants anyway.

Another argument against the use of 'bloom' to describe extremely large pulses of gelatinous zooplankton was that these pulses consist of billions of individuals of a single species. While 'bloom' could perhaps be used to descibe a 'normal' pulse, these outbreaks can be considered as analogous to a pathological state. Not surprisingly, no agreement was reached – only future actual usage will decide which term is adopted in the end.

How best to study gelatinous zooplankton?

Traditional plankton sampling is most suited to tiny, evenly distributed organisms, particularly if samples are being taken using nets. Jellyfish can have umbrellas of two metres in diameter, and tentacles 20 m long. Pyrosomes (a group of pelagic tunicates) can be 6 metres long. Plankton nets cannot trap such large animals, and fishing nets destroy them.

If gelatinous zooplankton are near the surface, they can be observed from on board ship, but this is not considered a scientific way to study plankton. So such observations are regarded as only anecdotal evidence, and are not quantified. Worst of all, there may be reports that 'we stopped sampling because the nets were clogged with jellies'.

Recently, 'blue diving' began to be used to study large plankton – scientists simply jump into the water and perform visual censuses. Submersibles are also extremely useful in this context. At the Naples meeting, Gabriel Gorsky (Villefranche-Sur-Mer) put forward the recommendation that there should be wider use of visual sampling (directly, or using video equipment) in plankton studies. Remote-sensing could also be a powerful tool for detecting large outbreaks of gelatinous zooplankton far offshore, but it seems that none of the sensors so far developed can detect gelatinous material.

Why gelatinous zooplankton are important

The misrepresentation of the abundance of gelatinous animals in plankton samples led scientists to consider them as episodic in occurrence and thus as freaks in plankton ecology. Of course, specialists do not agree with this assessment, but their views are mostly overlooked.

Gelatinous pulses, either as normal population increases of seasonal species, or as irregular outbreaks, have two functional roles: grazing on primary producers in the case of tunicates, and predation on secondary and even higher producers in the case of cnidarians and ctenophores (jellyfish and sea-gooseberries). Herbivore pulses often represent sinks of primary production and, since thaliaceans (e.g. salps) and appendicularians can feed on bacteria, they are also a link between 'traditional' food webs and the microbial loop. A pulse of salps, in spite of lasting only a short time, can redirect matter and energy within a marine food web, representing a short-circuit for routes that normally would involve a flow from phytoplankton to crustacean grazers, small fish, bigger fish and, eventually, humans.

Carnivore pulses can cause great problems for coastal economies. The outbreaks of *Pelagia noctiluca* (pearl jellyfish) that plagued the Mediterranean for three years in the early 1980s had a tremendous impact on fisheries (nets were clogged by jellies), human health (swimmers were badly stung) and tourism (tourists left because they could not swim without being stung). The impact of gelatinous predators became even more evident in the early 1900s, when the ctenophore *Mnemiopsis leiydi* suddenly became abundant in the Black Sea, after travelling comfortably in the ballast waters of a ship from the east coast of the United States. A tiny jelly blob started to feed on fish larvae and on their food (crustacean zooplankton), and the resulting population explosion caused a collapse of the fish populations and, consequently, the fisheries.

The irrefutable message is that small gelatinous predators can impact on both crustacean and bony prey. The most voracious predators of large fish like tuna, for instance, might be tiny jellies that feed on their eggs and larvae, and not large sharks and killer whales that feed on the adults, as is often implied in fisheries management models! Like herbivorous gelatinous plankton, carnivorous gelatinous zooplankton are a trophic sink. Energy and matter that should go into fish and perhaps, eventually, to us, are re-directed to tiny predators that produce huge populations and then disappear as suddenly as they came. If these animals can have disruptive effects on marine food webs when their populations are abnormally great, isn't it likely that they have at least some importance when their populations are 'normal' in size?

This is not simply a theoretical issue. All coastal states dedicate huge resources to study fisheries. Most of these research efforts are focussed on measuring fish in order to construct models of population dynamics. Mortality is almost invariably linked to fishing or to big predators. Once it has been established that larval mortality due to competition with, and predation by, gelatinous plankton is an important component of fish mortality, it is logical that this variable in fisheries science should be quantified (with proper research effort), and not treated as a black box!

Population dynamics

Gelatinous plankton appear suddenly, and then, as suddenly, disappear. This is a great disadvantage for those who want to (or should) study these animals. For most of the time they are not around in any numbers, and it is almost impossible to predict when they will appear. It is difficult to build up a career by studying an animal that is present for two weeks and then disappears, to come back only after a year! But, as we have seen, that animal can have a tremendous impact in a very short time and is therefore worth studying if we want to know how marine systems work.

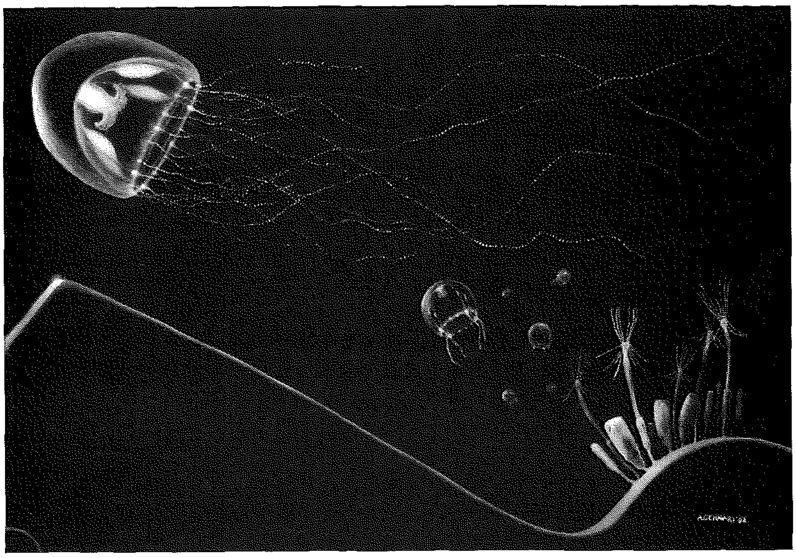
The sudden appearance and disappearance of gelatinous plankton is linked to the fact that they are almost the end-users of a fluctuating resource, in the form of phyto- and zooplankton pulses, so they have to take advantage of favourable trophic conditions which do not last long. The only way they can do this is to be present in great quantities when the resource is there, and disappear when the resource is not there.

This may be achieved in two different ways:

- **Life-history adjustment**: a species is represented by few individuals when conditions are unfavourable and by many individuals when conditions are favourable. Populations pass through seasonal bottlenecks, being alternately rare and abundant.

- **Life-cycle adjustment**: a species is represented by individuals active in the water column when conditions there are favourable, and by individuals that live somewhere else (i.e. on the sea-bed) when conditions are unfavourable. The total population size is more or less constant, the disappearance of active stages in the water column being compensated for by the presence of benthic stages that are often dormant.

Most jellyfish perform life-cycle adjustment, with benthic polyps that represent a way of escaping from the plankton. Furthermore, colonial polyps release enormous numbers of medusae over short periods, in sudden planktonic pulses – an optimal strategy to take advantage of favourable conditions that only last for a short while (such as the availability of



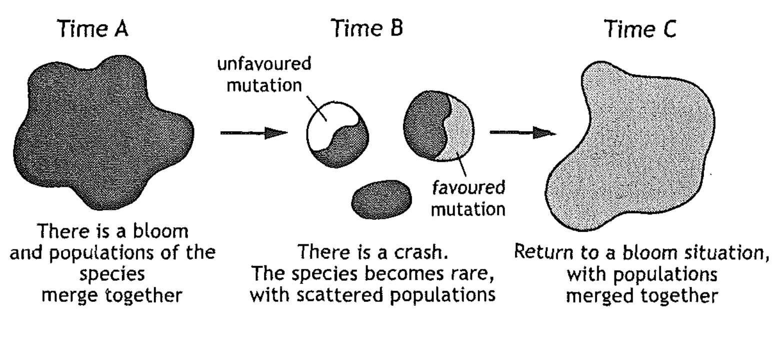
Painting by Alberto Gennari currently being exhibited at the Monterey Bay Aquarium in a special exhibition on 'Jellies as Art'

Figure 1 *Artist's representation of the life-cycle of* Phialella zappai *a hydrozoan of the family Phialellidae, named after the modern composer Frank Zappa.* Phialella zappai *lives along the coast of California. The polyp colony is shown on the right of the picture, in the middle are newly released medusae, and at top left there is an adult medusa.*

abundant prey). Other gelatinous zooplankton, however, do not have benthic resting stages and, thus probably perform life-history adjustment.

This leads to the problem of where the 'seed' populations can be found. For organisms with benthic stages, the problem is easily solved: the seeds are on the sea bed. Some perennial gelatinous zooplankton, however, must represent species that are holoplanktonic (i.e. permanent members of the plankton). It is a truism that such seed populations trigger massive events, and while this, paradoxically, provides the answer to the obvious question 'Why are they here now?', it in turn prompts the not-so-obvious question 'Where exactly were they when they were not here?' This question remains unanswered for most gelatinous species.

Figure 2 *Model to explain how 'bloom–bust' cycles result in large numbers of relatively few widely distributed species.*



Politics

Unfortunately, decision-makers are interested in obvious questions, and do not want to invest resources in investigating problems that are not so obvious. This means that research on gelatinous zooplankton is funded during troublesome outbreaks and is forgotten when these zooplankton are represented only by their seed. Research proposals are called for when an event occurs, but funds usually only become available after the event is over and are, therefore, almost immediately cut off. Such a research policy, linked to immediate results and fast answers, is invariably a failure. It is no wonder that there are so few specialists in this field.

The influence of blooms and outbreaks on evolutionary patterns

During discussions, G. Richard Harbison (Woods Hole, USA) addressed an interesting question: 'Why are there so few species of holoplanktonic gelatinous organisms?' If we exclude the small, highly diverse, hydromedusae found in shallow coastal water, the diversity of gelatinous plankton is rather low. In general, there are very few oceanic hydromedusae (Narco- and Trachymedusae): the Scyphozoa (true jellyfish), the Cubozoa ('sea wasps' and other genera characterized by cube-shaped bodies), the colonial Siphonophora, and the Thaliacea (salps and pyrosomes). There are also only a few dozen representatives of the Phylum Ctenophora. Furthermore, many species of gelatinous zooplankton are cosmopolitan – i.e. widely distributed. The question arises: Is there a reason for such a consistent diversity pattern?

The answer may be represented by the following model (cf. Figure 2). During blooms, and even more during outbreaks, species tend to form large populations that merge into huge, overlapping 'metapopulations', bridging the geographical gaps that usually keep local populations distinct from each other (Time A in Figure 2). This pattern of population growth overcomes geographic separation, the main cause of speciation and, thus, of increases in diversity. During non-bloom (or non-outbreak) periods, the metapopulation becomes fragmented into many small populations, represented by few individuals – the seed populations (Time B). This pattern, of course, is more applicable to holoplanktonic species with life-history adjustment, since the meroplanktonic species with life-cycle adjustments simply shift from the plankton to the benthos. The blooms and/or outbreaks of holoplanktonic species are population flushes, whereas the periods of rarity are population crashes leading to bottlenecks. Bottlenecks are conducive to genetic variation and thus are a way of changing the genetic structure of a population in a way that might result in better adaptations to environmental demands. Each population, reduced to a few individuals, thus becomes a 'genetic laboratory' for the species. When blooms occur (Times A and C in Figure 2), populations merge and new information is spread. Good information will pass from one population to the other, whereas bad information will be erased by intraspecific competition. During outbreaks, the homogenization of populations and meta-populations is even greater. Under these circumstances, species evolve by anagenesis, and cladogenetic processes become rather difficult because of periodic events of panmixia, so explaining the high rate of cosmopolitanism and the small number of species. This model could easily be tested using molecular methods, by comparing the genetic make-ups of cosmopolitan holoplanktonic species with those of more localized meroplanktonic species.

Is there a future for research on gelatinous plankton?

The information that we have about gelatinous zooplankton, and especially about the extreme cases of *Mnemiopsis* and *Pelagia*, clearly indicates that research on these animals cannot be episodic. Their pulses are one of the major determinants of the functioning of marine ecosystems. Crustaceans and vertebrates are the constant regularities, gelatinous animals are the irregularities, the episodic occurrences that remix the cards, disrupting food webs and bringing innovation into ecosystem structure and function. Jellyfish and ctenophores, furthermore, are the real top predators of the seas, feeding on all types of organisms (with the exception of marine mammals), through predation on eggs and larvae.

In conservation ecology, the presence of top predators is a symptom of good ecosystem quality. This view has been adopted in the context of the once-hated sharks, but is still far from being fully perceived for gelatinous predators. At present, we still do not even know exactly how diverse of these animals are, and a we have long way to go before we have a full appreciation of their diversity – which will be essential if we are ever fully to understand their ecological roles.

Programmes on taxonomy have been launched in the United States, where there is an active and flourishing school on gelatinous animals. The situation is not so good in Europe where, however, some islands of excellence still remain, such as the marine stations at Villefranche-Sur-Mer and Plymouth. However, Quentin Bone (Plymouth Marine Laboratory), lamented the interruption in the long-term programme of plankton-sampling in the Western Approaches off south-west England, harming the reconstruction of historical marine ecology. This unwise policy seems even more irrational now that it is becoming apparent that – for some reason, as yet not understood – global change is making conditions more favourable for gelatinous animals, in comparison with crustaceans and vertebrates.

More than 70% of the planet is covered by the ocean, and most biotic production takes place in the water column. Gelatinous sinks are not irrelevant freaks that can be casually mentioned in passing while speaking of energy budgets. We have dedicated much energy to studying the usual (chitin and bone), and the time is now ripe to recognize the importance of the *un*usual – gelatinous zooplankton – so bringing about a conceptual revolution comparable to that brought by recognition of the importance of the microbial loop.

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It may be downloaded from the CIESM website: http://www.ciesm.org

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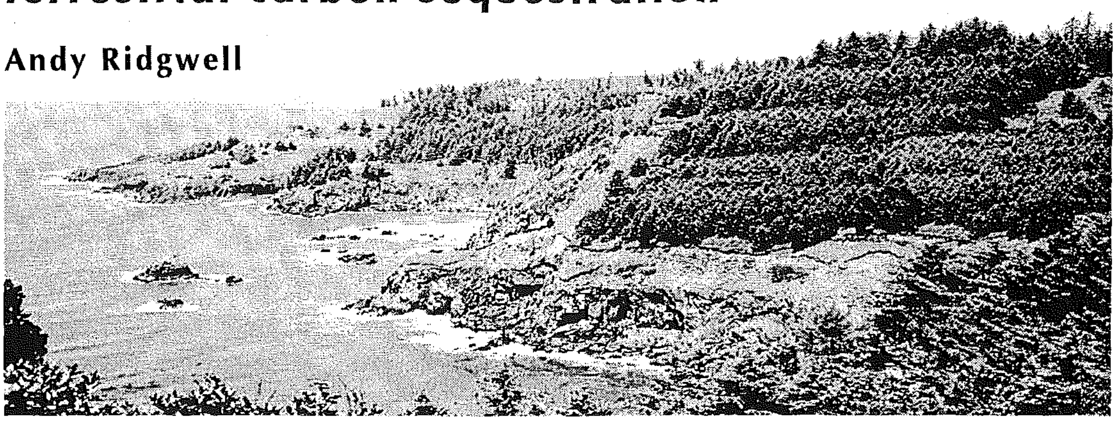
The 'inconvenient ocean'

Undesirable consequences of terrestrial carbon sequestration

Andy Ridgwell



It is now well established that the availability of iron exerts a fundamental control on biological productivity in the ocean. We also know that a significant source of this iron is deposition of mineral aerosol from the atmosphere to the ocean surface. That this supply of dust, in turn, is dependent on the state of the land surface, suggests that any future change in how the land is managed and used has the potential to affect atmospheric CO_2 via a remote controlling influence on ocean productivity. This teleconnection within the Earth system has important implications for how we might mitigate future climate change, particularly with respect to activities allowed under the Kyoto Protocol for the removal ('sequestration') of CO_2 from the atmosphere and its storage in vegetation and soils.

When the wind speed is sufficient to overcome the cohesive forces that exist between soil particles, fragments of rock minerals and other soil constituents are picked up and may be carried great distances through the atmosphere. Although the individual particles are often nearly invisible to the naked eye, billions of tonnes of material are eroded from the land in this way every year. Transport events can often be of sufficient intensity to be visible from space, as shown in the accompanying satellite image (Figure 1).

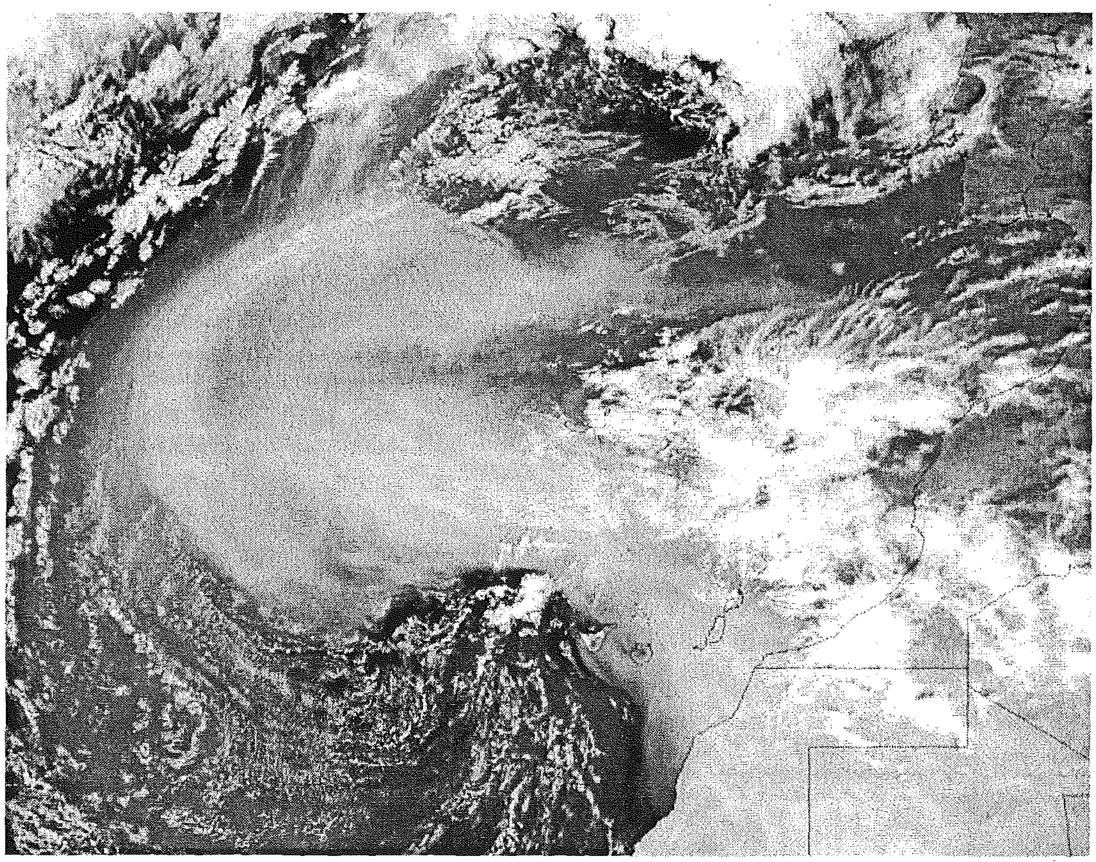
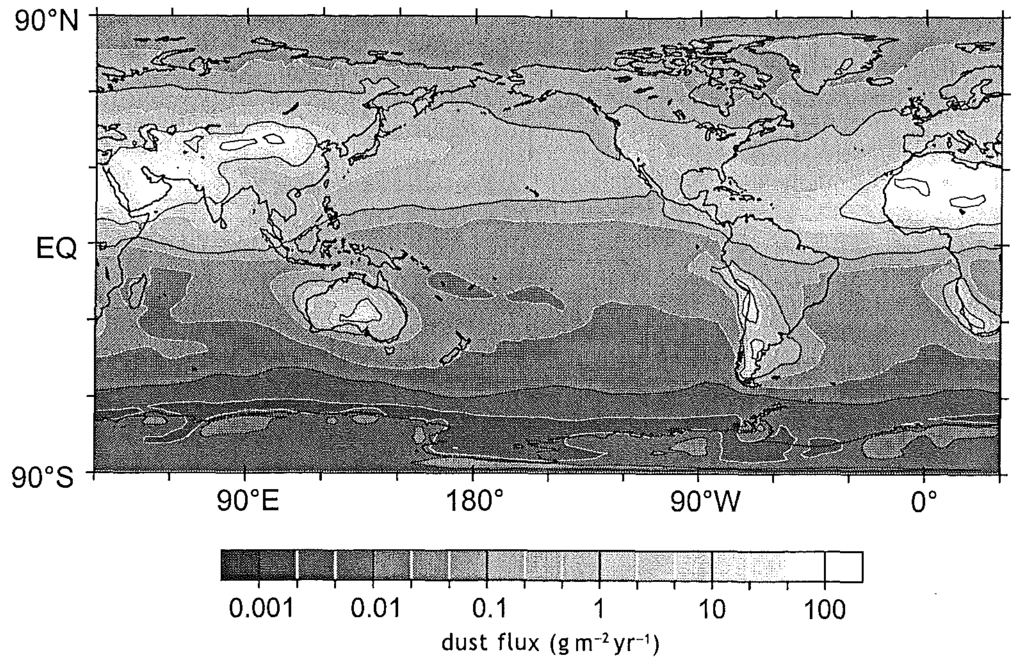


Figure 1 *Satellite (SeaWiFS) image taken on 26 February 2000, of a massive sandstorm blowing off north-west Africa and extending over 2000 km into the Atlantic.*

(This SeaWiFS image was provided by NASA DAAC/GSFC and is copyright of Orbital Imaging Corps and the NASA SeaWiFS project)



Over the oceans, most dust is deposited downwind of desert areas

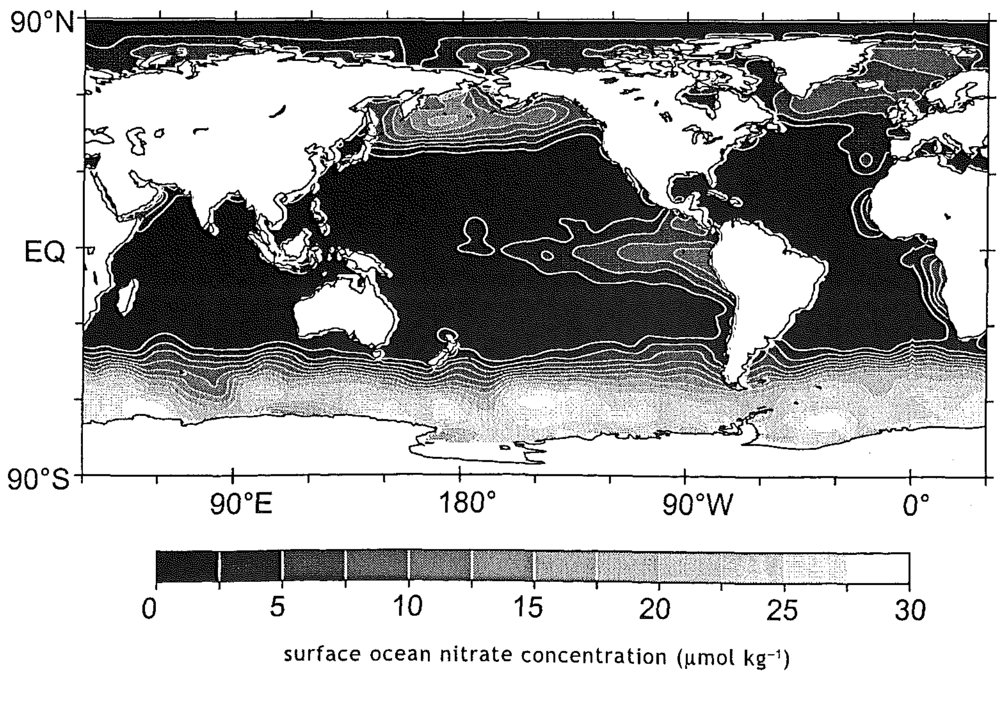
Figure 2 *Model-simulated distribution of the annual mean (1981–1997) rate of dust deposition to the Earth's surface.*

(For source of data, see end of Further Reading)

The entrainment of dust by the atmosphere is greatly facilitated by dry, arid conditions, when cohesion between particles is minimal, and also by the absence of vegetation cover, which allows greater wind speeds to be reached at ground level. It comes as no great surprise, therefore, to find that the srongest sources of dust at present are the Sahara and Sahel desert regions of North Africa. There are also important sources associated with the deserts of central Asia, while lesser sources are to be found in arid regions of southern Africa, Patagonia and Australia. As the prevailing winds carry the suspended dust away from its source, more and more of the intial load of material is removed by being 'washed out' by falling raindrops, or by sinking to the land or ocean surface under gravity. The distribution of dust deposited to the Earth's surface (Figure 2) then reflects a combination of the strength of sources of dust and the distance from them, and atmospheric circulation patterns. For instance, particularly high rates of deposition occur immediately downwind of the Sahara and Sahel desert regions of North Africa and extend out across the Atlantic to the Caribbean and north-eastern South America. In constrast, there will be very low rates of dust deposition in regions such as the Southern Ocean and the equatorial and southern Pacific, all of which are relatively remote from any major sources of dust.

Figure 3 *Global distribution of surface ocean nitrate (NO_3^-) concentrations.*

(For source of data, see end of Further Reading)



In the northern Pacific, eastern equatorial Pacific and Southern Ocean, high concentrations of NO_3^- in surface waters indicate that macro-nutrients are not being fully used by phytoplankton

One of the effects that this dust has on the Earth system is to alter the optical properties of the atmosphere. By modifying incoming (ultraviolet and visible) and outgoing (infra-red) radiation, the presence of dust in the atmosphere can affect the energy balance at the Earth's surface, producing seasonal local heating or cooling of as much as ± 2 °C.

Once deposited to the land surface, aeolian material can significantly affect soil structure, and with it, the nutrient- and water-holding characteristics of the soil. This is most apparent in the Loess Plateau region of China, where over the course of the last few million years, dust carried east from the Gobi desert has formed an extremely fertile soil sequence up to 200 m thick. Elsewhere, in places where soils would otherwise be poor and infertile, deposition of nutrients such as phosphate in aeolian material is potentially critical to maintaining the health and productivity of the ecosystem. Dust indeed appears to have such a role in parts of Amazonia (dust transported across the Atlantic from the Sahara and Sahel deserts) and the Hawaiian Islands (dust from the central Asian deserts).

It is clear, therefore, that dust has important effects in both the atmosphere and the terrestrial biosphere. However, it arguably takes on its most important Earth system role when deposited to the ocean surface.

Dust and the ocean carbon cycle

Iron limitation of the biota of the open ocean

A long-standing puzzle in oceanography has been why the primary producers of the open ocean (phytoplankton) do not always fully utilize the major ('macro-') nutrients – phosphate (PO_4^{3-}), nitrate (NO_3^-) and silicic acid (dissolved silica – H_4SiO_4) – that are supplied to them. As shown in Figure 3, in certain regions of the world ocean, most notably the eastern equatorial Pacific, the northern Pacific and the Southern Ocean, high concentrations of NO_3^- remain in surface waters (with a similar pattern apparent for both PO_4^{3-} and H_4SiO_4). Despite the ready availability of NO_3^-, standing stocks of phytoplankton are relatively low, leading to the designation of such regions as 'High-Nitrate Low-Chlorophyll' (HNLC).

Although physical conditions (temperature, light levels, and the depth to which the surface ocean is mixed) and grazing regimes must both play a part in controlling phytoplankton standing stocks in HNLC regions, it was suspected that growth limitation through insufficient availability of the micro-nutrient iron might also be important. Open ocean iron fertilization experiments were therefore carried out to test this hypothesis, first in the equatorial Pacific, and more recently in the Southern Ocean (see *Ocean Challenge*, Vol. 10, No. 3). The results of these experiments have demonstrated unequivocally that insufficient availability of iron in the surface ocean limits phytoplankton growth (particularly growth of larger diatoms).

Iron supply to the biota

Why should there be an imbalance in nutrient supply to the biota, with insufficient iron relative to the macro-nutrients in some locations in the ocean but not others? The answer lies in the dust distribution in Figure 2. To understand why this is we must look at how nutrients are cycled in the ocean. As phytoplankton cells grow and divide in the sunlit surface layer of the ocean (the euphotic zone), nutrients are removed from solution and transformed into cellular constituents. Much of this material is subsequently broken down by the action of bacteria and zooplankton within the euphotic zone, and the nutrients returned to solution ('remineralized'). However, a fraction (in the form of dead cells, zooplankton faecal pellets, and other particulate debris) escapes and settles through the water column under the influence of gravity, being broken down much deeper in the ocean. Although nutrients are eventually returned to the euphotic zone by upwelling and mixing, a vertical gradient is created, with lower nutrient concentrations at the surface than at depth. The action of removal by the biota of dissolved constituents at the surface and export (in particulate form) to depth is known as the 'biological pump' (Figure 4).

Supply of iron to the euphotic zone also occurs through upwelling and mixing up from below of deeper waters (which are enriched as a result of the degradation of biogenic material supplied from above, as per the macro-nutrients). However, unlike the highly soluble macro-nutrients, iron in the dissolved state is not thermodynamically favoured in the oxygenated seawater environment, and it is 'scavenged' out of solution by attaching to particulate matter settling through the water column. The consequence of this is that there will tend to be a relative deficiency (compared with other nutrients required for phytoplankton growth, such as NO_3^-) of iron in upwelled water.

Although transport by rivers is the dominant route by which iron is supplied to the ocean as a whole, rapid biological uptake and sedimentation in highly productive estuaries and coastal zones removes much of the newly supplied iron from the water column. The result of this is that in the open ocean, rivers are not an important source of iron to the euphotic zone. In order for NO_3^- to become completely used up at the surface, aeolian deposition must therefore supply the shortfall (relative to NO_3^-) in upwelled iron supply. However, inspecting the dust map (Figure 2), it is clear that the fluxes to the equatorial Pacific and Southern Ocean are extremely low – aeolian supply is insufficient to make up the shortfall, explaining the HNLC condition of these regions.

Iron supply and ocean CO_2 uptake

Alongside factors such as ambient temperature and pH, the concentration of dissolved inorganic carbon (DIC) determines the equilibrium concentration of gaseous CO_2 in the surface ocean. Processes that affect DIC concentrations will therefore influence the net transfer of CO_2 between atmosphere and ocean surface. The biological pump is one such process. This is because along with nutrients, carbon is also incorporated into cellular organic constituents by phytoplankton in the euphotic zone and later released into solution at depth (Figure 4). By affecting productivity in the ocean and thus the strength of the biological pump, changes in dust deposition will therefore influence the uptake of atmospheric CO_2 by the ocean.

Dust supply and land-use change

One of the consequences of historical changes in land use, such as conversion of natural systems to agriculture, is that the supply of dust to the atmosphere will have been increased. The results of models of the processes of dust generation, transport and deposition are consistent with a component of the total dust load in the atmosphere today being a direct consequence of such human-driven land disturbance. In regions of the ocean where natural sources of iron to the marine biota were previously insufficient to allow the complete utilization of NO_3^-, it is likely that this additional 'anthropogenic' dust component will have helped stimulate marine productivity, enhancing the rate of CO_2-uptake by the ocean. It follows that removal of this additional dust source would drive a reduction of CO_2-uptake. This has clear implications for future climate change. So, under what circumstances might a reduction in dust supply to the ocean occur?

Terrestrial ecosystem models suggest that in the future there will be a weakening of dust supply to the atmosphere, with global warming driving a substantial reduction in the area of desert and semi-desert vegetation. Working against this, population pressures are likely to drive an increase in soil disturbance via the intensification and extensification of agriculture. In addition to source changes, the efficiency with which dust is transported through the atmosphere may also change, with increased removal of dust particles by precipitation (under the more intense hydrological cycle that is expected as part of future climate change), resulting in a reduction in the supply to the remote ocean. However, it is also possible that the land surface might be deliberately modified on a large scale in an attempt to mitigate climate change.

Under the Kyoto Protocol, a variety of 'land-use, land-use change and forestry' (LULUCF) activities have been proposed for the sequestration of carbon on land. These include changes in soil management practices (including reducing tillage, enhancing the areal and seasonal extent of ground cover, and the 'set-aside' of surplus agricultural land), restoration of previously degraded lands, and forestation. As a result of reduced disturbance and increased stabilization of soils, many of these activities are likely to lead to a reduction in dust supply from the land to the atmosphere. Since dust exerts an important control on the biological pump in the ocean, the effectiveness of carbon removal from the atmosphere via sequestration on land may be diminished by a reduction in the quantity of carbon taken up by the ocean. The potential importance of this teleconnection within the Earth system, with deliberate actions taken on land producing unexpected side-effects in the ocean, has been investigated at the University of East Anglia with the aid of a numerical model of the ocean–atmosphere carbon cycle. Results of this model predict a significant impact on ocean productivity of any decrease in dust supply to the ocean, with, for instance, 15–30% less dust producing a reduction of up to 8% in the rate of uptake of anthropogenic CO_2 from the atmosphere. This perturbation of the global carbon cycle exhibits a considerable persistence, with the deficit reaching $20–50 \times 10^9$ tonnes of carbon (or 20–50 PgC) by the year 2250, and perhaps doubling by the end of the millennium (year 3000). To put this into perspective, the sequestration benefit of widespread alteration of agricultural management practices and forestation is perhaps in the region of 23–110 PgC. Clearly, suppression of the ocean sink has the potential to substantially offset the benefit to the atmosphere of sequestration on land.

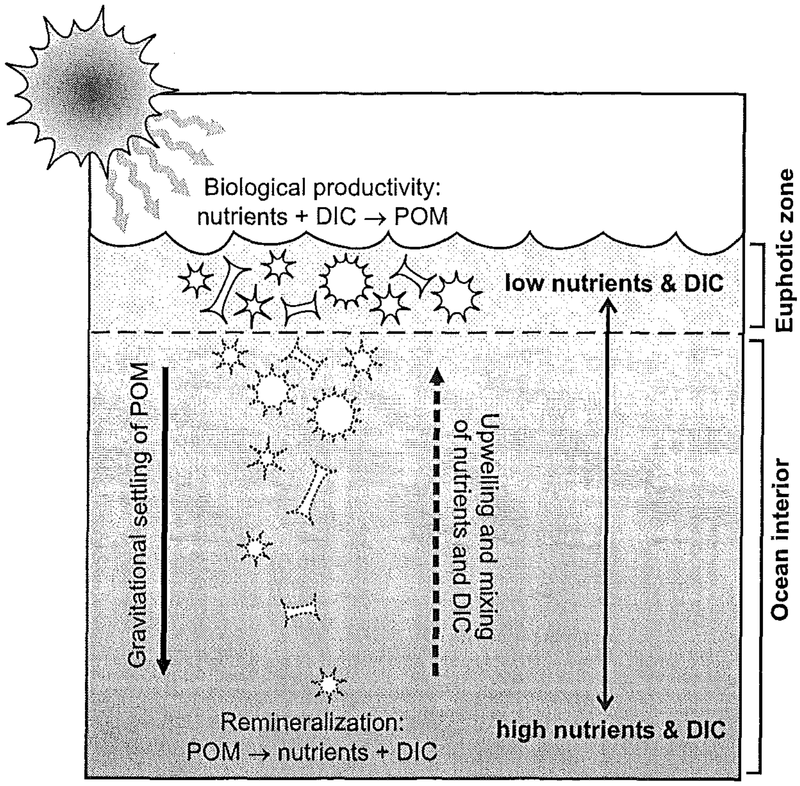


Figure 4 *Schematic diagram of the operation of the 'biological pump' in the ocean. DIC = (total) dissolved inorganic carbon ($CO_2(aq) + H_2CO_3 + HCO_3^- + CO_3^{2-}$). POM = particulate organic matter (primarily living and dead phytoplankton cells and zooplankton faecal pellets).*

The biological pump removes nutrients from the surface ocean and exports them to deeper waters; macro-nutrients (e.g. nitrate) can be replenished by upwelling, but this is not the case for iron

The precise effect of this 'land use/ocean productivity' mechanism will be critically dependent upon the details of any sequestration activities and the locations in which they take place. For example, land surface modification undertaken in arid and semi-arid regions will tend to have a much greater impact on dust supply than it will in moist, temperate regions (where dust sources are relatively unimportant). At a minimum, changes in dust supply and the response of the ocean may need to be taken into account when evaluating the relative economic benefits of carbon sequestration via certain LULUCF activities. However, it is within the range of uncertainty that the eventual benefit (in terms of removal of CO_2 from the atmosphere) obtained through implementation of LULUCF mitigation measures will be largely negated by an undesirable antagonistic response induced in the ocean.

Conclusions

The Kyoto Protocol takes a rather narrow and restricted (land–atmosphere) view of the Earth system in judging the benefits of removal ('sequestation') of CO_2 from the atmosphere and its storage in vegetation and soils. This has resulted in LULUCF activities being viewed as relatively safe and highly desirable mechanisms for helping reduce the rate of accumulation of CO_2 in the atmosphere. Since many of these activities have considerable ancillary benefits (for example, in improved soil fertility), they have even been termed 'no regrets' or 'win–win'. However, by ignoring both the role of the ocean, and the dust that links land, air and sea, certain 'side-effects' have obviously been missed. Quantifying the potential consequences of terrestrial carbon sequestration suggests that LULUCF activities may not be as benign as has generally been assumed, and terrestrial sequestration cannot, therefore, be wholly relied upon as a substitute for reductions in emissions. It would seem that it is only through taking a more holistic view and being receptive to the potential interaction of different components of the Earth system, that we can hope to understand the full consequences of our continued experimentation with the planet.

Further Reading

You can read more about the problems of terrestrial carbon sequestration and the possible dust-driven 'side-effect' in two recent publications:

Ridgwell, A. J., Maslin, M. A. and Watson, A. J. (2002), Reduced effectiveness of terrestrial carbon sequestration due to an antagonistic response of ocean productivity, *Geophysical Research Letters* **29**, 10.1029/2001GL014304.

Royal Society (2001), *The role of land carbon sinks in mitigating global climate change*, Royal Society Document 10/01. (http://www.royalsoc.ac.uk/files/statfiles/document-150.pdf)

Further articles on the role of dust in the global carbon cycle and climatic change can be found at: http://tracer.env.uea.ac.uk/e114/publications.html

The data used to generate Figures 2 and 3 are taken from: Ginoux, P., *et al.* (2001) Global simulation of dust in the troposphere: model description and assessment, *J. Geophys. Res.*, **106**, 20 255–73; and Conkright, M. E., *et al.* (1994) *World Ocean Atlas 1994 Volume 1: Nutrients*, NOAA Atlas NESDIS 1, US Department of Commerce, Washington, DC.

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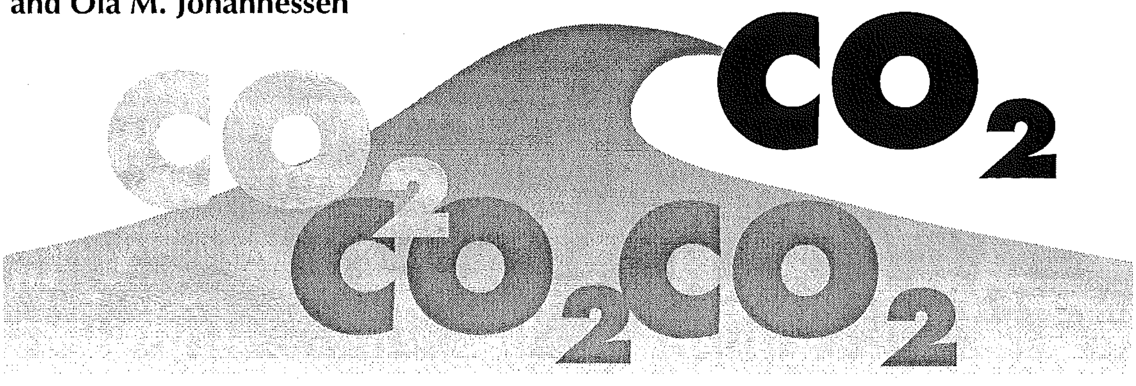
Ocean sequestration of CO_2

Helge Drange, Guttorm Alendal
and Ola M. Johannessen



The atmospheric concentration of carbon dioxide, the principal human-induced greenhouse gas, has increased from ~280 parts per million (p.p.m.) (i.e. ~ 0.028%) at the beginning of the Industrial Revolution to ~365 p.p.m. today. This increase has mainly been caused by the burning of oil, coal, and gas, and changes in the use of land. A growing human population, increased standard of living in the developing parts of the world, no apparent alternative large-scale energy substitute except for nuclear energy, and a known recoverable fossil fuel reserve of 3000–5000 Gt C, strongly suggest that anthropogenic emissions of CO_2 will double over the next century and that the fossil fuel era may last for several generations. Ocean storage of carbon dioxide (CO_2) has been proposed as an option for accelerating the natural net flux of CO_2 from the atmosphere into the ocean. Here we present results from a numerical modelling system that we have used to study the behaviour of CO_2 released at the Haltenbanken region in the eastern Norwegian Sea, and which indicate that injection sites located at about 1000 m depth could lead to efficient and long-term sequestration of CO_2 in the abyssal Atlantic.

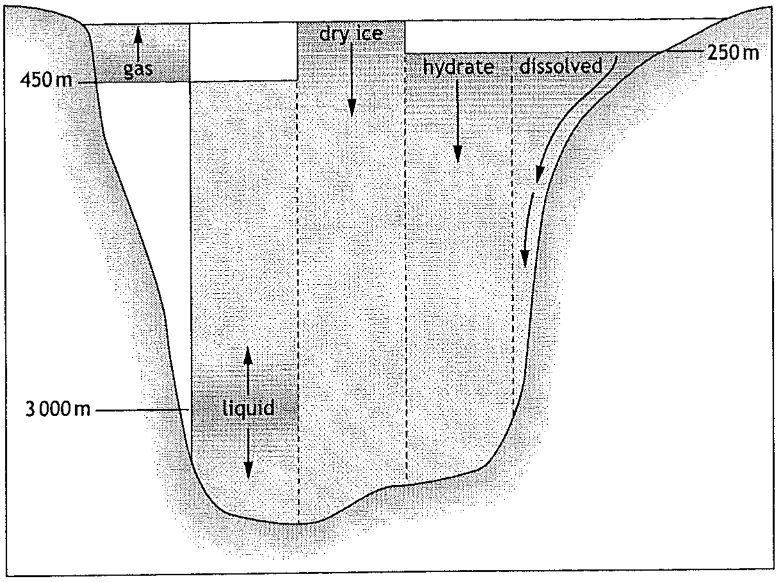
The world ocean waters and ocean sediments could absorb all but a few per cent of the CO_2 that would be released to the atmosphere if the known global fossil fuel reserves were utilized by conventional combustion schemes. Under present-day circumstances, about one-third of the annual fossil fuel CO_2 emissions of ~5.5 Gt C are absorbed by the ocean surface waters over 3–5 years. Unfortunately, the huge chemical absorption capacity of the marine environment is heavily rate-limited by the long (>1000 years) physical mixing time-scale between the world ocean surface, intermediate and deep waters, and the subsequent dissolution of sedimentary $CaCO_3$.

It is possible that atmospheric emissions of CO_2 could be reduced by improved energy efficiency both at the production end and at the consumer end, shifting from coal to oil, and from oil to gas, switching to renewables such as wind and solar power, and the use of, for instance, nuclear power. However, as suggested above, the availability of fossil fuel reserves worldwide, the increasing world population, and the urge for developing countries to improve their standard of living, will ensure that the fossil fuel era will continue well into the new millennium, with unforeseeable consequences for the global climate system.

It was therefore proposed by Marchetti (1977) that efforts should be made to accelerate the natural ocean uptake of atmospheric CO_2 by collecting the gas from point sources and releasing it into the ocean at appropriate locations, and at depths sufficient to avoid direct outgassing to the atmosphere. Marchetti identified the Straits of Gibraltar as a promising place – here the saline and dense outflowing Mediterranean water sinks to ~1000 m depth before spreading out over a large part of the Atlantic basin.

Marchetti was followed by Hoffert *et al.* (1979) who used a simple numerical model to examine the atmospheric response of ocean disposal of CO_2. Their model calculations were based on rather extreme emission rates (7000 Gt C released between 1900 and 2200), but the results show the effect of ocean disposal of CO_2, and indicate that injecting CO_2 into the ocean does significantly reduce the transient peak in the atmospheric CO_2 concentration. This result was later confirmed in similar studies and by using global three-dimensional ocean circulation carbon cycle models.

There are a number of different ocean disposal options, and the different options are closely related to the properties of the different phases of CO_2 for the various temperature and pressure



The various options for disposing of CO_2 in the ocean are constrained by the properties of the different phases of CO_2

Figure 1 *Overview of the different ocean disposal options, showing the depth intervals over which CO_2 in gaseous, liquid, dissolved, or solid (dry ice or hydrate) form, will ascend or descend in the water column.*

(From Alendal and Drange, 2001)

regimes encountered in the ocean, and to the density of gaseous, liquid, and solid CO_2 relative to the density of seawater (see Figure 1). Liquid CO_2 is more dense than seawater at an ocean depth of ~3000 m or more, while the density of dry ice is ~1550 kg m^{-3} and the density of pure CO_2 hydrate is ~1110 kg m^{-3}. It is therefore possible to dispose of fossil fuel CO_2 in various ways: blocks (or cylinders) of solid CO_2 will descend quickly through the water column, 'lakes' of liquid CO_2 will form if liquid CO_2 is released on the sea-bed at depths of 3000 m or more, and hydrates will accumulate on the ocean floor (cf. *Ocean Challenge*, Vol. 9, No. 2, pp. 10–11).

Carbon dioxide released in the ocean under conditions favouring hydrate-formation will be covered by a thin film of hydrate. The thickness of the hydrate membrane will depend on the ambient pressure, but will be small because of the lack of hydrate stability on the seawater side of the membrane. The lack of stability arises from the low chemical potential of dilute carbon dioxide in seawater. Theoretical estimates indicate that the initial hydrate forms rapidly, in the order of microseconds. Breaks in the thin hydrate film as result of stresses caused by (say) current flow, will therefore mend rapidly. In view of this, the mass transfer of carbon between the carbon dioxide and the surrounding seawater phases will be more complex than the situation usually envisaged by conventional two-film theories.

In addition, if liquid CO_2 is released between the condensation depth (at ~450 m) and a depth of ~3000 m, droplets of liquid CO_2 will ascend through the water column and partly or fully dissolve in the surrounding water because of the large difference in CO_2 concentration between the droplets and the ambient seawater. If the droplets of liquid CO_2 reach the condensation depth, or if CO_2 is injected at depths shallower than the condensation depth, bubbles of CO_2 gas will be formed.

Finally, the density of seawater increases as CO_2 is dissolved in it, and the increase in density may exceed 10 kg m^{-3}. An additional option is therefore to dissolve fossil fuel CO_2 in seawater (in a chamber, for instance) and release the dense, CO_2-enriched water on a sloping sea-bed, thereby creating a bottom gravity current that will transport the carbon to greater depths. Special care has to be taken to prevent the bottom-hugging gravity current so generated from moving at a constant depth in geostrophic balance, and therefore lifting off the bottom. This problem can be avoided by, for instance, releasing the CO_2-enriched water in a canyon.

Increased CO_2 concentrations in seawater reduce the pH value, with possible impact on the marine biota (Figure 2). The reason for this is that adding CO_2 to seawater will change the species composition of the carbonic acid system in seawater: reduced pH decreases the concentration of carbonate ion (CO_3^{2-}) and increases the concentration of dissolved CO_2, as the concentration of total dissolved inorganic carbon (ΣCO_2) increases. The change in the chemistry of seawater, together with the time that marine organisms are exposed to the affected water, are key input parameters for environmental studies. Modelling studies of diffusion and dispersion of the CO_2-rich plume at the injection site are therefore required to assess effects on marine biota in the immediate vicinity of the site. Such 'near-field' modelling of the released CO_2 will also provide information about concentration fields that can be used as a source function for larger scale models simulating the behaviour of the CO_2-rich water as it spreads through the ocean over longer time-scales.

In general (and irrespective of mitigation strategy) the marine disposal of CO_2 will only be successful if most of the CO_2 released in the ocean remains away from the atmosphere for centuries or more, if negative effects on the environment are negligible, if the energy requirements are small, and if the option is technically robust and economically feasible. For ocean storage of CO_2, the following questions are of particular importance:

- Is the storage method efficient? If the most of the injected CO_2 returns to the atmosphere within decades, the efficiency is low and the economic burden of separation, transport and injection is not justified.

- What will the biological impact be? Marine organisms, especially in the deep ocean, live in an environment with small fluctuations in the CO_2 concentration. Increased CO_2 concentration may stress the biota, both through lowered pH and through the increased CO_2 concentration itself. The extent to which animals will be affected will vary. Animals that form carbonate shells will be particularly vulnerable, but respiration of all animals (except marine mammals) will be affected, along with energy turnover and metabolism. A species identified as being sensitive to elevated concentrations of CO_2 is the open ocean squid (*Ilex illecebrosus*); on the other hand, the large worm (*Sipunculus nudus*) is believed to be able to tolerate them.

It is also possible that impurities such as metals and other gases associated with the CO_2 may affect marine life. Emphasis should be placed on minimizing the impact on biodiversity and ecosystems, and quantifying the risk of extinction of endangered species, including species that are as yet unknown in the deep waters. There could also be a negative impact on fisheries if fish eggs or larvae are exposed to elevated concentrations of CO_2 and corresponding reductions in pH.

The present situation

Over the last decade, ocean storage of CO_2 has been studied by means of numerical models, mostly by scientists in Japan, USA and Norway. The models range from (simplified) steady state bulk integrated models to (complex) high resolution two-phase droplet plume models.

As far as field experiments are concerned, the international Hawaii CO_2 ocean sequestration experiment, proposed by Howard Herzog and colleagues, is probably the most interesting project, and is currently the only experiment planned involving large-scale CO_2 storage. The project has been delayed because of problems with obtaining permits, and there are contingency plans for moving the experiment elsewhere, possibly to Norwegian waters. In addition, Peter Brewer and his group at Monterey Bay Aquarium Institute are undertaking a small-scale *in situ* experiment off the coast of California.

Ocean release of CO_2 at Haltenbanken: a case study

Oil and gas fields are already known, or are likely to be found, on the shelf and along the continental slope of northern Europe. Some of these fields are located in the vicinity of the particularly dense intermediate and bottom waters of the Nordic Seas. As a case study, we used a numerical model system to investigate the behaviour of CO_2 released at Haltenbanken, a continental shelf region off the coast of Norway at 65° N (see Figure 5). The CO_2 source could be deep water installations on the shelf or point sources on land. In either case, liquid CO_2 could be piped or shipped to the release site.

The numerical model system consists of four interfaced components: a near-source plume model (resolution < 10 m), a local three-dimensional large-eddy simulation model (resolution < 1 km), an intermediate scale three-dimensional Eulerian advection–diffusion model (resolution ~10 km), and a basin-scale ocean general circulation model (resolution 100–1000 km). The system is run with results from the smaller scale models as input to the next level up.

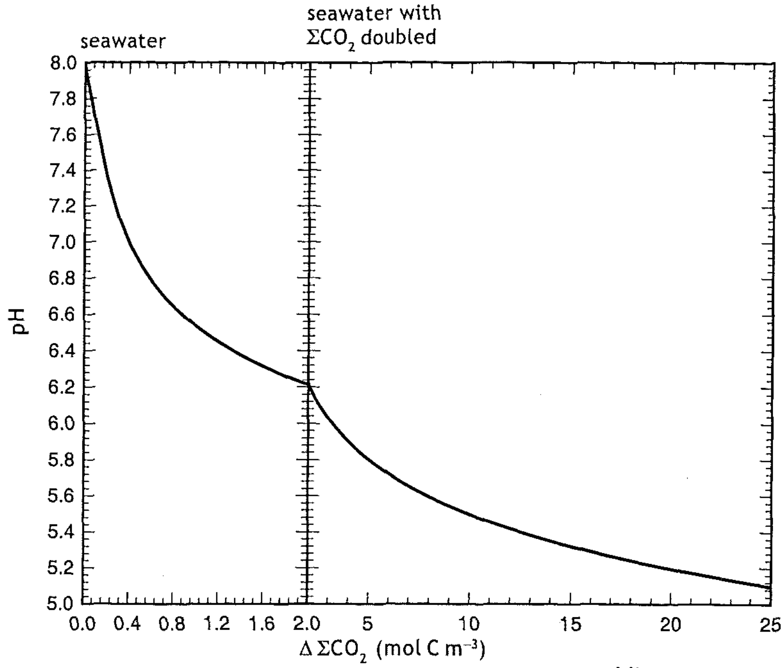


Figure 2 *Computed change in pH as CO_2 is dissolved in seawater at a pressure of 35 bar and a temperature of 8 °C. Here $\Delta\Sigma CO_2$ (mol C m^{-3}) denotes the amount of carbon added to seawater. Natural seawater has a pH value of ~8, and it contains ~2 mol C m^{-3} so $\Delta\Sigma CO_2$ = 2 mol C m^{-3} represents a doubling of the amount of dissolved inorganic carbon in seawater. Note the change part-way along the horizontal scale to allow the pH of small values of $\Delta\Sigma CO_2$ to show up.*

Adding CO_2 to seawater causes its pH to fall; doubling $\Delta\Sigma CO_2$ (increasing it by 2 mol C m^{-3}) causes seawater pH to fall from about 8 to just over 6

We assumed annual sequestration rates of 200, 400 and 800 Gg-CO_2, corresponding to CO_2 emissions from conventional 55–220 MW gas power plants. Release depths range from 350 m to 950 m, and it is assumed that the plant operates for 10 years.

Since liquid and gaseous CO_2 are less dense than ambient seawater at the depths considered here, clouds of CO_2 bubbles or droplets will form at the outlet nozzle and begin to rise. During the ascent, the large CO_2 concentration difference between the surface of the particles (i.e. the bubbles or droplets) and the surrounding seawater forces the particles to dissolve. The dissolution kinetics and near-field dynamics of the ascending particles, and the subsequent 'peeling off' of filaments from the dense, CO_2-enriched plume water, have been simulated by extending a dissolution model to an arbitrary number of particles, coupled to a buoyancy-driven plume model which uses conservation equations for mass, heat, salt, total dissolved inorganic carbon, and momentum.

We found that, for the injection rates and ocean depths given above, the plume will rise by at most 100 m if the initial particle size is 4 mm or less, and that a typical radial dimension of the plume is 5 m. In these calculations, possible formation of CO_2 hydrate has been neglected. If massive CO_2 hydrate films form on the particles, the dissolution rate will decrease and the plume will be able to rise higher. In this case, the reduced dissolution rate could be countered by having smaller particles, with a larger surface area to volume ratio, and this can be accomplished by increasing the pressure differential over the nozzle. Controlled experimental studies with single liquid CO_2 droplets have been carried out, but the effects of the size of the particles, and of turbulence and jet dynamics, on the dissolution rate of a cloud of hydrate-covered CO_2 particles, are still unknown. Field experiments, like a planned open ocean CO_2 sequestration experiment (see http://www.co2experiment.org), are required to clarify the effect of hydrate formation on the dissolution kinetics.

The CO_2-enriched plume water is dense because of the order-of-magnitude increase in the concentration of dissolved CO_2 in the water. Therefore, once CO_2 is dissolved, the plume water tends to sink in the water column, or to spread out on the ocean floor with potential impact on benthic organisms. To simulate this stage, the large-eddy simulation model was forced with CO_2 concentration and buoyancy fields from the plume model. Figure 3 shows vertical cross-sections through the centre of the CO_2-enriched water, assuming an injection rate of 200 Gg-CO_2 yr^{-1}, and a constant background current of 0.05 $m\,s^{-1}$. Figure 3(a) shows the flow pattern with one 'port' or nozzle, (b) the flow pattern with five. Note that in (a) the dense plume of CO_2-rich water reaches the sea floor before the main body of the water can be transported in the direction of the background current. As a result, water with pH < 6 is in contact with the ocean floor. As mentioned above, the acidity of CO_2-enriched seawater may affect marine life because most marine organisms are adapted to live in a relatively constant chemical environment. It is possible that lowering the acidity of seawater by 0.5 pH for a significant period of time could have sub-lethal effects on marine organisms.

Using one 'port' means that mixing of the relatively dense CO_2-rich plume with the surrounding seawater is restricted, so it sinks to the sea-bed and spreads along the bottom, both up-current and down-current. Use of five ports allows much more mixing and dilution, and avoids these problems

As shown in Figure 3(b), the acidification of the sea floor and of the surrounding water can be reduced by diverting the injected CO_2 through an array of ports oriented in the cross-stream direction. If the ports are 5 to 10 m apart, the plumes will interact with one another weakly or not at all, and the density effect and the acidification will be reduced. Acidification will also be reduced in the presence of a strong background current, so injection sites in regions with strong prevailing current systems are preferable.

As ambient water mixes with and dilutes the CO_2-enriched water, the density difference disappears, and the injected CO_2 follows the ocean dynamics as a passive tracer. This stage has been simulated by the Eulerian advection–diffusion solver with the initial concentration field and the source function taken from the large eddy simulation model. In this advection–diffusion model, the horizontal diffusion coefficient is given by the empirical expression $2.70 \times 10^{-7} t^{1.34}$, where t (s) is the time since the CO_2 was released. Quantifying the strength of the vertical mixing in the ocean is difficult as it depends on quantities like the vertical density stratification, dissipation of internal energy against topography, and velocity shear. On the basis of the hydrography of the Haltenbanken region, we have estimated the vertical diffusion coefficient to be between 5×10^{-5} and $5 \times 10^{-4}\,m^2\,s^{-1}$.

Our estimates for volumes and horizontal areas with a drop in pH between 0.1 and 1.0 are given in Table 1, for one and for five ports, and for background currents between 0.02 and 0.1 $m\,s^{-1}$. For a source of 800 Gg CO_2 yr^{-1}, the environmental impact volume – here defined as the volume of water over which pH drops by more than 0.1 – is ~0.5 km^3 (last line of Table 1, opposite). The corresponding horizontal area is ~18 km^2. These figures can be scaled up with the injection rate, as long as the number of ports is scaled accordingly.

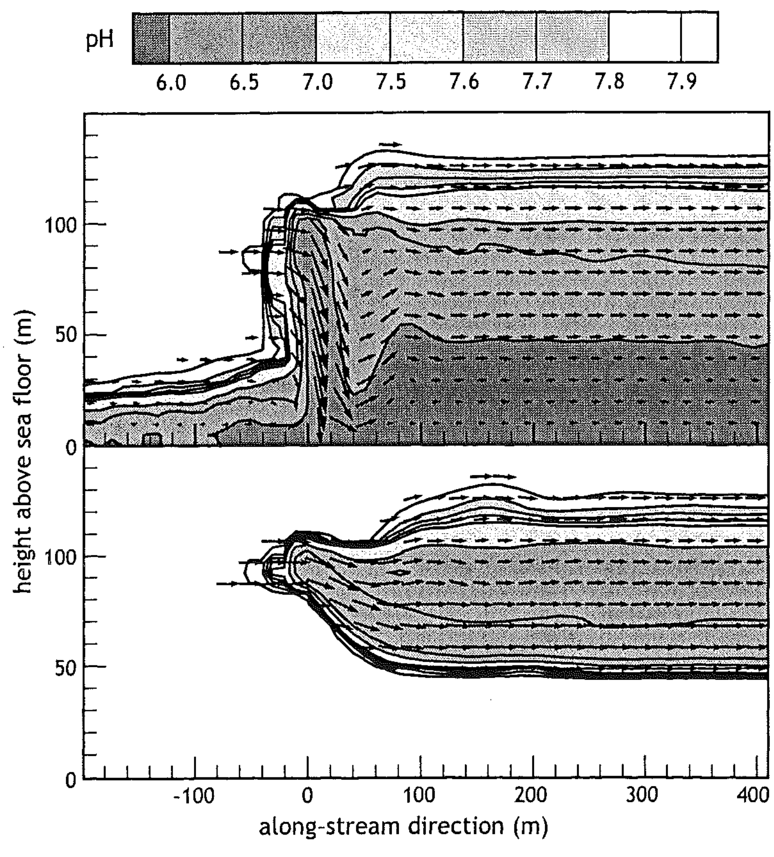


***Figure 3** pH-contours and velocity vectors generated by the large-eddy simulation model are displayed for an injection rate of 200 Gg-CO_2 yr^{-1}, and with a background current of 0.05 $m\,s^{-1}$ through **(a)** one port and **(b)** five ports (cf. bold values in Table 1, opposite). The vertical velocity profile, a result of the no-slip boundary condition at the bottom, increases the mixing close to the bottom, hence the upstream transport. The pH values have been computed assuming an ambient seawater pH of ~7.98.*

(From Drange et al., 2001)

Finally, the basin-scale mixing, transport, and subsequent outgassing of the released carbon has been simulated by a North Atlantic–Arctic version of a primitive equation, density-coordinate ocean general circulation model. The carbon distribution obtained from the advection–diffusion model has been integrated with a tracer module on-line coupled to the physical model, with a perturbation approach adopted for the computation of the change in the surface water concentration of CO_2.

The accumulated outgassing for a 10-year source of 800 Gg-CO_2 yr^{-1} located on the continental slope west of Haltenbanken is shown in Figure 4. For injection depths between 450 and 600 m, the accumulated outgassing exceeds 50% after 50 years, whereas the outgassing for the 950 m case is less than 0.4% after 70 years (the outgassing figures for the 200 and 400 Gg-CO_2 yr^{-1} cases are similar to the figures of the 800 Gg-CO_2 yr^{-1} case). Figure 4 clearly indicates that CO_2 should be released at depths greater than 600 m, possibly at depths greater than 800 m, in order to avoid rapid outgassing of the injected CO_2.

The difference in outgassing is caused by the oceanographic conditions in the region. If CO_2 is released in the upper ~600 m of the water column, some of it is mixed into the surface layer in winter, leading to some outgassing of the injected CO_2 later in the year. This is the reason for the zigzag pattern seen in Figure 4 for the first 20 years of integration for the 450 m and 600 m cases.

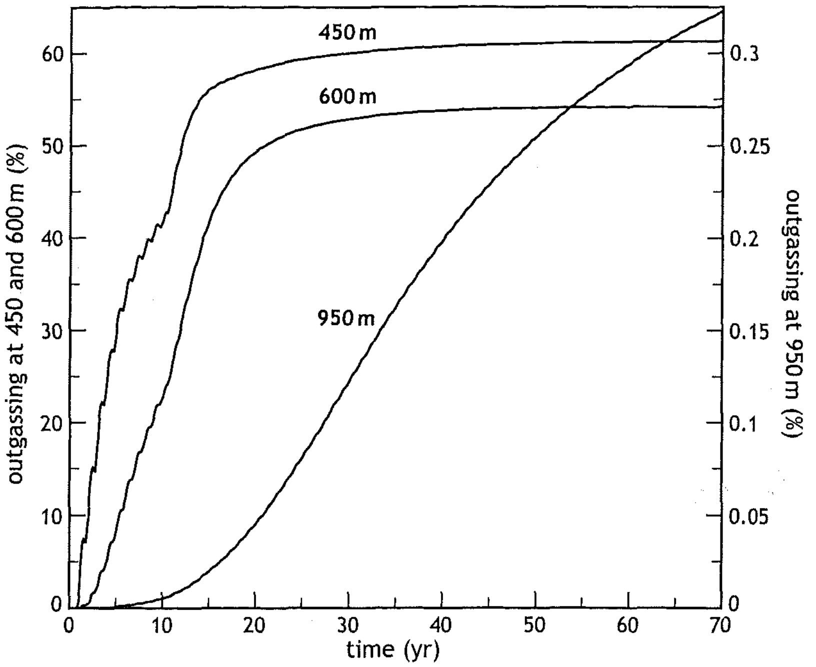


Figure 4 *Outgassing for a 10-year CO_2 source located on the continental slope off Haltenbanken at depths of 450 and 600 m (left-hand axis) and 950 m (right-hand axis). The release rate is 800 Gg-CO_2 yr^{-1}, and outgassing is shown as a percentage of the accumulated injected carbon.*

(From Drange et al.*, 2001)*

Modelling for the Haltenbanken site suggests that with injection depths of 450 m and 600 m, more than half the CO_2 would outgas to the atmosphere within 15 years

For the 950 m case, the CO_2-enriched water remains well below the upper mixed layer throughout the year, yielding almost no outgassing. In fact, the CO_2 injected at 950 m follows the movement of the intermediate water masses in the Norwegian Sea, and the major part flows into the Atlantic Ocean through the

Table 1 *Computed volume (km^3) of seawater with a drop of 0.1, 0.2, 0.5 and 1.0 pH-units, based on results from the advection–diffusion model. Data are shown for one and five release ports, injection rates of 200, 400 and 800 Gg CO_2 yr^{-1}, and background current velocities of 0.02, 0.05 and 0.1 m s^{-1}. The volumes are mean values from simulations with the vertical diffusion coefficient set at 5×10^{-5} and 5×10^{-4} $m^2 s^{-1}$. The bold type corresponds to the situations illustrated in Figure 3.*

(From Drange et al.*, 2001).*

Inj. rate (Gg CO_2 yr^{-1})	*Velocity (m s^{-1})*	*Volume with reduced pH value (km^3)*				
		0.1	*0.2*	*0.5*	*1.0*	
One port						
200	*0.02*	*0.730*	*0.124*	*0.013*	*0.004*	
	0.05	***0.198***	***0.046***	***0.004***	***0.001***	≺ ***Figure 3(a)***
	0.10	*0.042*	*0.006*	*0*	*0*	
400	*0.05*	*0.501*	*0.151*	*0.020*	*0.005*	
	0.10	*0.218*	*0.077*	*0.009*	*0.001*	
800	*0.05*	*0.425*	*0.153*	*0.026*	*0.011*	
Five ports						
200	*0.02*	*0.266*	*0.059*	*0.004*	*0.001*	
	0.05	***0.130***	***0.021***	***0.001***	***0***	≺ ***Figure 3(b)***
	0.10	*0.089*	*0.014*	*0.001*	*0*	
400	*0.05*	*0.380*	*0.076*	*0.006*	*0.001*	
	0.10	*0.260*	*0.046*	*0.003*	*0*	
800	*0.05*	*0.551*	*0.143*	*0.019*	*0.004*	

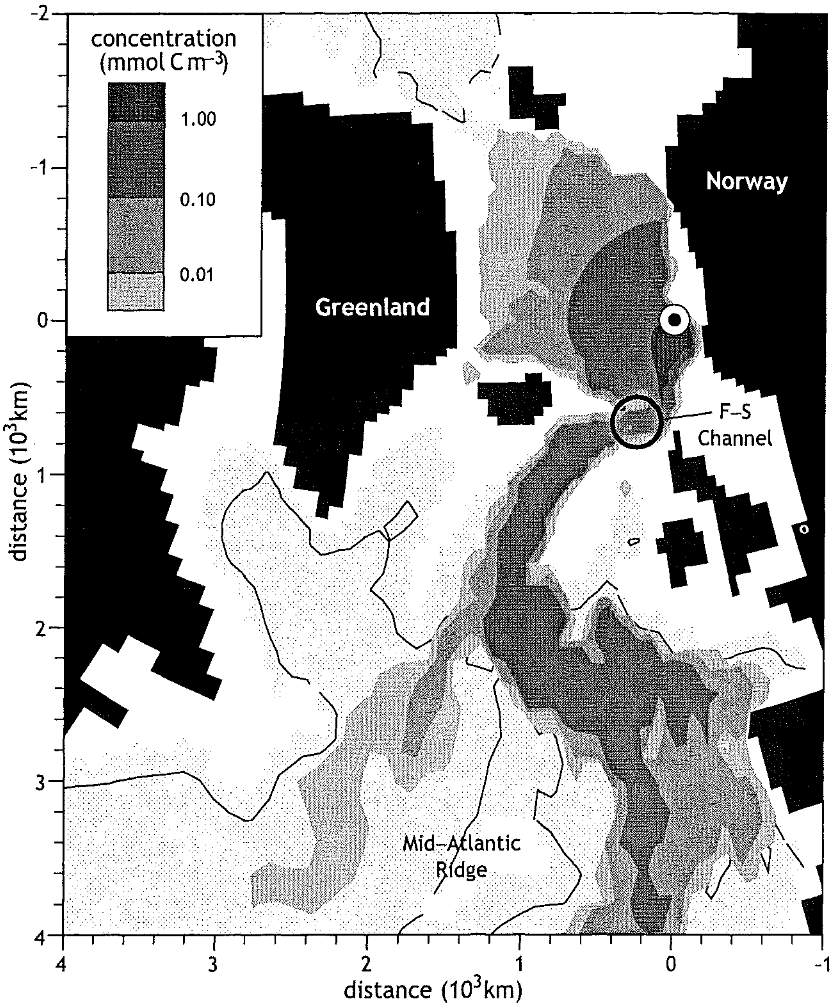


Figure 5 *Horizontal distribution of the water masses with the highest concentration of CO_2 at the end of year 10 for the 800 Gg CO_2 yr^{-1} case. The shading shows the concentration of total dissolved inorganic carbon in mmol C m^{-3}; the background concentration is ~2 mol C m^{-3}. The maximum concentration at the injection site is ~2.3 mmol C m^{-3}. Water deeper than 2000 m is pale grey, and the fine black line is the 3000 m depth contour; the axes show the geographical distance from the Haltenbanken site (bulls-eye). The black circle indicates the location of the Faroe–Shetland Channel (F–S).*

(From Drange et al.*, 2001)*

The model indicates that CO_2-rich water injected at the Haltenbanken site would spread north and west in the Norwegian and Greenland Seas, as well as south into the North Atlantic

Faroe–Shetland Channel, before it enters the northern part of the Atlantic Ocean as North Atlantic Deep Water (Figure 5). The overflow water will take part in the basin- to global scale thermohaline circulation with characteristic time-scales of centuries to a millennium. This means that the CO_2-enriched water masses in the deep Atlantic will remain isolated from the atmosphere for centuries, at least while the present-day ocean circulation regime continues. If ocean storage of CO_2 becomes operational, possible changes in ocean circulation need to be taken into account.

The drop in pH on the spatial scales resolved by the basin scale model, and for the given sequestration rates, is very small, typically 2 to 4 pH units, suggesting no biological effects. However, in the case of large release rates and several injection sites, basin scale effects on the marine biota cannot be excluded.

For a 80 km pipeline from (say) a production installation on Haltenbanken, and for an injection rate of 400 Gg-CO_2 yr^{-1}, the cost of investment and operation for liquid CO_2 injection, excluding the separation expenses, is expected to be ~$13 per tonne CO_2. Presently, the separation expenses for exhaust gas or for CO_2 containing natural gas are more than twice as high as the investment and operation expenses for transport and release of liquid CO_2. However, new separation techniques are being developed and tested with a potential saving in cost of >50%. This means that the total expenses may become comparable to, or even less than, the present tax of NOK300 (~$32) paid per tonne of CO_2 emitted from offshore installations in Norway. Technology for ocean storage of CO_2 at the depths, distances and amounts considered here is commercially available, and the necessary systems can be specified for installations with moderate engineering resources.

Conclusions

Before purposeful ocean release and storage of fossil fuel CO_2 can be made operational, theoretical results like the ones presented here require field experiment verifications for both a single source, and for the cumulative effect of many sources, including hydrate formation. Furthermore, it is of utmost importance that environmental issues, including direct and indirect effects on the marine biota and possible dissolution of calcareous sediments, are assessed. These effects should also be viewed in the light of ongoing and future acidification of the world ocean surface waters due to the natural ocean uptake of atmospheric CO_2. Since ocean storage will complicate quantification of the natural ocean sink of human-generated CO_2, and consequently the global carbon budget, a global ocean storage monitoring programme is needed. Finally, the example given in this study represents one realization of the mean advective spreading and dispersive mixing of CO_2 released off the coast of Norway. Small-scale variability and unresolved processes in the ocean environment will generate variability on shorter and smaller scales. To examine this behaviour, a high-resolution (eddy-resolving) ocean general ciculation model, driven by synoptic atmospheric forcing fields, is needed.

Finally, in light of the many challenges caused by human pollution of the atmosphere, it is clear that the different greenhouse gas mitigation options should be viewed as complementary and not competitive. The options should therefore be studied in parallel as they may all contribute to reducing the human-induced pollution of the atmosphere. For instance, a solution involving storage of CO_2 in geological formations, for example the Sleipner field in the North Sea, might be attractive for some locations, but impossible or totally unacceptable elsewhere.

Acknowledgement

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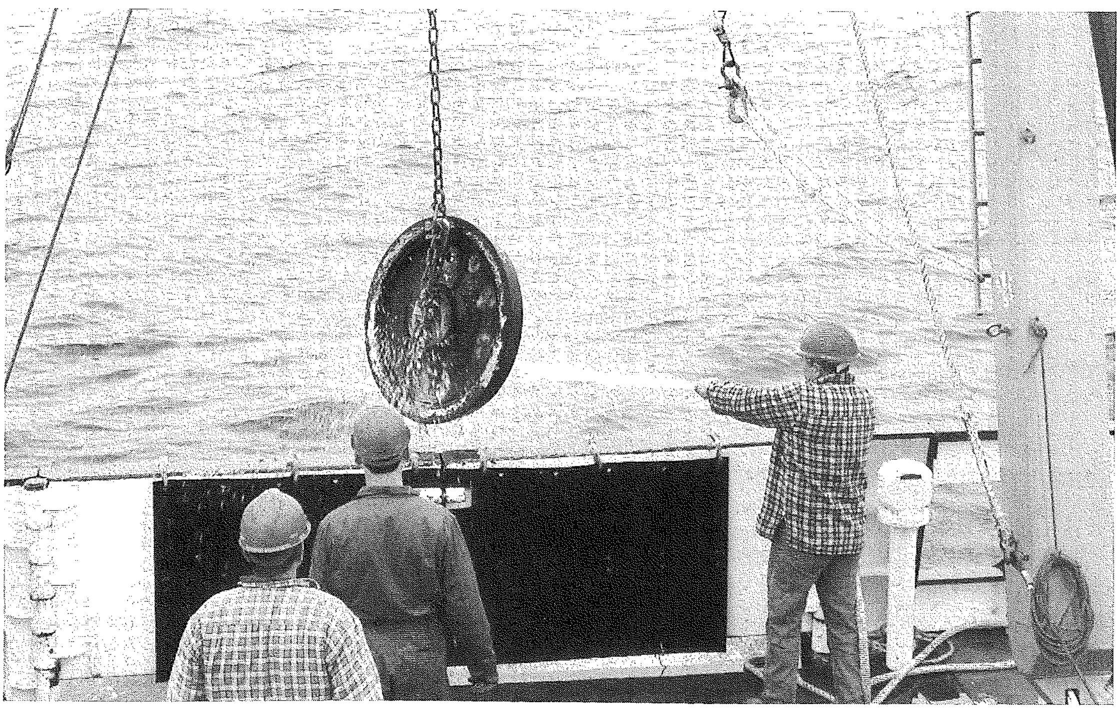
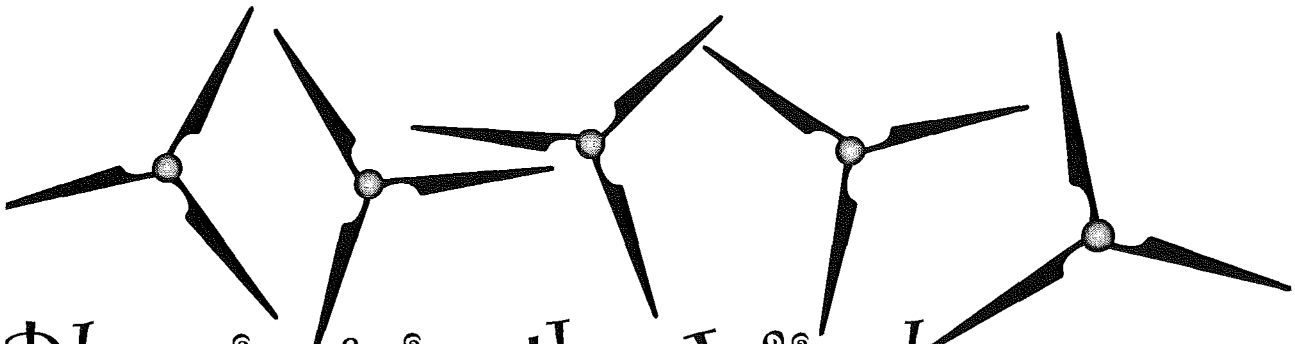
Bangor oceanographers think they have found the solution to sea-level rise ...



(With thanks to the the turbulence and mixing group at Bangor)



Blowing in the Wind

the future of wind turbines at sea

Jan Seys

If one phenomenon stirs up dust in coastal circles these days, it is the planned development of offshore wind parks in Europe. Considered a blessing by those who go all out to stimulate the use of renewable energy, there is no denying that the idea of offshore wind parks creates feelings of concern and impotence amongst at least some of the traditional users of the seas. Are these people tilting at windmills? What about the validity of their arguments and of those of the advocates of offshore wind energy? Let's have a closer look.

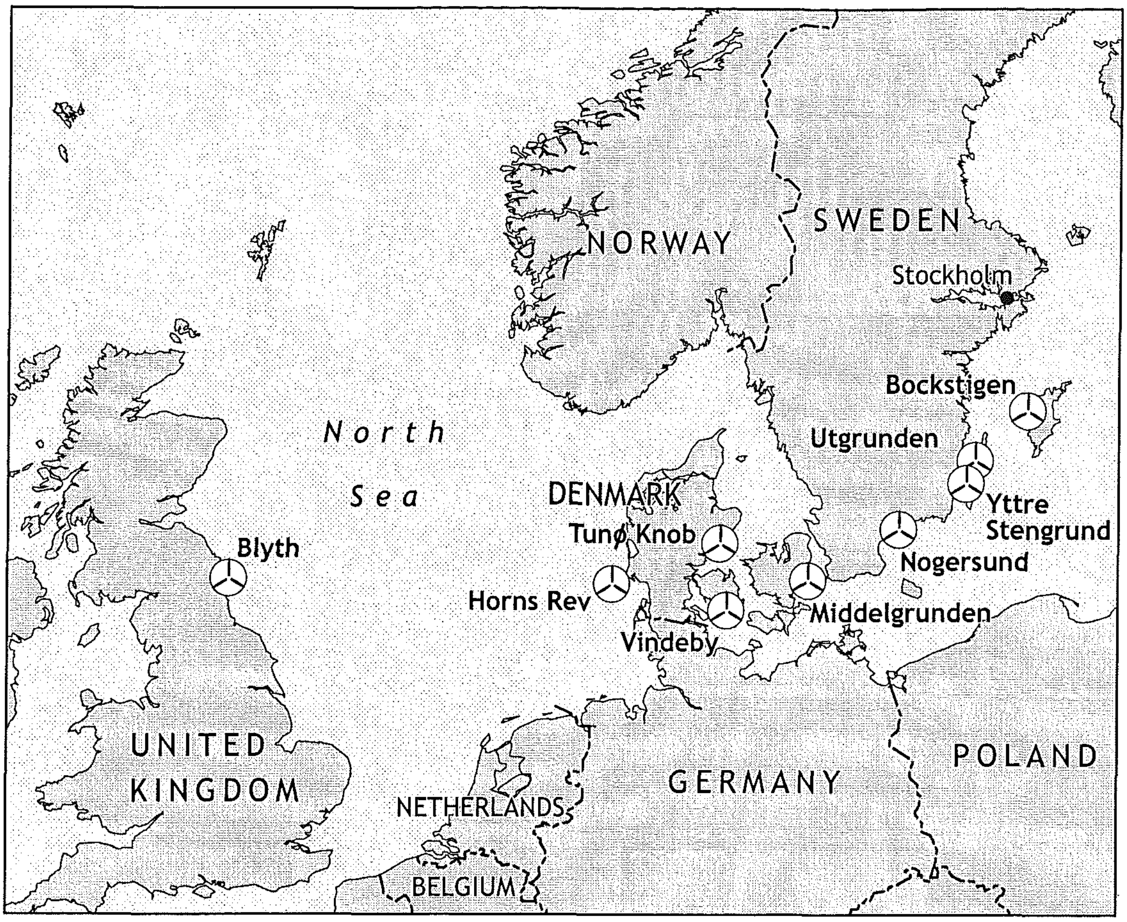
State of the art of a fast-growing industry

Wind is increasingly being used as an energy source worldwide. Today, the annual global capacity amounts to about 25 000 MW or the average energy consumption of 23 million people. Moreover, with a mean annual growth rate of about 30%, the future looks bright for developers of wind parks. Wind turbines have been installed, or are in the process of being sited, in all continents, including Antarctica. Europe – with pioneering countries Denmark, Germany and Spain – takes the lead with an installed capacity of 15 000 MW. Although the eight existing offshore wind parks so far contribute only 80 MW to this figure, it appears we are on the brink of important changes in this situation. Over the next ten years, plans will come to fruition for offshore parks from the southernmost tip of Spain to the icy waters of the Baltic, amounting to more than 20 000 MW (the equivalent of twenty large nuclear plants).

Table 1 *Operational offshore wind parks in Europe at present (2002)**

Built (year)	Country	Site	Number of turbines	Total capacity (MW)	Distance from the coast (km)	Depth (m)
1990	Sweden	Nogersund **	1	0.22	0.35	6
1991	Denmark	Vindeby	11	4.95	1.5–3	2–6
1995	Denmark	Tunø Knob	10	5	6	3–5
1997	Sweden	Bockstigen (Gotland)	5	2.75	4	6
2000	Sweden	Utgrunden	7	10.5	12.5	6–10
2000	UK	Blyth (Northumberland)	2	4	0.9	8
2000	Denmark	Middelgrunden (Copenhagen)	20	40	2–3	4–5
2001	Sweden	Yttre Stengrund (Öland)	5	10	5	6–9

** The Dutch 'offshore' parks Dronten and Lelystad have not been included because they were installed in fresh water.*
*** Abandoned in 1998.*



The large concentration of wind parks in Scandinavian waters reflects sheltered sea conditions and a more favourable political climate

Figure 1 *Map showing the sites of wind parks off northern Europe in 2001, and the Horns Rev park currently being erected off Jutland.*

Meanwhile, turbines are getting larger and more and more suitable for installation in windswept, unsheltered conditions, and the parks themselves are getting larger. The first generation (1991–1999) consisted of small parks (1–11 turbines) developed in bays and other sheltered locations, with turbines of less than 600 kW each (cf. Table 1). Since 2000, the turbine capacity has increased to 1–2 MW, and some of the turbines have been erected in rough seas with large tidal amplitudes (e.g. Blyth, north-east England). And if/when a pioneering phase with farms of 30–100 turbines of 2–3 MW each proves profitable in the near future, the next step might be the development of 'forests' of up to 500 wind turbines far offshore, yielding 1500-2500 MW of green energy (assuming a new generation of 3–5 MW turbines).

Does haste make waste?

On 10–12 December 2001, the European Wind Energy Assoiciation (EWEA) and the Belgian private consultancy 3E organized a special topic conference on offshore wind energy, in Brussels, attracting 500 participants from 29 countries. On this occasion, Belgium and France were praised for making major leaps forward in the development of wind energy projects. Although Belgium played a pioneering role by implementing one of the first coastal wind energy projects (21 turbines of 200 kW each) on a jetty of the outer harbour of Zeebrugge in 1986, no further offshore initiatives had been taken until recently. However, in 2001 three projects were put forward to place 290 turbines (615 MW) 5–17 km from the Belgian coastline – which itself is only 65 km long. More recently, a fourth initiative has been proposed in the more offshore location of the Thornton sandbank. So far, concessions have been granted by the Federal Secretary of State for Energy and Sustainable Development, Olivier Deleuze, for two projects of 50 turbines (100 MW), but only one of these will get an environmental permit from the Minister in charge of the marine environment, Magda Aelvoet. Even so, Belgium will achieve more in terms of installed capacity per square kilometre of sea than any other country in Europe.

The other side of the coin is that Belgium's fast-track procedure left very little time either for public involvement and/or participation, or for monitoring environmental impacts in a pilot phase of the programme. This seems to contrast with what happens in countries such as Denmark and Sweden, where at least some wind parks (e.g. Middelgrunden near Copenhagen) were conceived in close association with local communities, and where it took years to 'warm up' people to be receptive to the idea of wind energy. Today, Denmark gets 13.5% of its electricity from wind energy (enough for 1 million inhabitants) and has 16 000 people working in the wind energy business.

An open public dialogue right from the very beginning of the planning phase seems to be crucial for achieving social acceptance. That at least is what some northern countries have understood.

Look before you leap

NOVEM (a Dutch Centre of Expertise in Energy and the Environment) has calculated that for Europe to be provided with all its electricity requirements by offshore wind turbines, 58 000 km^2 of sea would need to be devoted to wind parks. This calculation is based on an installed wind power of 12 MW per km^2 and an average generating efficiency of 40%. With such a density of energy production, wind power would undoubtedly look very competitive compared with more traditional ways of energy production. If these figures are correct, it might be realistic to think of such a North Sea park somewhere far offshore within 10–20 years, with little or no interference with the best fishing grounds, tourism activities or bird migration corridors.

Unfortunately, today the situation is quite different. Although most people seem to support the idea of gaining renewable energy from the wind, very few would be happy if the turbines were constructed in their backyard. And since all present offshore wind farms, and most planned projects, target the shallow, coastal areas of the North Sea and the Baltic Sea – with their great value for tourism, fisheries and ecology – it is not surprising that developers and governments are meeting greater opposition than expected.

On the other hand, it goes without saying that energy production from a theoretically infinite source, that has the added advantage of not directly producing pollution, is worth investing in. In the context of the requirements imposed by the Kyoto Protocol regarding the reduction of greenhouse gases, wind power could be one of the most promising alternatives to other more polluting sources of energy. However, to make a well-founded choice, it is essential to have the correct information in order to decide what sacrifices must be set against the obvious advantages. And that's exactly where the shoe pinches. Policy-makers, researchers, environmentalists, and all those with interests in these coastal areas, have been taken by surprise. There is no doubt that at the moment we have insufficient scientific data and knowledge about possible negative impacts on the marine environment. Together with clear reasons for concern, as well as strong indication of other problems, this should lead us to adopt a precautionary approach – i.e. to monitor the impact of existing installations thoroughly before building many more.

Research actions speak louder than words: the 'bird problem' as an example

There are plenty of papers that elaborate on the presumed impacts of offshore wind farms on the environment. Most of them have been prepared by private consultants in the course of an environmental impact assessment (EIA) study, and they consist mostly of material recycled from other (terrestrial) 'studies' and claim to predict what might happen once the turbines were installed. Very few publications demonstrate what really happens after an offshore wind farm has become operational, a logical consequence of the fact that very little offshore capacity has been realized so far.

Noise and vibration transmitted down the tower into the water, both directly and via the vibration energy transmitted to the sea bed, might have an impact on marine mammals. Electrical fields surrounding the power cables might affect marine mammals and fish. Changes in the geomorphology and hydrodynamics within a wind park may have an impact on marine life there. And serious disturbance to the environment during the construction phase is to be expected.

As an example of the problems involved in predicting the impact of wind farms on animals, let's look deeper into possible effects on one of the groups most sensitive to this new development – birds.

All EIA's dutifully mention possible adverse impacts of offshore wind turbines on birds – direct loss of habitat, indirect loss of habitat due to disturbance, and collisions with turbine blades. As their next step, authors usually calculate how many birds are at risk on the basis of bird counts at sea performed by experts. Some go on to take the liberty of using collision figures or disturbance distances from terrestrial wind parks to underpin their hopes and prejudices that the effects on bird life will not be so bad after all. The truth is that at present there are no studies at all to indicate how many birds collide with offshore turbines. Collisions are to be expected mainly during poor weather conditions at night, when no observations can be made. Moreover, the chances of finding corpses afterwards are small, and radar studies, used to track flight behaviour of flocks of birds, are unable to monitor individual bird collisions with turbines.

However, what we *do* know is that wind turbines located on the coastline do cause direct mortality (Figure 2). Collection of corpses at the base of the 23 turbines on the eastern jetty of the Zeebrugge outer harbour (Belgium) revealed that an estimated 300–700 birds annually fall victim to the turning blades. Although the great majority of victims are gulls, in 2001 three Annex I species (i.e. highly endangered) of the *EC-Birds Directive* were also represented – two little terns, three common terns and a peregrine falcon (from a total of 55 corpses collected). However, this was apparently no reason for concern, in the light of plans to develop another fourteen 2 MW turbines along the western jetty of the Zeebrugge outer harbour, a location even closer to the next largest European breeding colony of common terns!

Similarly, at present it is very difficult to assess how serious the disturbance to resident birds and migrants might be at sea. Studies at Tunø Knob (Denmark), Ijsselmeer (The Netherlands) and Utgrunden (Sweden) all point towards avoidance behaviour by at least some species of seabirds. And although at Tunø Knob the effects on eider ducks proved not to be alarming, there are good reasons not to extrapolate these results to other species and larger farms. Or, as indicated by several speakers at an international workshop near Arhus, Denmark (Nov. 2001), on impacts of offshore wind farms on birds:

1. It is a reason for concern that most offshore wind farms are proposed for shallow areas where many resident and migrant birds congregate.

2. It is feared that the cumulative effect of a chain of wind farms all along the European coastline – where mass migration of many species occurs – might be worse than the sum of the effects of the individual parks.

3. Some species that are already threatened (scoters, divers) might be particularly sensitive to disturbance from wind turbines and hence be subject to major habitat loss. In fact, evidence can only be obtained after demonstration projects become operational in the near future.

The question remains: what will happen to a wind farm if the effects prove to be unacceptable? And what *is* unacceptable?

Information and communication: keywords for success

Social acceptance will be the key factor deciding the future development of offshore wind energy in Europe – acceptance that has to be achieved by creating an open dialogue early on in the project, and by investing in research. The latter must make sure that discussions can be held in the light of reliable background information, instead of having to rely on 'suspicions' and 'predictions'. To ensure that the results of these research and monitoring studies are as widely available as possible, scientists and governments must

Figure 2 *Decapitated little tern. The 23 wind turbines on the eastern jetty of the outer harbour at Zeebrugge kill 300–700 birds every year.*

Estimating the impact on birds of turbines at sea would be difficult, as it would hardly be possible to collect the corpses at sea

emphasize the need for networking with other European institutes and experts in setting up research programmes. By stimulating discussion and information exchange within the European marine science community, the available resources will be much more efficiently used and scientists will probably not be taken by surprise again. Wouldn't that be a real major leap forward?

For further information, see the website of the European Wind Energy Association: http://www.ewea.org/

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SCIENCE AS STAKEHOLDER

a proposal for Unique Science Priority Areas

Hjalmar Thiel

In recent decades, environmental concerns have resulted in the establishment of a wide range of protected areas in the terrestrial, freshwater and marine spheres. The relevant authorities recognize that different stakeholders have different interests and requirements, and may accordingly use different arguments for or against the establishment of protected areas. Although scientific arguments are frequently employed in these arguments, science *per se* has rarely been considered a stakeholder in its own right. In the interests of society as a whole, the actual or potential scientific use of an area should be sufficient reason for it to be selected for protection. Accordingly, a new concept for protective measures has been proposed: the Unique Science Priority Area (USPA).

The USPA concept

As the term Unique Science Priority Area suggests, science could be one of several potential stakeholders. It is recognized and accepted that other stakeholders might have an interest, now or in the future, but scientific research and monitoring projects should have dominant rights and should not be disturbed by any other usage. As the primary stakeholder, science would need to present sound arguments for protection of the area in question, and these could include precautionary measures. The arguments would not be those generally used for nature protection, i.e. the presence of endangered species or communities, and threats to habitats or biodiversity.

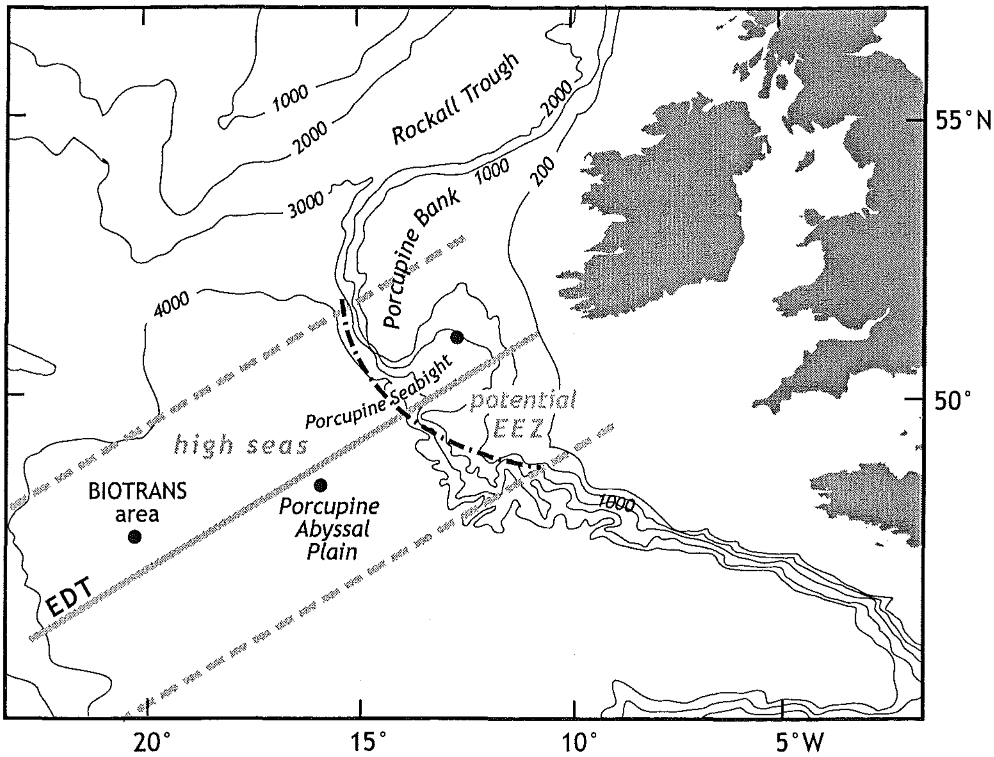
A proposed USPA on the high seas

A USPA is proposed for the European Deep-Sea Transect (EDT) in the north-east Atlantic Ocean (Figure 1). The EDT developed during the 1980s and 1990s, and connects three 'science hot spots' where the benthos and benthic processes have been intensively studied for many years. These are:

- The Porcupine Seabight, a wide and deep indentation in the south-western Irish shelf area, investigated in British programmes (~ 51° N, 13°W, continental slope depths to >3000 m). This is where phytodetritus from the spring bloom was first discovered in great masses on the sea floor.
- The Porcupine Abyssal Plain in the north-east Atlantic (~48°50' N 16°30' W, water depth around 4850 m), where British studies were concentrated, together with those funded by the European Community.
- The BIOTRANS area, centred around 47° N, 21° W, between 3800 m and 4600 m depth, where the German BIOTRANS and BIO-C-FLUX programmes concentrated their activities between 1984 and 1993. Because of these activities, the central north-east Atlantic JGOFS (Joint Global Ocean Flux Study) station was sited in this area, and understanding of how ecosystems function was greatly improved.

BIOTRANS and BIO-C-FLUX concentrated on biological transport and carbon flux in the near-bottom water layer, for the first time investigating a deep-sea area in mid-ocean and studying seasonal variability of ecological parameters, of standing stocks of benthos in different size groups, and of benthic processes. An even larger area was covered by NOAMP (North-east Atlantic Monitoring Programme) which involved physical and geological studies. The extent of German research activities in these overlapping areas is demonstrated by there having been no fewer than 25 expeditions or cruise legs in the region, and ships from other nations have also worked there. Tremendous efforts, large numbers of scientific and technical personnel, sophisticated technical equipment and large financial resources have been devoted to investigating this region. Similarly enormous resources have been devoted to the other science hot spots.

The data gathered from these three hot spots have given us a broad basic knowledge of deep-sea communities and ecological processes. Being close to Europe, these study areas will continue to be investigated for many years to come, and the existing datasets will serve as a reference for further basic research and biogeochemical investigations. Monitoring programmes in the context of climate change, in particular, should be conducted where a broad knowledge of the community has already been established.



The USPA proposed for the north-east Atlantic would protect scientific sites which have provided us with a great deal of valuable information, and would allow them to continue to do so in the future

Figure 1 *The position of the proposed European Deep-Sea Transect (EDT); the dashed lines indicate the extent of the buffer zone which would extend 100 n.m. either side of the Transect. Note that while most of the proposed USPA lies beneath the high seas, the easternmost part falls within a potential EEZ – the region currently declared by Ireland as an exclusive fishing zone.*

The results of basic and applied research conducted at these science hot spots are of general interest for society. Long-term series of data from the deep ocean are rare (as indeed they are from shallow waters) and it is essential for the evaluation of ecological variability in the deep sea that these specific localities remain undisturbed by anthropogenic impacts.

Potential anthropogenic disturbance of the NE Atlantic Ocean

If we try to imagine potential anthropogenic impacts in the areas selected for proctection, we see no particular danger in the near future. The north-east Atlantic Ocean harbours no mineral resources of any commercial value, so there is not likely to be any mining, and the use of the sea floor as a permanent repository for wastes is not possible under the existing regulations of the International Maritime Organization (although this ban is restricted to the 77 signatory states).

However, can we assume that this situation will remain unchanged for the long-term future? We need to consider this question carefully. Can we be absolutely sure that no dumping of wastes will occur during this or following centuries? No, we cannot! Between 1949 and 1982, low-level nuclear waste was dumped in the north-east Atlantic (mostly to the south-east of the proposed USPA) and sewage sludge has been discharged above the deep sea in other oceanic localities. Policies may change over long periods of time, and deep-sea disposal for some types of waste may one day become ecologically more advisable than permanent terrestrial storage. We have to think ahead on time-scales of several decades to centuries, for many generations (see, for example, *Ocean sequestration of CO_2*, pp.33–39 of this issue). Our descendents may be amused by, or even criticise, our precautionary provisions, but protective measures, i.e. avoiding future anthropogenic impacts and ensuring that selected regions are affected only by natural processes, can be never an erroneous judgement.

Having selected the science hot spots to be protected, it becomes essential to establish buffer zones to keep any anthropogenic impact at a safe distance. One hundred nautical miles (n.m.) on either side of the EDT connecting the three hot spots seems to be an appropriate provision, resulting in an area of >200 n.m. by about 500 n.m. However, these USPA limits may be refined with the help of physical oceanographers, to take into account the flow direction and speed of deep currents in the area. Stakeholder science has to define the mimimum size necessary for effective USPA protection.

USPAs and legal provisions

As non-lawyers, scientists would accept such a proposal without hesitation, but the legalities of declaring a protected area in the deep sea must be considered for two different situations:

- within Exclusive Economic Zones (EEZs), and
- on the high seas.

The United Nations Law of the Sea (UNCLOS) clearly gives a coastal state the right to use the resources on and below the sea bed within its EEZ, but it also assigns the responsibility for environmental protection to that state.

Protecting such areas falls within national jurisdiction, and the first protected areas within EEZs were declared over recent years by:

- The United States of America (large regions off the Hawaiian Islands for the mangement of the precious coral fishery).
- Australia (a series of seamounts for the protection of fish stocks).
- Norway (deep-water coral reefs of *Lophelia pertusa*).
- Portugal (hydrothermal vent regions to the south of the Azores).
- Also, in Britain, the protection of the Darwin Mounds region south of the Wyville Thomson Ridge (small mounds with *Lophelia pertusa* reefs) is under consideration.

UNCLOS has not assigned general responsibilities for protective measures on the high seas to any legal body, although the International Seabed Authority (ISA) has the role of regulating the mining of ores discovered in the Area (i.e. on the sea floor below all high seas regions), and in this context is also responsible for environmental protection. No national or international legislation is available for the declaration of protected areas on the high seas.

Request for UNCLOS amendments

Marine ecologists have been aware for some time of the serious threat to deep-water fish populations, and to coral reefs and their communities, by fishing for demersal and pelagic fish species which swim close to the sea floor. Populations of deep-living fish are characterized by longevity, late maturity, and low recruitment rates. Therefore, exploitation of those stocks results in short-term overfishing of these top predators, and fishing further down the food web progressively destroys lower trophic levels. In the case of shallow coastal waters, serious permanent changes in community structure and biodiversity have been impressively substantiated by Jackson *et al.* (2001) (see Further Reading), who have documented historical overfishing. In deep water, such effects have become apparent after only a few years, and recovery will be a very long process, if it occurs at all.

Scientists have also become aware of the legal problems hindering the establishment of protected areas on the high seas, and the difficulties in arriving at protective measures for species and communities, habitats and biodiversity. Various steps have been taken, notably during UNICPOLOS (United Nations Open-ended Informal Consultative Process on the Law of the Sea) or, in short, the ICP, the Informal Consultative Process.

These discussions were promoted by the Secretary General of the United Nations to consider shortcomings of, and propose amendments to, the 1982 UNCLOS, ten years after it entered into force in 1994. Three ICP meetings have been held during 2000–2002, with support for deep-sea protective measures coming particularly from the Australian delegation, the Worldwide Fund for Nature (WWF), the World Conservation Union (formerly the International Union for the Protection of Nature, IUCN), and others including the delegation from the EC. The international Expert Workshop, held on the island of Vilm in 2001, brought together legal experts, conservationists and marine scientists, and provided a broad basis for discussion (see *Ocean Challenge*, Vol.11, No.1) and their report was included in the 2001 Annual Report of the UN Secretary General.

The 2002 ICP report contains a specific section on 'Protection of marine biodiversity on the high seas' (see Further Reading). Thus, scientists and non-governmental organizations have successfully stimulated discussions on high seas protected areas. Regional (fisheries) organizations should implement protective measures, and the UN is requested to provide additional legal background to further this aim. Hopefully, these actions will become effective before there has been too much damage and destruction of high seas species and communities, habitats and biodiversity. Scientists need to cooperate to form a strong lobbying community, and must employ clear scientific arguments to steer the establishment of USPAs through the necessary administrative channels.

A European USPA for the OSPAR region

The Vilm workshop revealed another route for progress – the European step forward. During this workshop, legal experts expressed the opinion that the establishment of a protected area on the high seas by any state or group of states would not violate UNCLOS regulations. But they added that such a unilateral step would not be binding on other states and that therefore establishment of a protected area by a single state, or a group of states, might not be an effective way to protect scientific investigation in the long term.

At the core of these problems is the geopolitical situation. European countries do not need to act as individual units making unilateral decisions. The European Community (EC), as a group of states, may designate the EDT together with its buffer zones as a USPA, and the area would be quite well protected by its geographical position close to Europe. This USPA would fall into the OSPAR region (defined by the Oslo and Paris Convention), and under this Convention protective measures are already put forward for territorial seas, EEZs and the (common) high seas. The OSPAR region is limited to the south by the 36° N line of latitude and to the west by the 46° W meridian. The EC assumes rights to establish protected areas in the OSPAR region, and in the high seas this would not violate UNCLOS according to the above mentioned statements from the Vilm workshop. The proposed European USPA would result in effective protection because no other country is likely to use this region, for example as waste repository. The EC should declare the proposed USPA for the primary use by science as stakeholder, and the geopolitical situation would ensure long-term protection.

One problem remains to be solved: the north-easternmost part of the proposed USPA reaches into a potential Irish EEZ (see Figure 1). The Porcupine Seabight is situated within 200 n.m. of the Irish coast. Concerted negotiations between Ireland and the EC should allow the designation of the north-east Atlantic USPA with the extent shown in Figure 1, otherwise it will have to be curtailed by the outer EEZ limit.

USPAs and the freedom of the high seas

The 'freedom of the (high) seas' is a generally accepted principle, although the area of high seas has shrunk since the extension of the territoral seas to a maximum of 12 n.m., and the establishment of EEZs, which pushed back the high seas to 200 n.m. from the coast, or even more under certain conditions. USPAs are not intended to reduce the area of high seas still further. They are not thought of as separate from the high seas, but as a special part of the oceanic commons. USPAs are not intended to limit the freedom of the high seas, but to protect them from adverse uses. A compromise must be found between the freedom of the high seas on the one hand and their protection from human impact on the other.

In fact, many protective measures already exist for high seas regions, e.g. various regulations established by the UN Food and Agriculture Organization (FAO) or the Intermaritime Organization (IMO). For example: fishing regulations limit the freedom of the high seas, and so does the ban against discharging oil and other substances into the sea. Regulations effective in high seas areas set limits for certain actions, and it would be the same in the case of regulations to establish protected areas such as USPAs. All those regulations were laid down to combat anthropogenic contamination of the high seas and the loss of biodiversity, or to retain and regain sustainability of living resources. All regulations are issued in the interest of human populations or humanity as a whole. Nothing specific or secret is concealed in the proposal to establish USPAs. In the interest of humanity, science becomes the primary stakeholder for the protection of science hot spots.

Support requested for USPAs

The establishment of USPAs is essential for continued research by science as stakeholder, and a case has been made for the protection of the EDT and the three science hot spots by means of the north-east Atlantic Ocean USPA, in this and in earlier papers. European marine scientists, particularly deep-sea ecologists, and their societies, are requested to support this proposal. National delegations to OSPAR and EC meetings need to be convinced of the importance of setting aside areas as science hot spots, and by the need for priority for scientific long-term investigations.

Generally, marine scientists do not have the right background to formulate new regulations such as the development of the legal framework for protective measures on the high seas. However, now that scientists have made a case for USPAs and have put forward scientific arguments for their establishment, the follow-up steps must be taken by policy-makers, administrators and politicians. But they may need regular encouragement and advice to achieve the goal which scientists are aiming for. Lobbying is the keyword for further progress towards the designation of the EDT as an USPA, and other such protected areas on the high seas.

Further Reading

Jackson, J. B.C. *et al.* (2001) Historical overfishing and the recent collapse of coastal ecosystems, *Science* **293**, 629–38.

Thiel, H. (in press) Approaches to the establishment of protected areas on the high sea.

Thiel, H. and J. A. Koslow (eds) (2001) Managing Risk to Biodiversity and the Environment on the High Sea, Including Tools such as Marine Protected Areas – Scientific Requirements and Legal Aspects. In *Proceedings of the Expert Workshop held at the International Academy for Nature Conservation Isle of Vilm, Germany, 27 February–4 March 2001.*

United Nations Open-ended Informal Consultative Process on the Law of the Sea, 2002. Report of the meeting held at the United Nations Headquarter from 8 to 15 April 2002. Discussion Panel A: Protection and preservation of the marine environment. Section: Protection of marine biodiversity on the high seas, paragraphs 54–60 (updated 27 June 2002). See: www.un.org/depts/los/consultative_process/consultative_process.htm

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The Magazine of the Challenger Society for Marine Science

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To advance the study of Marine Science through research and education.

To disseminate knowledge of Marine Science with a view to encouraging a wider interest in the study of the seas and an awareness of the need for their proper management.

To contribute to public debate on the development of Marine Science.

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Ocean Challenge aims to keep its readers up to date with what is happening in oceanography in the UK and the rest of Europe. By covering the whole range of marine-related sciences in an accessible style it should be valuable both to specialist oceanographers who wish to broaden their knowledge of marine sciences, and to informed lay persons who are concerned about the oceanic environment.

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Articles for *Ocean Challenge* can be on any aspect of oceanography. They should be written in an accessible style with a minimum of jargon and avoiding the use of references. If at all possible, they should be well illustrated (please supply clear artwork roughs or good-contrast black and white glossy prints). Copy may be sent electronically.

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