Special European Issue
Volume 13, No. 2

OCEAN Challenge

Volume 13, No. 2, 2003
(published summer 2004)

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 and technological associations specializing in research and education pertaining to the marine environment.

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.efmst.org

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

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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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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Ocean Challenge is published three times a year. The subscription (including postage by surface mail) is £80.00 ($US 152) per year for libraries and other institutions. New subscriptions, renewals and information about changes of address should be sent to Parjon Information Services, PO Box 144, Haywards Heath, West Sussex, RH16 2YX, UK.

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OCEAN Challenge

The Magazine of the Challenger Society for Marine Science

SOME INFORMATION ABOUT THE CHALLENGER SOCIETY

The Society's objectives are:

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.

The Society aims to achieve these objectives through a range of activities:

Holding regular scientific meetings covering all aspects of Marine Science.

Supporting specialist groups to provide a forum for discussion.

Publication of a range of documents dealing with aspects of Marine Science and the programme of meetings of the Society.

Membership provides the following benefits:

An opportunity to attend, at reduced rates, the biennial five-day UK Marine Science Conference and a range of other scientific meetings supported by the Society.

A monthly newsletter (*Challenger Wave*) which carries topical marine science news, and information about jobs, conferences, meetings, courses and seminars.

The Challenger Society Website is
www.challenger-society.org.uk

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The subscription for 2004 costs £40 (£20.00 for students in the UK only). If you would like to join the Society or obtain further information, contact the Executive Secretary, Challenger Society for Marine Science, Room 251/20, Southampton Oceanography Centre, Waterfront Campus, Empress Dock, Southampton SO14 3ZH, UK;
Fax: +44(0)23-80-596149; Email: jxj@soc.soton.ac.uk

ADVICE TO AUTHORS

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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Cover printed by Trade Winds, London.
Text printed by Halstan & Co. Ltd, Amersham.

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Most of figures and maps were drawn by John Taylor of the Cartography Office at the Department of Earth Sciences at the Open University.

The cover was designed by Ann Alded Associates.

The cover photograph of the ROV Isis *descending into the water is by Chris German.*

A Message from the New EFMS President

The European Federation of Marine Science and Technology Societies was founded in 1998 by a group of European scientific societies and associations in the field of marine scientific and technological research and education. At present, the EFMS represents more than 5000 European scientists belonging to eleven societies (see map), but it aims to be much more than the sum of its parts.

Since its foundation, the objectives of the EFMS have been to contribute to the advancement of research and education in marine science and technology, and to promote their dissemination. These objectives, although clear and based on a real European need, are hard to achieve. Many of us are on the treadmill of searching for funds and publishing results, and national societies are busy with their internal affairs. As as a result, little energy remains for coordinating intellectual and educational initiatives that have no short-term or financial gain. Still, we have to make an effort to identify new research and technological perspectives and to attract students – future scientists – to marine research. We also need to identify new avenues of employment, and stimulate investment in marine science and technology.

In recent years, there has been a fundamental change in European science as it has become progressively integrated, with experience and technologies being exchanged between countries of northern and southern/western and eastern Europe. There has also been a growing awareness that the oceans are the world's most interconnected ecosystem. In both these contexts, marine science and technology societies have an important role to play.

EFMS has clear – and hopefully not overambitious – plans for the future. The first is to continue the process of enlargement by including not only those societies that have already shown an interest in joining, but also those of Eastern European countries, which are becoming an integral part of the enlarged Europe. I think that this progressive expansion of EFMS will be useful for all participating societies and their members. Indeed, EFMS might act as a forum for coordinating initiatives undertaken by individual societies or members, and disseminating, or even promoting them, to others. This could stimulate scientific activities throughout Europe and increase our interconnectedness.

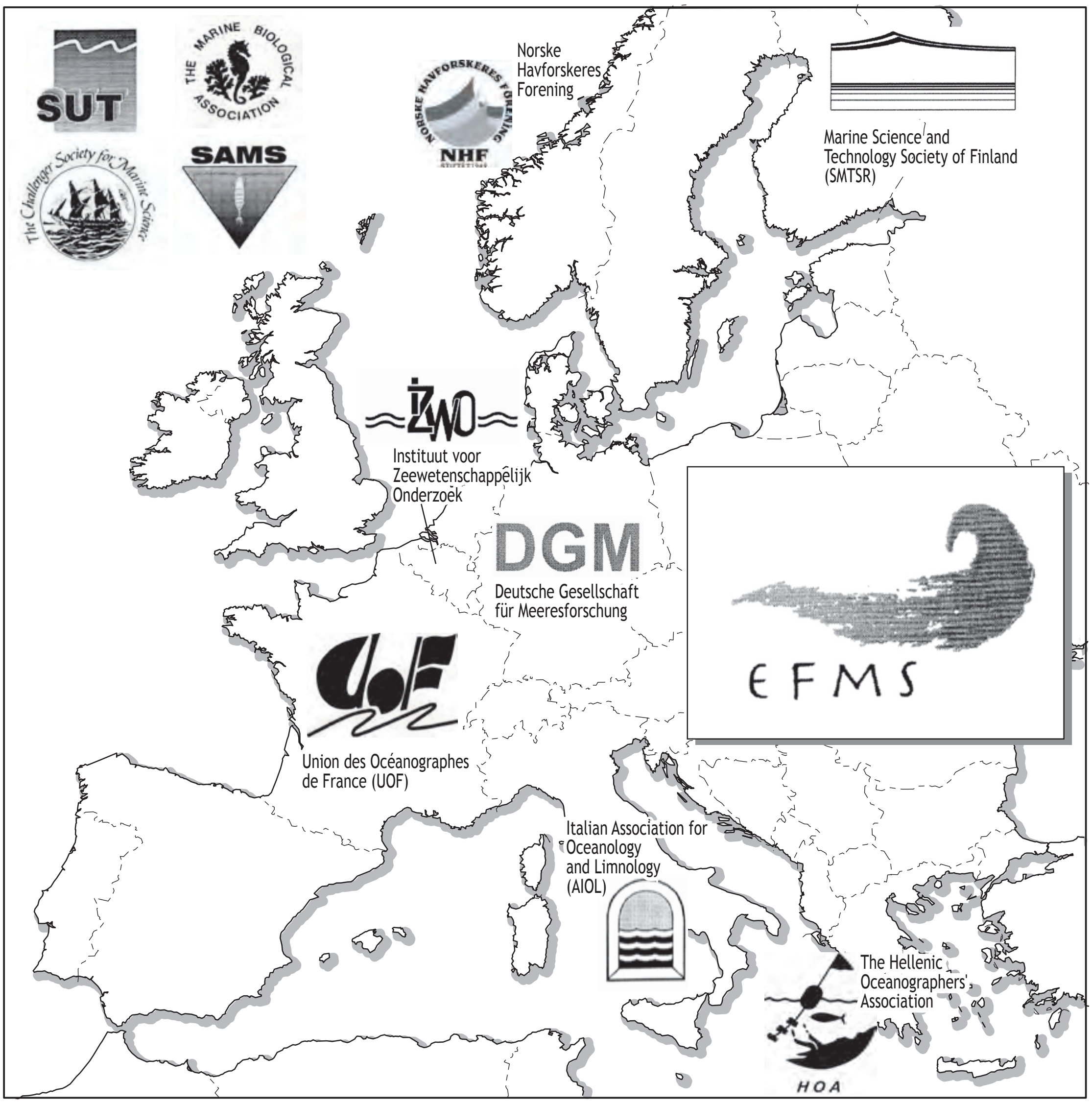
For instance, a forum on ethical aspects of research and exploitation of natural marine resources would have an important role in future European initiatives in the field of marine protected areas, marine biotechnology and so on. EFMS has already started a number of working groups, but we have to find a way of opening the discussion to as many members as possible.

EFMS does not intend to compete for funding with other research institutions, preferring to connect individual scientists and coordinate initiatives in order to create an interface between marine science and public opinion and politics.

Specific objectives for the next three years include:

- expanding the EFMS and making it more relevant;
- creating a network for communication and exchange among all members of associations and societies belonging to EFMS;
- creating a forum for addressing key issues such as environmental problems, and for identifying future 'hot topics' in marine science;
- improving links between EFMS and the EU so that we can pass on the findings of our working groups and forums to politicians and decision-makers;
- promoting the study of marine science among students by means of dissemination, the media, and increasing interaction with secondary schools.

continued opposite



Map showing the societies currently belonging to the EFMS. It is hoped that societies from Sweden, Spain and the Netherlands will join in the near future. The Estuarine and Coastal Studies Association (ECSA) is an Associate Member.

I sincerely thank the previous EFMS President, Graham Shimmield, for the work done over the past three years and for the help that he will be able to give me by virtue of his experience. In a previous issue of this journal he wrote: '*The challenge of EFMS is to place the marine realm at the core of developments within EU priorities*'. We are still far from that point, and much work still has to be done. Enormous amounts of money have been spent on landing on Mars, searching for martian water and looking for extraterrestrial life. In Italy, there is an old saying about people who do not recognize obvious and important things which are beneath their nose: 'They do not notice the water in the ocean'. Our planet is covered by water and more than 90% of the ocean volume is deep sea, yet we still do not know how many species there are in the deep ocean interior, waiting to be discovered; nor do we know what energy and resources could be exploited from the sea, yet we are looking to other planets. EFMS must act, through its members, to help politicians and the public to appreciate what remains unexplored in our world, and the benefits we can gain from the oceans.

With best wishes from myself,
and the two EFMS Vice Presidents, Manos Dassenakis and Graham Shimmield.

Roberto Danovaro
President of the European Federation of Marine Science and Technology Societies

Profiles of three founding member societies of the EFMS

Italian Association for Oceanology and Limnology (AIOL)

The AIOL was founded on 27 June 1972 by a group of scientists from the universities of Genoa, Naples, Padua, Rome, Trieste and Bologna, as well as the directors of the Hydrographic and the Hydrobiological Institutes, at Genoa and Pallanza respectively.

AIOL is financially supported by subscriptions from members, and occasional sponsorships by private and/or public institutions, as well as by payment of registration for the congresses. The number of registered members exceeds 400, and includes honorary, ordinary and junior members. Most belong to Italian universities, the CNR (Italian National Research Council), the ENEA (Italian National Agency for New Technologies, Energy and the Environment), and the Anton Dohrn Zoological Station of Naples.

The AIOL is governed by an Executive Board elected at the General Assembly, and the Assembly of Members meets once a year.

The aim of the Association is to promote interdisciplinary collaboration among scientists working in different fields of Oceanology and Limnology. AIOL also aims to disseminate scientific results and increase the participation of young scientists in research projects.

The National Congress is held every two years, with foreign scientists invited to give lectures at the plenary sessions in English. The official language of the Congress is Italian.

The papers of the proceedings are submitted to referees and are published, together with other peer-reviewed manuscripts, as *Transactions of the Italian Association of Oceanology and Limnology*. Proceedings can include all aspects of these disciplines and include contributions in Italian (with English summary) or in English.

A six-monthly Bulletin is sent to all members, informing them about the activities of the Association.

The current President is Professor Vincenzo Saggiomo, Stazione Zoologica Anton Dohrn, Naples.

Contact person: Dr Adriana Zingone, Stazione Zoologica Anton Dohrn, Villa Comunale, 80121 Napoli, Italy; Email: zingone@szn.it.

Website: http://www.aiol.info/

Union des Océanographes de France (UOF)

The UOF was created in 1968 and its first President was Dr Pierre Drach, Marine Biologist, and Professor at the Pierre and Marie Curie University, Paris.

UOF brings together approximately 200 researchers in marine science and technology, belonging to the various French private and public research organizations (INSU/CNRS, Ifremer, universities, INRA, IRD (ORSTOM)). The society is financed by subscriptions from members and member organizations.

Its objectives are:

1. To bring together all those concerned with teaching oceanography, oceanographic research and ocean management (researchers, students, technicians, sailors etc.) .
2. To broadcast the views and needs of members.
3. To inform its members about research programmes and the development of specialized organizations, research programmes, new ideas, job vacancies, etc..
4. To encourage the promotion and co-ordination of oceanographic activities such as teaching, research and development, mainly by organizing working groups, or the whole UOF, and by national and international symposiums.
5. To stimulate the necessary advancement of oceanographic structures.
6. To ensure the representation of its members in all legal situations and to organize contacts with national and international organizations dealing with oceanography and related activities.

The UOF organizes two symposia a year, one of which is the Young Oceanographers' Forum. Every three years there is a scientific Congress with the Association Française de Limnologie. In 1998 the UOF created a Research and Reflection Unit on the employment of young marine scientists.

The UOF publishes a scientific journal (*Journal de Recherche Océanographique*) and a newsletter (*Lettre des océanographes*). It has also pubished a *Directory of the French-speaking marine and freshwater scientists* and manages a database of marine and freshwater French-speaking scientists.

The UOF provides the EFMS Secretariat in Paris.

The current President is Professor Ivan Dekeyser, Director of the Centre Océanologique de Marseille.

Contact: uof@compuserve

Website: http://www.uof-assoc.org/

Hellenic Oceanographers' Association (HOA)

The HOA was established in 1986 by a team of postgraduate oceanographers from the University of Athens. Seven members are elected every two years.

Today it has 322 members, all of whom possess an M.Sc or Ph.D in oceanography. The Executive Board of HOA runs the Association, which currently includes 104 biological oceanographers, 73 chemical oceanographers, 83 geological oceanographers and 62 physical oceanographers.

The objectives of the association are:

1. To contribute to the advancement and promotion of oceanography in Greece.
2. To contribute to the promotion, improvement and dissemination of oceanographic studies at all levels (BSc., MSc., Ph.D).
3. To advance and protect the professional activities and rights of Greek oceanographers, in all fields relating to the marine environment (planning, research, protection, management, education).
4. To cooperate with the State, and with governmental and non-governmental organizations, in particular topics and projects, and in the planning of marine environmental policies.
5. To help oceanography students to successfully finish their studies and help unemployed oceanographers find a job appropriate to their speciality.

Some of the activities of HOA are:

- Organization of scientific seminars, meetings, conferences and conventions.
- Participation in scientific research in cooperation with universities and research centres.
- Participation in scientific conferences.
- Intervening and exerting pressure on the Government to solve problems that threaten marine and coastal environments.
- Social activities such as excursions, dancing nights, and speeches.

Every three months, the HOA publishes an 8-page leaflet entitled *Mesopelaga* to inform members about subjects that concern them. The leaflet is also distributed in many governmental and non-governmental organizations of Greece.

The current President is Dr Serafim Poulos, Depatment of Geology, University of Athens.

Contact person: Professor Manos Dassenakis; Email: edasenak@cc.uoa.gr

Website: http://www.oceanographers.gr/

Young marine scientists and career prospects in Europe

Report of the second CEMSE Workshop, Athens

Ilse Hamann

Secondary school graduates in Europe find many multidisciplinary study opportunities for marine science degree courses open to them. With sustainable management of aquatic resources a key component of the European economy, the specialist knowledge and skills of marine science graduates are indispensible, and such graduates have reasonable expectations for stable employment. However, the marine science community, policy makers, public agencies and private industry in environmental and maritime fields each have their own needs. Finding ways of matching the expectations of young marine scientists with the needs of prospective employers is a principal goal of the EFMS Working Group on Comparison of European Marine Science Education (CEMSE), which has been investigating the state of marine science education, and job prospects for marine scientists, throughout Europe.

Many people see marine science as a professional calling in itself. However, in view of the growing role that this discipline will play in the future, it is worth thinking beyond such idealistic notions and moving towards more wide-ranging professional training. At the second CEMSE Workshop, held the day before the Athens Conference,* it became obvious that, from the polar circle to the Aegean Sea, from Scotland to the Netherlands mudflats, and from the French Atlantic coast to the North and Baltic Seas, prospective oceanograpers have access to a wide range of marine science study programmes which provide a solid knowledge base for careers in marine science – and sometimes much more. Representatives from Greek, French, Norwegian, Scottish, Dutch and German universities described a range of marine science programmes, many of which are becoming more European.

Graduate programmes build upon foundations in the traditional scientific disciplines laid during the undergraduate phase (ending with the Bachelor of Science degree) and offer more specialized courses on techniques and research methods applicable to the ocean environment (ending with the Master of Science degree); these include individual student research projects, and the writing of theses. In addition to the study programmes presented during the CEMSE-II Workshop, and described here, there are numerous others which can be found via links from the EFMS website [1] compiled after the first CEMSE Workshop in Lille, France, in 2001.

Thus in Europe (as elsewhere), potential recruits to marine science are presented with an enticing array of university degree programmes at marine science departments attractively located close to the sea. Nonetheless, during the past few years many of these programmes have recorded declining numbers of first-year students. One reason for this may be uncertainty regarding job prospects for graduates in physical, biological, chemical or geological oceanography. A particular aim of the CEMSE Workshop was therefore for representatives from national member societies of EFMS and invited guests to share their experiences relating to this problem, and discuss previous analyses of the work status of people trained as marine scientists.

A key question in this context is: For new graduates in marine science, what can scientific and political establishments do to ease the transition from university to a sustainable career? To begin to answer this, we need accurate information about the professional situation of graduates from different marine studies programmes.

A wealth of marine science study programmes

Professor Maria Apostolopoulou from the Department of Marine Biology of the University of Athens began by presenting an overview of the curricula of the four-semester Masters Programmes in Biological, Geological, Physical and Chemical Oceanography at Athens University. Professor Manos Dassenakis and Dr Manos Ladakis from the Chemistry Department (University of Athens) then reported on results and conclusions of a study of job prospects for marine scientists in Greece, initiated by the HOA (the Hellenic Oceanographers' Association) [2]. Greece is a maritime country, and marine scientists make up the largest proportion of all scientists graduating from Greek universities (minimum MSc.). Most of these 600 marine scientists are biologists, and the next-largest group are those specializing in geology. Graduates are generally content with the quality of their study programmes but tend to be dissatisfied with the relevance of these study programmes to the job market; biologists are the least critical group in this respect. Overall, marine scientists employed in scientific research in Greece expressed their satisfaction with conditions at work but were dissatisfied with their salaries. Apparently, a higher proportion of marine science graduates from foreign universities have work, and they find their knowledge base sufficient for their jobs (most of those with foreign MSc. degrees obtained them in Great Britain and France; the majority of Ph.Ds are from the US).

In France, the UOF (Union des Océanographes de France) supports the RDV.Competences Network (RDV.Competences = Le Réseau de Développement et de Valorisation des Compétences). Christelle Caplat from the University of Caen (on the Normandy coast of the Channel) reported on her involvement with this network, which was founded in 1997 by young university graduates in France, and is available to students in the final phase of their education, along with researchers who are re-orienting themselves in their profession, and other professionals who use limnological and experimental oceanographic methodologies in their jobs. RDV.Competences plans to create a dynamic network for the exchange of information on (for example) job openings, and to develop a database of techniques used in limnology and marine science, as well as a database of experts applying such methods (to serve as a general resource).

Professor Philippe Ozanne from the École Centrale de Paris (Marine Technology), speaking on behalf of Professor Ivan Dekeyser (Marine Sciences), the President of the UOF, outlined the French educational system in general [3], and a number of marine science programmes in particular. A written compilation of marine science study programmes in France is available from the Oceanographic Centre at the University of Marseille [4].

In France, the Association Bernard Gregory, the FEDORA European Forum for Student Guidance, and the Employment

*See *Ocean Challenge*, Vol.12, No.1 for an account of the first scientific conference in Athens in Sept 2002, 'Oceanographical Aspects for a Sustainable Mediterranean'; www.efmsts.org/acts.htm

Service of the University Denis Diderot in Paris, have jointly published results of a survey of the professional situation of those with Ph.Ds in 15 European countries (sciences, arts, human and social sciences) [5]. This study does *not* distinguish marine scientists from other Ph.Ds, but nonetheless provides useful guidance for further analysis of future work prospects for this group.

EFMS President, Graham Shimmield, Director of the Dunstaffnage Marine Laboratory at Oban (Scotland) gave an overview of training possibilities and professional practice of marine scientists in Great Britain. He noted that, as in Greece, biological oceanography is the most popular branch of marine science (and physical oceanography the least popular). This reflects problems with the teaching of maths and physics in secondary schools.

Recently, new guidelines for UK marine science programmes have been designed with input from a number of agencies funding research and education, heads of marine science departments, and representatives from private industry. Assuming life-long learning, the programmes are tailored to suit a wide variety of students, e.g. high school graduates, mature students with vocational training, overseas students and interested amateurs, as well as student minorities with special needs. As part of the reform process, new technologies and standards were developed. For example, courses will be available to a diverse and geographically distributed group of students, with web-portals and educational pages disseminating marine information of general interest. National standards are being matched to the Quality Assurance Agency 'benchmark' for Environmental Science [6], and the quality of research and teaching will be regularly assessed.

For the new millenium, a comprehensive concept for interdisciplinary education and research has been developed in Scotland (all natural and social sciences, and the arts), with a strong contribution from the Scottish Association for Marine Science (SAMS). Thirteen colleges and research institutions distributed around Scotland are synergistically connected to form the University of the Highlands and Islands (UHI). Thanks to its decentralized structure, UHI can reach more people and more target groups. This extended access is one of the 'outreach' objectives of UHI, as is the engagement of local communities. It is hoped that the participation of local communities will mean that their needs will be better met in the future, via mechanisms such as local and regional partnerships, promotion of local ownership and management, and empowerment of local communities. Modern telecommunication technologies such as video conferencing, telephone, data networking, email and intranet are amongst the tools that will help to meet the logistical challenges faced by UHI.

It is not yet clear what role marine science will eventually play in UHI, but its definition will build upon the results of a study of the professional fate of environmental science Ph.Ds in the UK. Between 1995 and 1998, about a quarter of these were employed under fixed-term academic contracts, 7% had permanent academic posts, 15% worked in private industry, 12% found jobs in the government and public sector, and about 20% were unemployed. A smaller contingent was teaching in secondary schools or engaged in further training; and for about 20% of the Ph.Ds no data were available. From 1998 to 2000 the number of environmental science Ph.Ds declined from about 300 to 260, of whom about 10% left Britain to continue their careers overseas.

In its interdisciplinary approach, and with institutes spread over a number of islands of the Aegean archipelago, the University of the Aegaean in some ways resembles the Scottish UHI. Its Department of Marine Science was founded in 1997 at Mytilini on the island of Lesbos. Professor Mixalis Karydis from the Laboratory of Aquatic Ecosystems (Department of Environmental Studies, School of Social Sciences) explained that courses in fisheries management, aquaculture, remote sensing, operational oceanography, coastal zone management and marine microbiology are all being offered for third- and fourth-year studies in the BSc. programme. A one-year MSc. programme in Coastal Management is offered in co-operation with the Departments of Environmental Studies and Geography and the National Centre for Marine Research; this programme includes additional interdisciplinary courses on Integrated Coastal Zone Management, and on international policies in relation to the practice of coastal management. During the academic year 2002/2003 the Department of Marine Science was participating in the ERASMUS/SOKRATES programmes of the European Commission, which promote mobility of university students within Europe.

Professor Karydis was optimistic about job prospects for graduates of the Department's marine science programmes because the Greek government is passing legislation to ease the transition from university to careers where marine science training is regarded as an asset. For example, the Greek Ministry of Education is funding a project to enable students to have placements in companies and institutes. Furthermore, Presidential Decree 50/2001 guarantees that graduates may be accepted for environmental positions in the public sector. Another presidential decree in preparation acknowledges graduates' expertise as ichthyologists, and ongoing negotiations with the Ministry of Education should lead to acceptance of graduates as teachers in secondary schools.

Michael Scoullos from the Mediterranean Information Office for Environment, Culture and Sustainable Development, and Professor at the University of Athens, predicts an increasing demand for managers not only in the coastal zone but also for offshore areas. He enumerated several administrative and socio-economic challenges where marine science expertise could be put into practice, e.g. fisheries, mariculture, offshore industries, pollution (monitoring, risk minimization and damage assessment), recreational activity along the coast, and nature conservation in wetlands. Areas like these should be considered when marine science curricula are designed in the future and should be supported by appropriate teaching/learning methods. Prof. Scoullos recommends a problem-solving approach applied in the context of case studies, to elucidate the roles of everyone involved, including non-academic 'stakeholders', e.g. private industries, local and regional administrations, international organizations, and citizens living along and near the coast.

Aud Larsen (Microbiology Institute of the University of Bergen), representing the Norwegian Association of Oceanographers, introduced workshop participants to marine study programmes at four Norwegian universities (Tromsø, Trondheim, Oslo and Bergen), as well as at the University Centre in Longyearbyen on Spitsbergen (UNIS). In Norway, as in other European countries, there is a trend towards internationalization of marine science education; for example, a two-year MSc. programme in International Fisheries Management at the Norwegian School of Fisheries (University of Tromsø) is conducted in English.

Besides its regular marine science programmes, the Norwegian University of Science and Technology (NTNU) at Trondheim offers a two-year MSc. course on Marine Technology, which includes Coastal Engineering, Port Construction, Marine and Offshore Technologies, and Naval Architecture. With EU funding, NTNU has established three so-called Marie Curie Training Sites, where Ph.D candidates from EU countries can carry out part of their research with salary support and travel expenses. The NTNU Marie Curie Training Sites are intended for planktological studies, i.e. ecology, dynamics and use of marine plankton, marine cybernetics (modelling and control of hydroelastic structures), and fish 'value-added' food chains. The University of Bergen offers traditional BSc. and Masters programmes and Marie Curie Training Site programmes in marine ecology, comparative marine molecular biology, the role of ice–ocean–atmosphere processes in high-latitude climate change, sedimentary processes, and natural changes in European high-latitude oceans. At UNIS on Spitsbergen, less than half the students are Norwegian, and all courses are therefore given in English. Here, a Marie Curie Training Site programme has been established covering 'Aeronomy and remote sensing in the high Arctic – measurements and modelling'.

CEMSE Chair, Ilse Hamann (Institute of Oceanography, University of Hamburg) gave an overview of the five university locations where postgraduate marine science degrees are offered in Germany. These are Bremen, Kiel, Hamburg, Oldenburg and Rostock. Several international BSc. and Masters programmes supplement the traditional curricula.

At the University of Bremen, the two-year MSc. in Environmental and Marine Sciences aims to enhance the understanding and modelling of natural processes and their practical application in geoscientific problems relating to anthropogenic environmental changes on land and in coastal regions. Another two-year MSc. – International Studies in Aquatic Tropical Ecology (ISATEC) – is run in cooperation with the Centre for Tropical Ecology, and develops ideas and methods for sustainable use and conservation of tropical ecosystems. At Kiel University, a three-semester MSc. course in Coastal Geosciences and Engineering prepares students for professional careers in applied geoscience and engineering in coastal states such as Schleswig-Holstein, Mecklenburg-Vorpommern and Lower Saxony.

Students working towards their doctorate also find interesting opportunities in Europe's universities. In Hamburg, for example, two International Max Planck Research Schools opened their doors in 2002, inviting German and foreign students to prepare doctoral theses in a structured format and offering excellent research conditions for a period of three years. The International Max Planck Research School for Earth System Modelling offers opportunities for multi- and interdisciplinary Ph.D studies in numerical modelling applied to climate research, and the science of the Earth system. Amongst important scientific questions addressed are:

- How will human activities (economic development, population growth, policy implementation etc.) affect climate in the future?
- Will the percentage of additional carbon removed from the atmosphere grow or shrink in the 21st century?
- What physical/chemical/biological mechanisms stabilize the greenhouse effect of the atmosphere in the long term?
- Is the Earth system at all manageable in terms of long-term 'climate steering'?

Marine science and the 'real world'

The other International Max Planck Research School at Hamburg is in the field of Maritime Affairs. This will also take an interdisciplinary approach, enabling students to combine scientific and economic research, and hence to analyze the present legal framework for maritime affairs, and formulate sound suggestions for policy makers. Hamburg, as a harbour city, has other institutions and bodies dealing with maritime affairs, including the International Tribunal for the Law of the Sea. Similar goals are pursued at the graduate college Habitat North Sea Coast at Bremen University, which tries to counteract the tendency of Ph.D students to isolate themselves while working on their (generally) highly specialized theses. At this college, relationships and interplay between environment and society in coastal regions of the North Sea are studied in an interdisciplinary way, and at different space-scales and time-scales.

A felicitous example of dialogue between science and stakeholders was described by Margot Bik, co-ordinator of ProSea, a marine education foundation in the Netherlands. Once a year, the Marine Environmental Awareness Course for Students and Officers in Maritime Shipping is offered free of charge (and in English) on the island of Texel. Lectures address topics in marine science as well as economic and legal problems, and the programme is interspersed with short excursions to the tidal flats (followed by evaluation of observations and catches), visits to the exhibitions at EcoMare and the Maritime and Beach Museums, and other joint activities. On the last day of the four-day course, participants divide into five groups to discuss one of five shipping-related propositions. The results are then briefly presented to all participants along with a panel of external experts representing different organizations or groups involved in maritime shipping (e.g. shipping companies, the Ministry of Traffic, Public Works and Water Management, the North Sea Foundation, Marine Science, interested laypeople), and a discussion follows.

The value of cross-cultural experience

In order to achieve optimal results and lead to adequate employment, study programmes and guidance need to be complemented by initiatives on the part of students themselves. Career planning should be an essential part of the student curriculum, which ideally should also include time spent at a foreign university. One objective of the trend towards internationalization in Europe's university departments is the establishment of profitable business links with those graduates who expect to establish themselves abroad in the future. Such relations would benefit from German counterparts who have some intercultural experiences themselves.

Professor Hans Hartmann (Marine Biology and Ecology Laboratory (LBEM) at the University of La Rochelle, France) described his experiences as co-ordinator of a number of intercontinental exchange programmes in Europe, and in North and Central America. Bilateral or multilateral intercontinental scientific exchange of post-BSc. students, as well as of lecturers and researchers, should facilitate communication when different nationalities work together to try to solve environmental problems. Thanks to funding from the US Department of Education and the EU, trans-Atlantic and transdisciplinary links in science and languages are being established by infusing traditional language learning with a curriculum suitable for marine science students (Marine Science Student Mobility Program). Participants in the first three-week linguistic and cultural transition course came from three European and three North American partner institutions, and Professor Hartmann later co-ordinated another exchange programme with partners from Central America. He recommends that active consortium members familiarize themselves with three languages, e.g. English, Spanish and French. He also believes that exchange programmes work better if schedules at participating institutions are compatible (semesters, terms, quarters), grades and credits are acknowledged mutually (e.g. as in ECTS, the European Credit Transfer System [7]), institutional resources are comparable (laboratories, personnel), and faculty members not directly involved in the programme are cooperative. The planning phase should be sufficiently long, and integration of other disciplines into the programme (e.g. economics and liberal arts) is an advantage. Synergistic effects may be possible if the exchange project can build upon established intergovernmental treaties or agreements, and if the experiences of others can be utilized. Each project needs a long-term financial strategy (EU funds are available for the start-up phase only) and evaluation of the programme should be an integral part of the proposal from the beginning.

Hartmann pointed out that students participating in these exchange programmes acquire qualifications for international tasks which are valuable 'recruitment assets' for developing their careers; while faculties benefit from the extra stimulation and heightened awareness gained by involving themselves in such programmes. The host universities will also increase their visibility and gain recognition both nationally and internationally.

Self help

For a young person with a degree involving ocean science, it should not be too difficult to adopt the motto 'think global, act local' and use the scientific insight gained during study (if possible augmented with knowledge of wider socio-economic implications) to look for, and find, a personal route to involvement in, or initiation of, a marine (science) project that provides gainful employment.

Useful hints can be found in Peter Fiske's books *Put Your Science to Work* [8] and *Graduate School and the Job Market of the 1990s: A Survey of Young Geoscientists* (co-authored by C.M. Golde) [9]. An important message from these publications is that in looking for employment it is better to present one's specific knowledge about the ocean as an 'add-on' qualification and to highlight the more general skills that are transferable to a variety of professions. Amongst these transferable skills are a proven ability to work independently (demonstrated by a completed Masters or Ph.D thesis), effective communication (who hasn't given a seminar, most probably in English?), structured reporting (an ability documented by scientific publications and project reports), raising funds (acquisition of finances for a research project), and managing them (providing accounts and justifying expenditure). Instead of joining the chorus 'jobs for marine scientists are steadily decreasing', it is better to analyze the situation thoroughly and understand the implications for one's own personal circumstances. With great insight, Fiske describes a systematic approach to career management and planning, following a sequence from self-assessment to exploration of the world of work, while focussing on specific opportunities and the actual job search.

Conclusions

To summarize, the Athens Workshop identified the following steps as likely to be useful in improving the situation for marine science graduates wanting to make the transition from university education to employment:

- Analysis of the work situation of marine science graduates in all European countries, starting with an extension of the GOA study in Greece to the other countries represented by the EFMS.
- Evaluation of career advice services with respect to placement of marine science graduates, including those advice centres on campuses and at recruitment fairs, along with private foundations and organizations (e.g. the Association Bernard Gregory in France) and 'head-hunter' companies (also information about job exchanges and networks which can be found in various media).
- Evaluation of the effectiveness of expert databases for the placement of marine scientists into jobs, and/or brokering contracts for expert or appraisal reports (e.g. services such as scientific translation).
- Development and opening up of additional fields of professional activity for marine scientists, e.g. in local, regional and federal administrations. Also, investigation of what additional legal or business and administrative training is available to science graduates.
- Ministries of Education in Europe might follow the Greek example and ease the transition for marine science graduates into careers in secondary teaching.
- Intensifying the dialogue about marine environmental topics amongst a variety of societal groups, e.g. by increased efforts in public relations by marine science university departments and research laboratories, and by participatory governance of coastal zone and marine matters [10].

If 'brood care' of marine science fledglings is to succeed, securing the continuation of this population, a degree of flexibility is called for from everybody concerned. While we observe readiness in the universities for the challenges at hand, certain legislation is presently sending at best mixed messages. For example, the bill recently passed in Germany, to limit the length of fixed-term contracts to no more than six years after the Ph.D, ignores the realities of funding and employment, and does nothing to promote the supposedly desirable 'horizontal mobility' of scientists between the public sector and private industry. In fact, those of us who have been living on short-term funding, and whose 'soft-money' positions have consequently been fixed-term, will be undeservedly excluded too early in our careers from large areas of professional activity where marine science expertise should be an asset. This kind of development will certainly *not* help secure the future for young oceanographers.

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Links to all projects/progrmmes referred to in this article may be found on the efms website [1].

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Marine Research in Europe

Tony Mayer and Niamh Connolly

Plus ça change, plus c'est la même chose! *Alphonse Karr*

The European Science Foundation (ESF) last featured in *Ocean Challenge* in 1998.* Four years on, it is pertinent to look at the changes which have occurred over the intervening period.

Political changes

Perhaps the most significant change has been political acceptance of the need to put science and research at the forefront of European development. In June 2000, the Lisbon European Council (the Heads of Government of the EU) endorsed the concept of a European Research Area (ERA) and pledged themselves to make the EU the world's leading knowledge-based economy by 2010 – quite a target! Then we saw the introduction of the Bologna Process on higher education which seeks to achieve common standards for degrees across Europe which, hopefully, should in turn lead to greater mobility and exchange in this sector (www.unige.ch). Together, the ERA and the Bologna Process could be said to represent the new 'European Knowledge Area'.

However, while it's easy for politicians to make political declarations (especially about research), implementation is another matter. Indeed, in the 12 months following the Lisbon Council, the percentage of GDP devoted to research and development, whether private or public sector, actually fell! Perhaps that is why the Heads of Government meeting in Barcelona in March 2002 committed themselves to achieving a 3% GERD† by 2010, two-thirds of which is expected to come from the private sector. Without a coordinated effort across Europe, in tandem with fiscal incentives and additional public investment in research at the national level, this may well be another case of good intentions not followed up by concrete actions.

However, let's be positive and accept that once EU governments honour these obligations, research, including marine research, can expect to benefit from new injections of finance. Already new ways of working are being developed, which should materially aid European research. One such proposal is a European Research Council (ERC) – a major funding agency, acting at a European level, providing mechanisms for competition and funding within Europe. An ERC will also provide Europe with the leadership in research which it has long sought. While this is an idea whose time has come, it is a sobering thought that it was first proposed in 1971. Nevertheless, at least there is now general acceptance that such a structure must be created, and it is expected that the Irish and Danish EU Presidencies will provide its political launch in 2004. In the meantime, the idea is being studied by the ESF (which has recently published an independent report on the topic: http://www.esf.org/newsrelease/63/ERC.pdf) and by the ERC Expert Group (http://www.forsk.dk/eng/eupresidency/index.htm).

Although a major contribution to the ERA, the EU's Sixth Framework Programme (FP6) is only one of a number of activities. Nevertheless, the European Commission and FP6 are still ofen constrained by bureaucratic inflexibilities, imposed both from within and without, including by the European Parliament. It has to be said that in the private sector such rigidity would not be acceptable, and the result is a funding mechanism difficult for researchers to grasp and appreciate.

A disappointing aspect of ERA development – one that is close to the heart of marine research – is support and development of research infrastructure. At the Strasbourg Research Infrastructure Conference** in September 2000 it was recognized that a new approach was needed and that research infrastructure is a matter of common concern, where we must all act in concert; nevertheless, governments have reserved this matter for national action so that (for example) we still replace or build new research vessels as national facilities, without taking into account the added value that would come from a European research fleet.

So what contribution have the ESF and its Marine Board made to the ERA and to changing research in Europe?

Contributions by the ESF and its Marine Board

Perhaps the most important recent contribution within the ESF has been the development of new research support mechanisms, especially EUROCORES (European Science Foundation Collaborative Research Programmes) and the ESF's 'Scientific Forward Looks'.

EUROCORES

EUROCORES is designed to provide a framework for competition for funds to undertake fundamental science, so that funding goes only to the best in Europe. It is a new departure for the ESF which hitherto has functioned only as a networking body. EUROCORES operates at the European level, through the ESF, with agencies coming together to define calls for proposals and agreed work programmes, receiving collaborative proposals, having a single peer-review system and post-award networking of the successful groups. What remains at the national level is funding of the research groups by the subscribing funding agencies (the ESF Member Organizations). EUROCORES has been a matter of 'learning by doing' and encouraging national research agencies and organizations to work together. This has not been easy and has demonstrated the many bureaucratic rigidities that exist nationally across Europe. Gradually, as the agencies have learnt to work together through the ESF, there has been an increase in flexibility.

Of course, bringing together funds into a 'common pot' would make EUROCORES truly European but perhaps we have to wait for a European Research Council (see above) for that to happen. The contribution that EUROCORES is making to the development of the ERA is recognized within FP6. The first EUROCORES programme of relevance to the marine community was EuroMargins, which aims to look at the various processes occurring in continental margins around Europe, and which has mobilized more than €12 million of research funding.

Scientific Forward Looks

Scientific Forward Looks are intended to provide medium-term perspectives on multidisciplinary topics at a European level. They bring together researchers and funding agencies so that scientists' aspirations can be factored into planning by the agencies. Forward Looks should generate ideas for EUROCORES and other ESF activities, and influence the EC and national agencies. The first formal Forward Look focussed on research into global change, where marine sciences figure prominently. The need to develop monitoring systems could well lead to new EUROCORES projects in this area.

*'Europe's Grand Challenge: achieving coordination in marine research' by Tony Mayer and Laurent d'Ozouville, *Ocean Challenge*, Vol. 8, No.2, pp.20–21.

†GERD = Government expenditure in R&D measured as a percentage of GDP)

**A joint meeting between the European Commission, the French EU Presidency and the ESF.

Improving infrastructure
The third important new ESF activity has been to increase its provision of scientific advice on research infrastructure. We are pressing ahead with work on the EU Fleet for Airborne Research (EUFAR), and with the infrastructure necessary to support the EC/ESA initiative on Global Monitoring for Environment and Security (GMES); also with a review of marine research vessels in Europe and the case for a new polar research vessel (*Aurora Borealis*). The Marine Board has two working groups focussing on research vessels: one addresses research vessel operations in Europe, the other addresses the need for oceanographic research vessels – the 'European fleet'. Another science and infrastructure project with which the ESF is deeply involved is development of the European component of the International Ocean Drilling Project (IODP).

Changes in ESF organization
On the narrower ESF domestic front, there have been changes in the way in which some of our Expert Groups are structured. In 1998, the European Marine and Polar Sciences Board (EMaPS) was separated into its constituent parts, the ESF Marine Board (EMB) and the European Polar Board (EPB). Together with the European Space Sciences Committee (ESSC), they form an 'environmental' triad within the ESF structure. All three are now working closely together, and with other parts of the ESF, to promote a range of interesting multidisciplinary initiatives of which GMES is currently the most prominent.

There have also been personnel changes: Laurent d'Ozouville was replaced by Niamh Connolly who joined the ESF from University College Cork in Ireland. The EPB also has a new Secretary, namely Paul Egerton from the British Geological Survey in the UK.

What has not changed?
The marine environment remains high on the agenda of science and politics, and is under continual and increasing pressure from all sides; we need to fully understand its functioning, the processes which operate within it, and impacts on it and the coastline. Future policy, globally, as well as at the European, national and regional levels, must be based on good scientific understanding. The EU Common Fisheries Policy is a clear example of the need for a sound scientific basis for policy making, but we must also recognize that human beings are part of the marine system. Indeed, we need integration of the natural and socio-economic sciences throughout the marine research agenda – a key point which emerged from the ESF Forward Look on Global Change. For example, the fundamental role of the oceans in global change has yet to be communicated to the public and to politicians.

We also have to understand the impact of 'development'. Even 'eco-solutions' for energy supplies have their environmental and socio-economic impacts. What, for example, are the environmental consequences of major wave energy installations? What are the impacts of aquaculture on the gene pool as well as on the local environment? Do we understand the potential for recovery of exhausted fish stocks? Are we depleting newly targeted stocks such as monkfish and the orange roughy without truly understanding the population dynamics of these species? What are the impacts of increasing leisure use and development in the coastal zone? These examples show not only the importance of marine research but also the need to develop dialogues with politicians and decision-makers and to inform and listen to the general public. This is not easy and is demanding on that most precious of resources, time. Nevertheless, it is essential. The marine environment and marine science are of major public interest and concern and must build on the goodwill evident throughout Europe. Here, the ESF Marine Board is in the front line; with its membership of 25 marine research organizations from 17 European countries, it provides a unique forum for expressing a vision for integrating marine science in Europe. A meeting convened in 2001 to brief MEPs was successful in terms of the dialogue created, even if only a handful of MEPs were present. A huge task remains to communicate successfully and raise general awareness throughout the European and national parliaments.

Future marine perspectives
The ESF Marine Board has put together a Position Paper, *Integrating Marine Science in Europe*. Although not formally part of Forward Looks, it is a good example of a medium-term science perspective, built on extensive debate within the research community. A result of two years' in-depth consultation, it provides a comprehensive summary of the important role of marine science in sustainable development and in meeting societal needs; it represents the first detailed overview of the status and priorities of marine research in Europe. It identifies exciting new developments in science and technology, highlights long-term observational needs, and summarizes access to large-scale infrastructure and outreach activities. It also emphasizes the vital importance of Europe playing an active role in global ocean affairs.

Integrating Marine Science in Europe represents another contribution by the ESF towards making the European Research Area a reality, a process in which the ESF itself and the ESF Marine Board expect to play leading roles. Presenting the Position Paper to Commissioner Busquin at the launch of FP6 in Brussels in November 2002, Jean François Minster, President of the French Marine Institute (Ifremer) and newly elected Chairman of the ESF Marine Board said: 'We have established an important milestone in the process of integrating and developing marine science as a key component of the European Research Area. We have provided a basis for developing mechanisms for better co-ordinating Member States' Marine R&D programmes, facilitating interagency co-operation and maximizing the benefit for marine science and the marine sector for the EU Sixth Framework Programme. With this report, the ESF Marine Board intends to be a catalyst for the creation of a European Marine Research Area.' Geoffrey O'Sullivan (Marine Institute, Ireland) emphasized the importance of the Position Paper 'as a significant milestone in creating a European Marine Research Area'. He also noted that it 'set out the marine research priorities to be addressed by Europe over the coming decade.'

The motivation for the ESF Marine Board in producing the Position Paper was to provide an integrated marine science vision for input to national research programmes, and to the ERA. Achieving its goals will involve more than the Directorate General Research, and will require input from other DGs, including those for Fisheries, Environment, Regions, and International Cooperation. In the next few years, the Marine Board will develop specific collaborations with these DGs, as well as with other appropriate European bodies, including the European Parliament, the Council of Europe, the Committee of the Regions, and the Committee for the Ultraperipheral Regions.

In the context of the European Research Area, EU Research Ministers agreed in 2000 to pursue a range of initiatives focussed on the progressive mutual opening of national research programmes. In 2002, five priority areas were identified for immediate action, of which one was marine research.

Conclusion
Europe's seas and coastal zones are part of our European heritage. To use them sustainably, thereby conserving them for future generations, is a huge challenge requiring a sound and comprehensive knowledge of the ocean and coastal processes, and of human and

social factors. In turn, marine research in Europe must be adequately supported with funds and infrastructure and must be able to both attract and retain the most able scientists and, especially, to promote the development of young researchers. That is the challenge for the future, to which researchers from all disciplines, politicians, policy makers and the general public must respond. It needs a European approach, to which the ESF, especially the Marine Board, is committed.

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Noctiluca: a new research catamaran

Kevin J. Flynn and Jukka M. Pajala

Marine biologists at Swansea have a new vessel to help them work effectively in the tough conditions of the Bristol Channel, which is strongly affected by the adjacent Irish Sea, with its high waves and strong currents. RV *Noctiluca* was officially launched by the School of Biological Sciences, University of Wales, in April 2002. This state-of-the-art boat was built in Finland by Mobimar after an innovative design process conducted with close co-operation with the end-users. The vessel has effectively doubled Swansea's capabilities for marine research in coastal waters off south-west Britain, and is a tremendous boost to the facilities available to students.

Noctiluca is a small diesel-powered catamaran. It is capable of speeds in excess of 20 knots, and at a more modest speed of 16 knots (still twice the typical speed of a research vessel) it has a range of 500 nautical miles. The vessel provides a 'floating laboratory', the deck of which serves as a highly flexible working platform from which a wide range of sampling gear and oceanographic equipment can be deployed. In addition, there is a 'moonpool' – a sheltered safe space under the superstructure between the vessel hulls – for deployment of smaller sampling and measuring devices. Catamarans differ from single-hulled vessels in other important ways: two narrow hulls permit a wide working area and high stability without making big waves at speed. Dynamic responses of catamarans in waves are also favourable for marine surveying. The vessel is equipped for single crew operation, leaving more staff free for teaching or research support.

Noxtiluca's main characteristics are

Overall length: 12.5 m
Overall beam: 4.5 m
Displacement, loaded: 11 tonnes
Dead weight tonnage: 1.5 tonnes
Draught : 1.0 m
Speed: 20+ knots
(with one engine: 10 knots)
1-tonne drag at towing speed 10 knots

The hull and superstructure are marine grade aluminium alloy. The propulsion plant consists of two 140 kW/3800 r.p.m. marine diesel engines (Volvo TAMD41) with marine gears (trolling valve included) and fixed-pitch four-bladed propellers, diameter 450 mm. One engine has an additional 12 V DC 130 A charger and the other a hydraulic pump for the winch and A-frame. The main electric system is 12 V DC incorporating a total of three 80 Ah batteries. The third battery is for special equipment and is connected to a converter to obtain 220 V AC. When in port, 220 V AC can be obtained directly via a ship-to-shore mains connector. There is also provision for an additional portable 40 kW generator.

Deck outfitting is designed for the university's educational and marine survey work, with a maximum capacity of 12 adults (berths for 4). A 0.75 tonne double-drum winch (North Sea Winch GF-18) is installed on the aft deck for stern trawling and midship sampling.

The vessel has proved an immense success. For delivery it was sailed around the southern coast of the UK from Hull to Swansea via Land's End, in what was at times atrocious weather; its sea-keeping capabilities have been well proven. Also, using one engine forward and the other in reverse, it can turn on the spot, a great advantage when deploying research gear. Its speed and stability enable several groups of students to be trained at sea in one day, whereas in the past only one sortie would have been possible. The vessel has also made overnight research exercises, studying sea mammals, birds and turtles off the Gower Peninsula and in Camarthen Bay.

The original hydraulic system has been replaced with an up-rated one, but other than that, the vessel design could not have been better, except perhaps for installation of slower diesels, which would require less servicing. Acoustic systems can be 'pinged' directly through the aluminium hull; trials of the Meridata UASP with a 28 kHz transducer were most satisfactory. Fuel economy is excellent and the aluminium hull easy to maintain; it is also light enough, and just narrow enough, to be hoisted out of Swansea Marina on the standard hoist. Perhaps not a thing of beauty, but hard to criticise from a practical point of view!

See: http://swan.ac.uk/bs/facilities/noctiluca/info.htm.

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Noctiluca*: The hydraulic A-frame on the transom is capable of lifting and towing the UOR, nets and others samplers. Clearance under the A-frame is 3 m.*
Photo: © Peter Dyrynda, Swansea.

social factors. In turn, marine research in Europe must be adequately supported with funds and infrastructure and must be able to both attract and retain the most able scientists and, especially, to promote the development of young researchers. That is the challenge for the future, to which researchers from all disciplines, politicians, policy makers and the general public must respond. It needs a European approach, to which the ESF, especially the Marine Board, is committed.

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Photo: © Peter Dyrynda, Swansea.

EurOcean: Bridging Information Gaps in Marine Science and Technology

Laurent d'Ozouville

The European Centre for Information on Marine Sciences and Technology – EurOcean – is the fruit of a report entitled *Towards a new marine dimension for Europe through research and technological development* (http://ioc.unesco.org/eurocean/files/europe.pdf). This was prepared by a group of 15 European governmental experts who gathered in Lisbon in 1999–2000, and was presented to the European Council of Research on 15 June 2000 by the Portuguese Minister for Science and Technology, José Mariano Gago.

Portugal's Foundation for Science and Technology (FCT) and Ifremer (French Research Institute for the Exploitation of the Sea) decided to implement the recommendations of the report and signed a cooperation agreement to set up EurOcean. A small permanent secretariat, jointly funded by FCT and Ifremer, and initially staffed with a Director and an Assistant, was established in Lisbon in September 2001. EurOcean is keen to enlarge its membership up to two members per country willing to be representatives of their major national research institutions and to be the EurOcean focal points in their country. Institutions from the EU and European organizations could also be members of EurOcean. Negotiations have begun with several partners who have expressed an interest in joining. EurOcean's main objective is to enhance awareness of ocean affairs in Europe, and to foster cooperation amongst a wide spectrum of governmental and non-governmental stakeholders, who will be potential providers and end-users of information in marine science and technology.

EurOcean is eager to be a flexible mechanism of cooperation and to develop its activities in such a way as to favour collaboration between its members. EurOcean functions through networks and, to avoid duplication of effort, relies as far as possible on the competent structures existing at national and European levels; it aims to promote synergies in the field of information for marine science and technology in Europe. For example, close links have already been established with the Marine Board of the European Science Foundation and with the Intergovernmental Oceanographic Commission (IOC).

It should be noted that there is absolutely no duplication between the roles of the national oceanographic data centres (NODCs) and the functions of EurOcean. Our role is related to information management while the NODCs' remit is to manage oceanographic *data*. EurOcean may provide information about where to access certain oceanographic data by identifying links to the appropriate oceanographic centres but it would not handle the actual data.

Creating an internet portal

Recognizing that information on European marine science and technology is very dispersed on the web and difficult to access, EurOcean decided that its first priority should be the creation of an internet portal providing an integrated and interactive electronic platform for information on marine S&T in Europe. In this context, the portal aims to facilitate communication, exchange and synergies in Europe between:

- the various science and technology sectors related to the oceans;
- the diverse actors and users of marine research including academics/scholars, policy-makers, decision-makers, the private sector, defence, NGOs, media, educators, and society in general;
- the different structures relating to marine research and its applications, at the regional, national, European and international levels.

The two main aims of setting up the internet portal are: (1) to compile information (databases, a directory of URLs, a virtual library, and forums); (2) to develop dedicated tools for optimizing access to information and interactivity for users. Tools for interactive communication (e.g. mailing personalised information, dedicated search engines, management of forums) are being made available to users.

Implementation of the internet portal, officially opened in March 2003, is being undertaken in close collaboration with all institutions and individuals in Europe interested in participating in its development, in supplying information, and in controlling its quality. More specifically, EurOcean cooperates with the IOC, which is implementing regional portals relating to a wide range of ocean-related issues. It was agreed that the IOC regional portal for Europe be part of the EurOcean portal. In exchange, IOC provides EurOcean with the appropriate software to operate the functionalities of the EurOcean internet portal.

Internet databases of marine research infrastructure

Priority has been given to compilation of information about what is available in terms of marine research infrastructure, focussing initially on

EurOcean's main functions

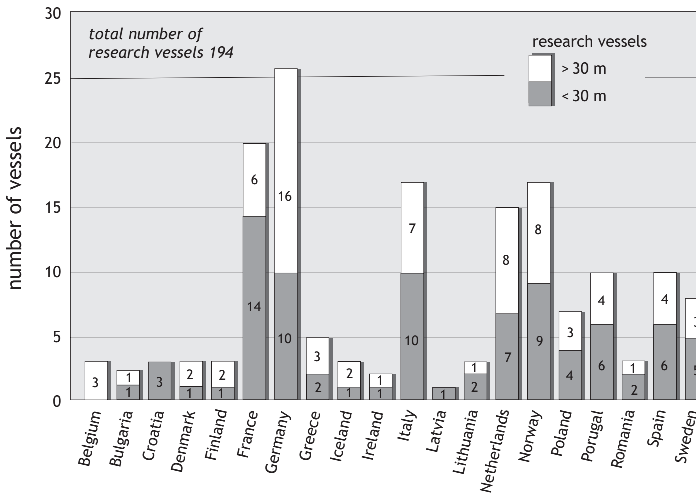
- To facilitate access to, and compile relevant information on, marine science and technology.
- To stimulate the development of quantitative performance indicators in research, environmental and socio-economic sectors related to marine science and technology in Europe.
- To encourage communication between European organizations involved in marine research activities.
- To initiate preparation of analyses, reports and other products, as required by EurOcean members or under agreement with cooperating organizations.

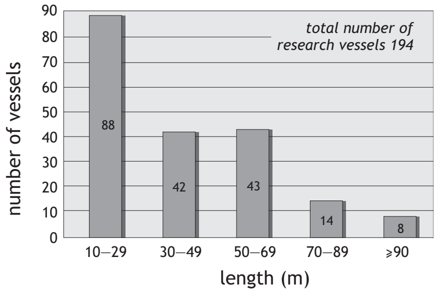
Information to be found at http://www.eurocean.org/

- **Marine research infrastructure**: coastal/high seas research vessels and related equipment, satellites, experimental and testing facilities, monitoring and observing networks, large databases and biological collections, facilities for data processing and management.
- **National Research, Technology and Development (RTD) information**: national marine science and technology profiles; policy documents; directories of research centres, institutions, researchers and research equipment; press releases; websites; national calls for research proposals, jobs and fellowships.
- **European RTD information**: Projects and European organizations funded under Fifth and Sixth RTD Framework Programmes (FP5 and FP6).

Other potential categories of information, for future consideration, are:

- industrial: living resources, renewable energies, oil and minerals, shipbuilding, maritime transport;
- indicators;
- relating to society: decision-makers, media, education.





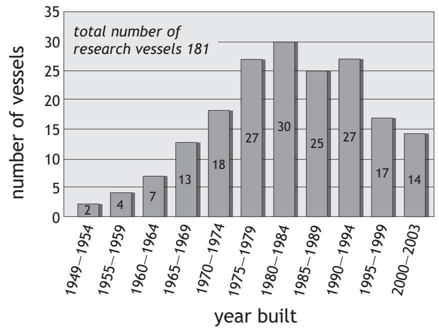


Figure 1 *Some statistical analyses drawn from the EurOcean database of European coastal and high seas research vessels.*

national research vessels. The webpage on coastal/high seas research vessels includes: a database with 118 research vessel specifications and 22 search criteria; a virtual library of publications on infrastructure; and a directory of useful links.

In order to build up this webpage, privileged association has been established with OCEANIC (Ocean Information Centre of the University of Delaware), whose website partly covers the content of the EurOcean database on marine research vessels. EurOcean updated and validated the information already in the Oceanic database, and added coastal research vessels that had not been included. This task, which represents an inventory of approximately 200 research vessels, is near completion and information already validated is available on the web. Some results of statistical analysis of the content of the research vessel database are presented in Figure 1. EurOcean is now collecting information on underwater research vehicles, and an inventory of 50 such vehicles is already online.

Furthermore, an inventory of 136 experimental and testing facilities in Europe in the fields of hydraulics, geophysical fluid dynamics, ship dynamics and ice engineering research, put together by the HYDRALAB network (funded under FP5), can also be accessed via the EurOcean website.

National RTD information

Coordinating national research policies and programmes is a key part of implementing the European Research Area (ERA), to which EurOcean is dedicated to actively contributing. Establishment of a web-based electronic platform making available details of national marine programmes, human resources and infrastructure will greatly help to make the ERA become a reality.

The content of the webpage on national RTD information from European countries is curently being determined; it will most probably include:

- standardized information on existing national marine RTD programmes.
- Announcement and dissemination of calls for proposals, fellowships, positions, etc.
- A directory of links to national contacts (URLs of national research centres, etc.).
- A virtual library of documents (national policies, programme managements, etc.).

The availability of this information will be a key contribution to starting up new research programmes, which is one of the objectives of the ERA.

European RTD Information

Since dedicated marine science programmes have disappeared from the 5th and 6th RTD Framework Programmes, EurOcean considers that it has an important role to play in facilitating access to information relating to marine research that exists in CORDIS (Community Research and Development Information Service) and via other EC websites. EurOcean has already undertaken some specific analyses to extract marine information from CORDIS and put it online in the internet portal so it is accessible to scientists and decision-makers.

Two examples of analyses carried out by EurOcean and available on
http://www.eurocean.org/

- The Fifth RTD framework programme: an inventory of the major marine research infrastructures, financially supported under FP5 for trans-national access. Making this information available online is a way of giving higher visibility to the opportunities of free access to marine research infrastructures.
- The Sixth RTD framework programme: list of the Expressions of Interests (EoI) related to marine science in the FP6 Thematic Priority 'Sustainable development, global change and Ecosystems' in 2002. From 2851 EoIs registered in this thematic priority, EurOcean identified 192 that were related to marine science. Such information has been useful for scientists involved in the preparation of proposals for Integrated Projects and Networks of Excellence.

To conclude, bridging information gaps in marine science and technology in Europe is a challenging and ambitious initiative. To be successful, the functionalities offered by the internet portal have to fulfil the needs of the end users, which means that they need to be involved in it, from its development to management of its content. This is a priority issue for EurOcean, and contributions to EurOcean from all interested readers of *Ocean Challenge* will be most welcome.

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see also http://www.eurocean.org/

The Changing North Sea: Tackling new Challenges

Jürgen Sündermann

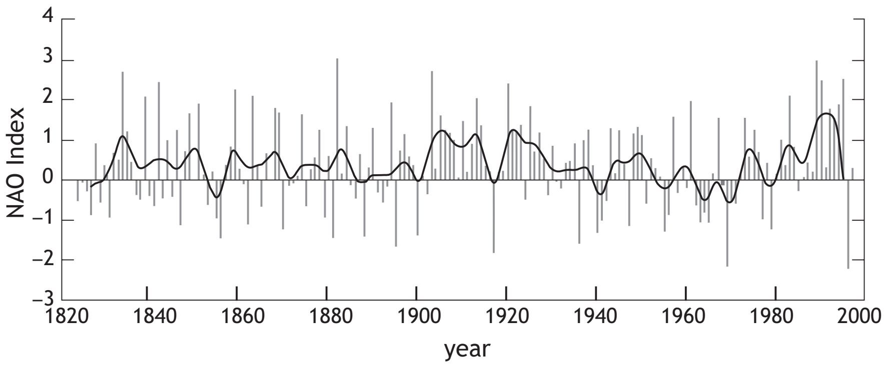

Figure 1 *Index of the North Atlantic Oscillation (NAO) in terms of the difference in atmospheric pressure between Gibralter and Iceland (winter values relative to sea-level). The columns represent annual values; the curve shows smoothed data. Since 1988, the mean NAO Index has been at its highest ever.*

In the early 1990s, the quest to understand the North Sea system made great progress, as a result of large national projects (e.g. Circulation and Contaminant Fluxes in Germany, and the North Sea Project in the UK) as well as numerous European projects in the Marine Science and Technology Programme. Since then, however, a certain stagnation has set in, even though we now have to face new challenges as a result of the impact of global change on the North Sea region.

To address this shortcoming, the German project SYCON – Synthesis and New Conception of North Sea Research – was carried out from 1998 to 2000. As well as issues relating specifically to the North Sea, SYCON considered general challenges to interdisciplinary shelf-sea research and sustainable management in the context of global change. The project was led by Hamburg University, and benefited from an international advisory board.

Research challenges

The questions which society requires researchers to answer about North Sea science can be condensed down to three:

- What is the present state of the North Sea system?
- What changes are to be expected in the future, as a result of natural variability and human impact?
- What environmental strategies would best support sustainability of the North Sea system?

To compile a sensible programme of research to address these questions, we need to be aware of the strengths and weaknesses in our current understanding, and be clear about the aspects of our research techniques that need improving. At present, there are societal concerns and questions about the North Sea system that cannot be directly addressed by scientific research because there are basic areas of knowledge which are not sufficiently explored. Only when the scientific foundations have been laid can we can begin to look for answers and make progress in an applied environmental context.

Specific SYCON objectives

Evaluation of the present state of knowledge about the North Sea system in the face of the challenges outlined above was undertaken in four interdisciplinary areas. First, a comprehensive survey was made of existing North Sea data. *In situ* and remote sensing data, as well as data from models, were evaluated with regard to reliability and completeness in space and time. As the North Sea is strongly influenced by external factors (e.g. conditions in the adjacent North Atlantic and the local wind field), forcing and boundary conditions were also included in the data collected.

To interpret data quantitatively and develop models, we obviously require adequate understanding of the processes involved. Parameterizations of processes such as mixing are based on the results of small-scale field experiments or on laboratory experiments, as well as on schematic calculations for test situations. SYCON surveyed the status of such parameterizations and evaluated their usefulness for making predictions about the North Sea ecosystem. The most important European model codes were then classified and characterized according to their strengths and weaknesses – including their completeness, how they represent processes, their four-dimensional resolution, and their computational complexity.

Finally, SYCON looked at the instrumental and methodological capabilities, the level of development of which ultimately determines how well we are able to understand the system. The potential and the limits of available measuring equipment and computer generations were also surveyed. Knowledge in all these areas was put together to yield an overall picture of our current ability to understand the North Sea system; and as the North Sea system is oblivious of its political setting, our conclusions and recommendations are valid in a general, international sense, and can make a useful contribution to other national or European programmes relating to shelf-sea research. (The fact that SYCON was supported by an international advisory board is also valuable in this context.)

Understanding the nature of the North Sea system

We know that, as for all natural systems, conditions in the North Sea are determined by the interplay of external forcing (e.g. the influence of the North Atlantic) and internal dynamics (e.g. formation of salinity fronts). Accordingly, the North Sea must be understood as a part of the larger North Atlantic–European shelf system, and the dominant processes affecting this larger system must be quantified. A major signal is certainly the North Atlantic Oscillation, or NAO (Figure 1).

On the basis of statistical analysis of empirical data, it is largely agreed that the natural climatological variability of the Atlantic (as manifested by, for example, the NAO) is transferred to the North Sea. Furthermore, the North Atlantic influences not only physical processes in the North Sea, but also biological processes. This is demonstrated by Figure 2, which shows that it is possible to use the NAO Index to make reasonable estimates of abundance and species numbers for macrobenthos in the North Sea, showing that climatic

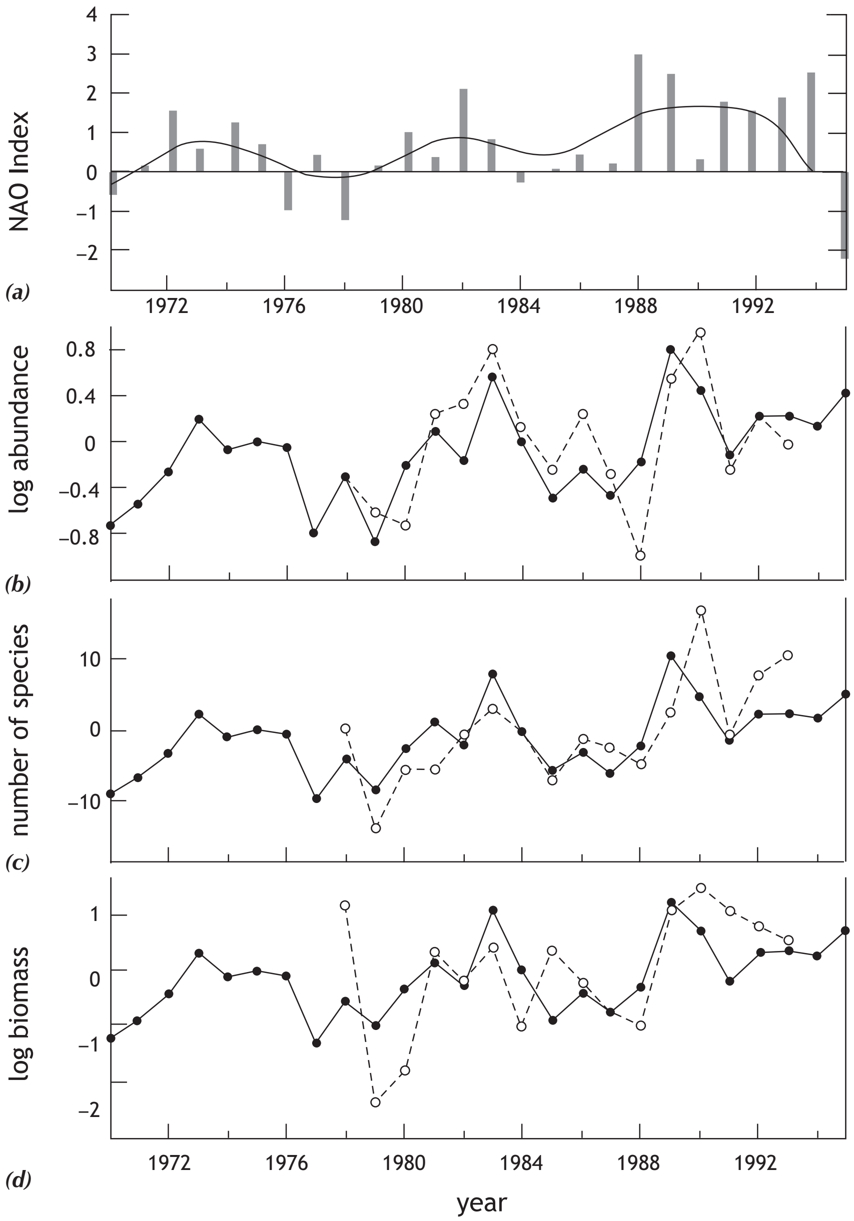

***Figure 2** **(a)** Variation in the NAO Index since 1970 (taken from Fig.1). **(b)–(d)** Estimated (solid) and observed (dashed) anomalies of, respectively, log-abundance, number of species and log-biomass of macrobenthos (e.g. seastars or mussels) in the North Sea in the second quarter of the year. The estimates were derived from the NAO Index during the preceding winter using statistical correlations.*

((b)–(d) Kröncke *et al.* 1998)

conditions in the North Atlantic must be influencing, or feeding through to, the North Sea. However, the actual chain of causation between climatic conditions in the Atlantic (circulation, distribution of kinetic and heat energy), the shelf-sea circulation, and the North Sea ecosystem, is not clear.

The SYCON group agreed that we need to know more about how variability in the Atlantic is transferred to the North Sea, and that this variability should be analyzed and quantified over seasonal to decadal time-scales, for both the physical and the biological subsystems. A coupled four-dimensional model of the north-east Atlantic and the North Sea–Baltic Sea system must therefore be developed; it must be appropriate for oceanic as well as shelf-sea scales, and have sufficiently high resolution, particularly of the transition area over the shelf edge.

Meteorological data on net freshwater fluxes (evaporation and precipitation), solar radiation, deposition of dissolved and particulate substances (wet and dry deposition) need to be considerably more detailed and accurate than hitherto. This means developing new approaches to modelling.

Conditions in the North Sea system are dominated by numerous interactions within and between the physical, chemical and biological subsystems. We need to set up new research initiatives in the following key areas: surface layer dynamics, eutrophication mechanisms, algal blooms, contaminant dynamics, trophic relationships, recruitment, morphodynamics, pelago-benthic coupling and nutrient regeneration. These processes have been studied before, but they are still not sufficiently understood. For each of these complex topics, targeted process-oriented field investigations should be combined with laboratory experiments, including the use of mesocosms (tanks large enough to contain representative ecosystems), and the development of models.

Successful understanding of the system is ultimately expressed in the development and implementation of complex coupled models which can realistically describe and predict the functioning of various aspects of the North Sea system. Work has begun on a model coupling the atmosphere and the ocean for the North Sea–Baltic shelf-sea system. This work should be continued, and once tested and validated, the model should become available as a standard tool for research and routine use.

We also need to develop a coupled hydrodynamic–morphodynamic model influenced by biological feedback, which can make successful predictions on episodic to decadal time-scales. The coupling of physical, chemical and biological components to a comprehensive model of the North Sea ecosystem should be continued, enabling us to compute the North Sea's response to different scenarios of natural and anthropogenic disturbances (see later).

Natural and anthropogenic changes

A sensible environmental policy for the North Sea system depends on our being able to differentiate natural variability from human disturbance on different time-scales. Achieving this is one of the main tasks still remaining.

Natural variation is the rule and not the exception, and it is an idle undertaking to try to combat it (although humans must try to alleviate the effects of natural change, such as shifts in vegetation zones). As climate, with its strong fluctuations, is a significant factor in the external forcing of the North Sea system, particularly on the decadal time-scale, the North Sea should have its own climate research programme to investigate specific effects of climate on this region, and attempts to study climate change in the North Sea/Baltic area must be improved and extended. Particular attention must be paid to the following aspects: secular changes occurring as a result of global-scale effects of the NAO; wind statistics (cf. Figures 3 and 4); mean sea-level; surface wave statistics; and circulation patterns.

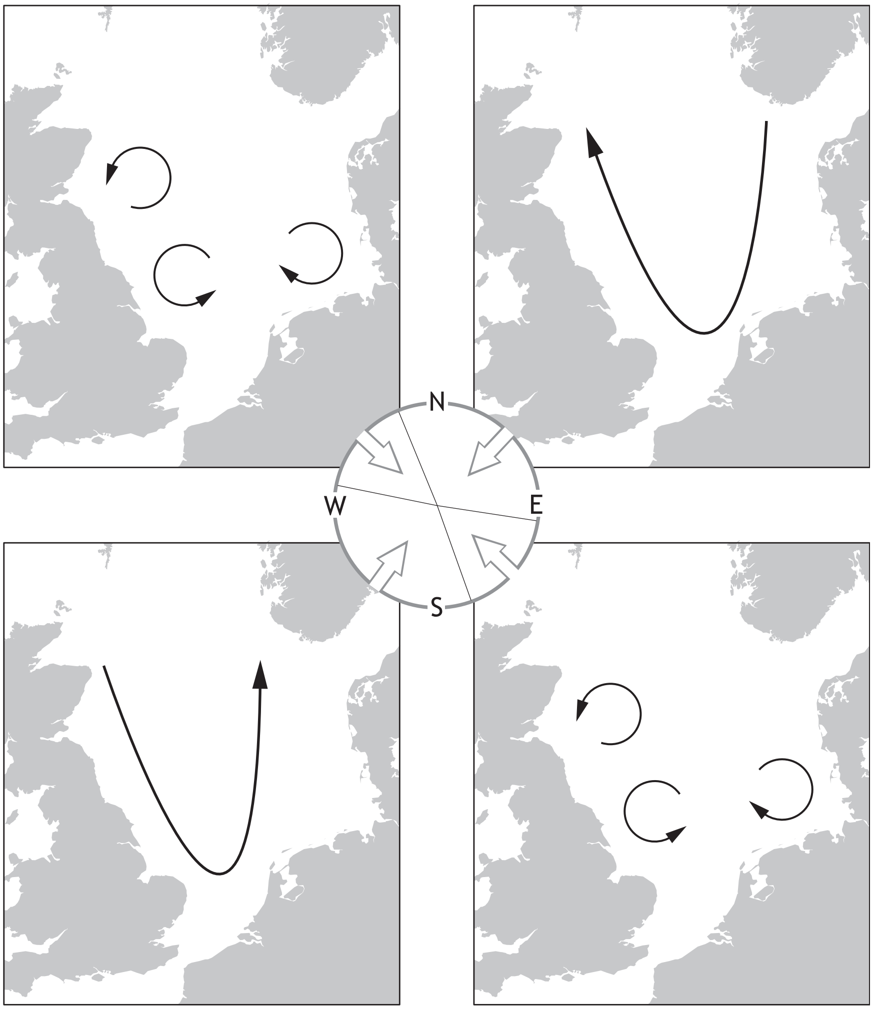

Figure 3 *Dependence of the basic circulation pattern of the North Sea on the wind direction. For each of the four maps, the 'compass rose' in the centre of the figure shows the direction from which the prevailing winds come, and the current arrrows show the general circulation system that results. At present, we most frequently have the situation at lower left, with winds predominantly from the south-west and a stong cyclonic (anticlockwise) flushing of the North Sea.*

(Schematic representation: after Jan Backhaus)

Anthropogenic disturbances, on the other hand, are basically controllable, and we should aim for sustainability within the framework of a wise environmental policy. In this context, North Sea research must be devoted to the assessment of change and of the efficacy of mitigation measures.

Perhaps the most significant anthropogenic changes in the ecological state of the North Sea–Baltic Sea system are caused by discharges of nutrients and contaminants via rivers and the atmosphere. Reduction measures have been successful in achieving a decrease in heavy metals, pesticides and phosphate, but pollution from motor vehicles, aeroplanes (via the atmosphere) and ships, and discharges of new organic contaminants with unknown effects, have for the most part increased. A survey of the contamination status of the North Sea is long overdue – the last one was carried out during the ZISCH/TOSCH programme in 1986/87 – and needs to address new contaminants and their degradation products. The effects of these substances on organisms and communities must be determined through field observations, laboratory experiments and mesocosm experiments (cf. pp.37–43). By making estimates for different scenarios, we can then evaluate the effectiveness of the measures which have been taken, and any which are being planned. We also need to study the combined effects of eutrophication and contamination and possible effects of one-sided reductions (e.g. of one specific nutrient).

According to the most recent Quality Status Report for the North Sea (OSPAR Commission 2000), fishing ranks amongst the greatest human impacts on the area: '... effects occur on all levels of the ecosystem (from benthos to mammals)'. As well as obvious measures such as fleet reduction, catch limitations and protected areas, we need to develop a multispecies approach toward fisheries, which considers the effects of fisheries on the entire ecosystem. New ideas are needed for defining protected areas so that they include habitats for juvenile fish and benthic communities.

An additional source of disturbance is the introduction of exotic species, mainly through shipping and aquaculture. These alien species can become dominant in certain situations and thus cause considerable shifts within marine communities (see pp.26–31). Possible long-term effects on the ecosystem have hardly been investigated.

Strategies for sustainable use

If we are to achieve the goal of using the resources of the North Sea while protecting the ecosystem, there must be long-term integrated planning and management. Governments, stakeholders and scientists must cooperate in this planning and management, and a key aim must be the timely recognition of potential conflicts and the efficient use of scientific and administrative measures to solve problems. Existing approaches to North Sea management need to be brought together and developed into an integrated, objective and practical package.

Specific problems in this connection are the development of objective, commensurable assessment criteria, the (monetary) appraisal of natural systems, and the evaluation of decision-making pathways. Model formulations will be helpful in this respect, for example in estimating future storm surges under global warming; see Figure 4.

Any marine nature reserves which are set up must be based on ideas with strong scientific foundations. Collaboration between natural scientists, economists, sociologists and legal experts is needed, so we can decide what to aim for and the measures we must take if we are to achieve our aims, as well as to analyze the wider implicatons for society generally.

Monitoring and operation

Observational data underpin all North Sea research. Along with targeted, problem-oriented experiments, there is a need for continuous representative monitoring of the North Sea system. Such measurements must be complemented by results from operational models, for these alone are capable of covering the four-dimensional space–time continuum and making predictions. Finally, the entire body of experimental and numerical data must be stored, administered and made available to those who need to use it (cf. pp.20–24).

We particularly need long-term, spatially and temporally well-resolved data series for physical, chemical and biological parameters at the places where the Atlantic meets the North Sea, between Scotland and Norway, and in the Chan-

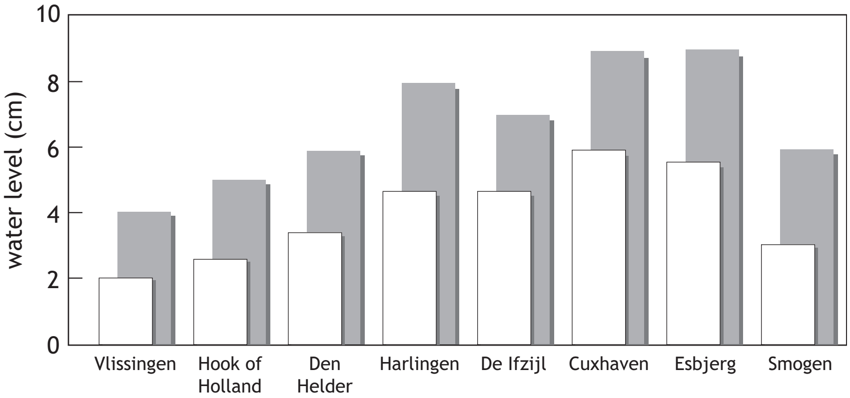

Figure 4 *Increase in maximum water level of moderate storm surges at various locations around the southern North Sea, estimated for an atmosphere with double the present concentration of CO_2 (grey) compared with twice the standard deviation for data from the years 1900–1996 (white). The predicted values are significantly higher than the present natural variability.*

(Langenberg *et al*.,1997)

nel. Similar data series are necessary for the transition zone between the North Sea and the Baltic.

If we are to recognize changes in water quality and in ecosystems, we also need long-term point measurements at representative locations in the North Sea. Furthermore, regular collection of data would provide valuable additional information. Thus, the Continuous Plankton Recorder (CPR) series must be continued, and further datasets should be collected from ships of opportunity.

Monitoring must be supplemented and amplified in its effectiveness by the simultaneous employment of operational models into which observational data can be assimilated. This would give us routine information about the state of the North Sea with high spatial and temporal resolution.

There is also an urgent need for a standardized North Sea-wide digital topography with a resolution of approximately 1 km, to be made available to all states bordering the Sea. With the help of remote sensing, this would allow us to monitor decadal changes in the morphology of the coast and sea-bed of the North Sea, and to correct bathymetric data.

Future North Sea research

The research deficits alluded to above suggest that new initiatives are needed for the North Sea and for shelf seas in general. The 6th Framework Programme of the EU will not explicitly support North Sea research, but hopefully it will provide opportunities for coordinating the efforts of coastal states (and others interested in shelf-sea research) by means of Networks of Excellence. It presumes, however, that national programmes for shelf-sea research are funded. Shelf-sea scientists should lobby for such funding whenever possible.

The perspectives for future North Sea research developed during SYCON are summarized in a Synthesis Report (see below), eleven single-discipline reports (http://www.rrz.uni-hamburg.de/SYKON/) and an illustrated booklet for the general public, *The North Sea: Problems and Research Needs*, obtainable from Susan Beddig, Centre for Marine and Climate Research, University of Hamburg, Bundesstrasse 55, 20146 Hamburg, Germany (beddig@dkrz.de).

Acknowledgements

The SYCON Project was carried out with the support of the German Federal Ministry of Education and Research under Grant No. 03F0215A. This article is based on the SYCON Synthesis Report (Sündermann *et al.* 2001).

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A fisheries ecosystem approach: from counting fish to herding cats

Sophie des Clers

As one of the last industries to harvest wild natural resources, commercial fisheries have socio-economic and environmental problems that marine scientists can help understand and address. At the moment, fisheries biologists survey the abundance of fish and use research cruise results to balance the books of commercial fisheries statistics. The exercise is labour-intensive and fraught with difficulties: ICES scientists deplore the unreliability of reported catch data – a perverse but well known side-effect of catch limitation policies; and fishermen argue that Virtual Population Analyses (VPAs),* used in setting catch quotas, have no reality. Has Fisheries Science been reduced to fish counting?

I would argue that until we have a model that links ecosystem, environmental change, fisheries production, capital and labour, with the economic development of fisheries-dependent European regions, fisheries scientists have little scope to be more than accountants.

So, what if we could start again, armed with our knowledge of the marine ecosystems that sustain fisheries – their spawning grounds, coastal nurseries, specific habitats, species and environmental conditions?

It is often said that trying to get professionals (especially academics) to cooperate is rather like trying to herd cats. But what if ecologists, biologists, sociologists, economists and fishermen could work together to describe and monitor species, habitats, fishing practices, markets and ecosystem production? Fisheries managers might then encourage co-operative management and co-ordinate with other industries that use the sea bed. Policy-makers might take environmental change into account and design policy measures to reduce pressures on estuaries, coastal and marine sea-bed habitats, and act to mitigate the effects of climate change.

All this would be a great step forward, and some of us hope that it could be made to happen through our participation in the seven Fisheries Regional Advisory Councils officially set up by the European Council of Ministers in May 2004.†

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*VPAs are reconstructions of past fish population biomass on the basis of numbers fished by year-class, together with assumptions about catchability and natural mortality.

† http://europa.eu.int/comm/fisheries/news_corner/press/inf04_23_en.htm

Two new Nordic research facilities …

... off western Norway

Lars Golmen

A marine field research station is being planned for the island of Runde off the west coast of Norway (see Fig. 1). The island has about 150 human inhabitants, along with myriad seabirds, of which about half-a-million nest in the cliffs on the western side. The flora and fauna and the beautiful scenery above and below the water attract several thousand visitors annually, of whom many are specialists in various fields of the natural sciences; others come for scuba-diving, and yet others merely as tourists.

The seas around Runde have a very rich marine flora and fauna, with species typical of both northern and southern Norway, as well as species found throughout Norwegian waters. This area therefore has the richest and most diversified coastal fishery in Norway, with the local community of Heroy being top in earnings from fishing. The reason for the marine variety and richness is a combination of topographic and climatic factors, in itself a basis for local studies and monitoring. The Norwegian Current carrying warm salty water of North Atlantic origin has a marked influence, causing the highest winter temperatures to be found along the Norwegian coast. In addition, the Norwegian Coastal Current brings less saline nutrient-rich water which sustains the marine food chain.

Oil and gas production are inexorably approaching Runde, and a gas terminal is being established about 100 km to the north-east. This and the risks associated with the steadily increasing traffic of large oil carriers from north-west Russia for the European market represent a potential threat to the fauna of Runde. Locally, there is a growing need to serve visitors in a professional way, as well as to maintain a local oil spill contingency (booms, dispersants, special facilities for washing contaminated seabirds etc.). These are some of the factors behind plans to establish the field station, which will have a permanent staff of two to four persons (seasonally dependent), six offices for visitors, wet/dry labs and field equipment including a vessel suitable for observations, ROV surveys, sampling and diving. Accommodation for visitors will be arranged in co-operation with existing hostel owners on the island. Construction should begin in 2005, with completion in 2006. Users of the station will initially be regional and Norwegian agencies and universities, but the planning group is now also seeking contacts with potential users and collaborators from elsewhere in Europe.

A project to link Runde to other field stations in the Nordic countries has already been funded, and this networking will be expanded, linking Runde to existing Nordic and European networks for marine research and observation, and field stations. A productive international workshop was held in May 2004 to develop plans further.

Activities may be expanded to include, for example, marine bioprospecting, energy from the ocean, and mariculture R&D. Information and communication technology are also key. A bridge connects Runde (which is 25 km south-west of Ålesund) to the national road grid, and the travel time to the nearest airport is about 1 hour.

A website for the station and its services will soon be established. Meanwhile, see www.runde.no and www.runde-dykkesenter.com for information about Runde. For more details, please contact Lars Golmen (lars.golmen@niva.no) or Nils Roar Hareide (nilsroar@online.no).

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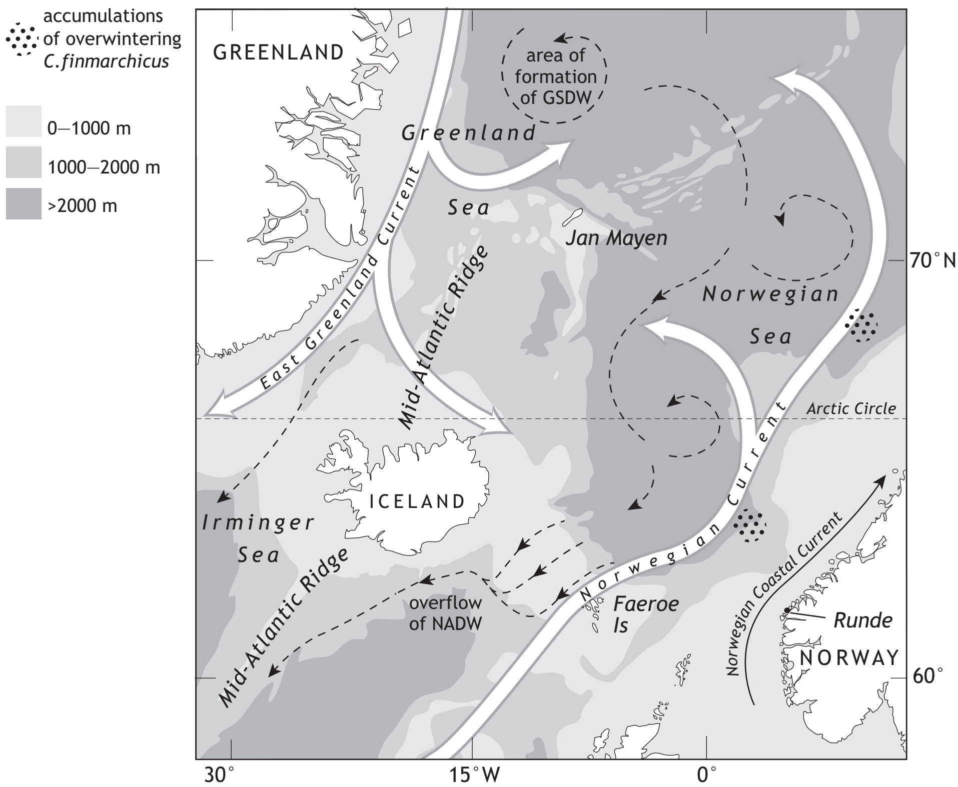
... and on Jan Mayen?

Stig Skreslet

In 2003, the NATO Scientific and Environmental Affairs Division funded an Advanced Research Workshop (NATO ARW) to address the possibility of establishing a joint international scientific observation facility on Jan Mayen. As the NATO country co-director, I, along with Professor Krzysztof Birkenmajer from Poland, the Partner country co-director, invited 27 scientists from North America and Europe to participate in the Workshop, which was held in Oslo, Norway, last November.

The intention behind the workshop was to perform a feasibility study on whether existing infrastructure on Jan Mayen could be used to support an international base for multidisciplinary research. The infrastructure includes integrated spacious living quarters and other facilities of a high standard. There is a meteorological observation post, and a Loran navigation facility run by the Norwegian Ministry of Defence. However, modern satellite positioning systems have superseded Loran, and the system will probably be phased out in 2005, providing the opportunity for the facility to be transformed into an international research base. As the island is Norwegian,

Figure 1 *The oceanographic setting of Jan Mayen and the island of Runde. Dashed arrows indicate the general direction of flow at depth, and the overflow of North Atlantic Deep Water (NADW) and hence Greenland Sea Deep Water (GSDW) into the northern Atlantic.*



the Norwegian government will need to take on the responsibility.

The proposal is particularly, but not exclusively, related to large international programmes like GLOBEC (Global Ocean Ecosystem Dynamics) and CLIVAR (Climate Variability and Predictability). So far, Norway has made only small contributions to these programmes, and the Norwegian research community is seeking ways to come to grips with the ongoing international activities. One possibility is to offer the wider research community the opportunity to participate in the running of a research facility located in an area that is a focus of international scientific interest. The scientific programme would relate particularly to one of the three main areas of CLIVAR, the DecCen programme (Study on Decadal to Centennial global climate variability and predictability). This programme includes research into the North Atlantic Oscillation or NAO,* and the Atlantic thermohaline circulation. The latter involves the generation of North Atlantic Deep Water and its advection to the Southern Hemisphere, and the return surface flow from the Pacific to the North Atlantic. This conveyor-belt system comes to the fore whenever variations in global climate are discussed. In our post-glacial time, the main area of winter formation of North Atlantic Deep Water is the Greenland Sea, in waters just north of Jan Mayen (Fig. 1). The physical coupling between the atmosphere and the Greenland Sea was therefore a major focal point of the workshop.

Implications for biology

The flow of Greenland Sea Deep Water/NADW to the North Atlantic proper probably transports wintering stages of the herbivorous copepod *Calanus finmarchicus* from a large part of the Nordic Seas to habitats near the Norwegian continental slope (Fig. 1). *Calanus finmarchicus* is a major prey species for planktivorous fish such as herring (*Clupea harengus*) and capelin (*Mallotus villosus*), and its juvenile stages (nauplii) are key prey for larvae of most fish species in the north-east Atlantic. This makes it of central importance to north-east Atlantic fisheries and the focus of TASC (Trans-Atlantic Study of *Calanus finmarchicus*), a GLOBEC research programme with participation and financing from the USA, Canada, the EU and other European nations. Both empirical data and modelling have indicated that the species forms a large population that circulates in the Nordic Seas, reproducing in some areas, growing to adolescense elsewhere, and spending months in an inactive wintering mode in cold waters near 1000 m depth, at which time they can be caught up in newly forming deep water that transports them towards the Norwegian shelf where the anual reproduction starts. Thus *Calanus finmarchicus* is important not only in the transfer of biomass from algal primary production to carnivorous fish, but also in conveying pollutants from low to high levels in the food web. The transfers occur over large spatial and temporal scales that interconnect ecological processes throughout the Arctic and the subpolar seas between the Eurasian and North American continents.

* The NAO is the continual oscillation in the difference in atmospheric pressure between the Iceland Low and the Azores High; cf. p.14.

Figure 2 *A fulmar approaches the breeding colony on the fog-covered cliffs of Jan Mayen. The glaciers of the volcano in the background, the 2277 m-high Beerenberg, are an archive of atmospheric information.* (Photo: Ø.K. Kymre)

Jan Mayen's remoteness raises interesting questions about biogeography and about geological processes relating to the Mid-Atlantic Ridge, and there are numerous apsects of the waters around Jan Mayen, and of the island itself, that warrant research. There is a land-locked population of Arctic charr on the island, which contain high levels of PCBs and DDT. The origin of the pollutants is not known: some may be transferred to the lake by local precipitation or meltwater from the glaciers of the Beerenberg (Fig. 2), from seawater in the form of aerosols or spray, or in seawater flooding in during stormy weather. However, the main source seems to be droppings or pellets from seabirds that visit the lake in large numbers, after foraging perhaps far from the island.

The landscape is barren, with a vegetation mainly of moss and a poor flora of vascular plants; populations of insects are even poorer. The remoteness of the island raises interesting questions about immigration and links with distant populations of plants and invertebrates. The vertebrate fauna consists of breeding seabirds, a few polar foxes and some stray polar bears – all part of the marine food web.

Each year, a number of institutions and individual scientists apply to Norwegian authorities for logistical support for scientific research on Jan Mayen, but with negative results. The area is rather inaccessible to research vessels in winter, due to the formation and drift of sea-ice. The distance from European harbours also makes research efforts in summer rare and brief. Both marine research and terrestrial operations require high-tech logistics for field operations, as well as for supply systems and support from a home-base in Norway. There is an airfield on the island, and transportation of personnel and cargo is mostly by plane and ship from Bodø in northern Norway. However, foul weather and low visibility due to fog are frequent, and transportation and landings are erratic and sometimes risky.

A number of practical difficulties have to be overcome if Jan Mayen and its waters are to be studied in detail. The scientific output per invested unit of capital could probably be optimized if logistical support were installed to allow land-based monitoring, short sea excursions by hovercraft, and helicopter operations when the sea is ice-covered, and by moderately sized ships when the sea-ice retreats.

The participants of the NATO ARW confirmed that access to a research station on Jan Mayen woud be very useful to international cooperative research projects, as well as national research interests. They recommended that the existing infrastructure to service the Loran-C operations should not be dismantled at great expense in the near future. The buildings could be very useful during the International Polar Year in 2007–2008, if facilities are made available to the international scientific community. This view has been made known to NATO, Norwegian authorities, and international organizations

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Marine Data Management

We can do more, but can we do better?

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The planning and implementation of research, and the efficient management of the resulting data often appear to be two widely separated worlds. Data managers consider the careful collection, management and dissemination of research data as essential for the effective use of research funds. Many researchers, on the other hand, consider data management as technical, boring and an (un)necessary evil; so data management is often insufficiently planned, or not planned for at all, and is assigned a low priority. This is unfortunate, as there is much of social relevance and applicability in the colourful world of oceanographic data management. Our objective is to guide you through some of the many initiatives related to marine data management and to present the main players. We focus mostly on physical and biological oceanographic data (Boxes 2 and 3 overleaf), less on hydrographic, chemical and geological data. We also discuss the new trends and developments that will determine the future of this field.

Tackling a growing problem

The social relevance of measurement and sampling at sea, and the need to disseminate the results as widely and in as user-friendly a manner as possible, cannot be overestimated. More services and products useful to industry, the general public and policy makers, could, and should, be extracted from databases. The oceans cover two-thirds of the Earth, and about half the world population live in coastal areas, so monitoring the health, resources and 'tantrums' of the global ocean is no luxury. There are many applications of data-management that relate to climate and weather, safety at sea and along the coast, fisheries, offshore activities, management of the seas, etc. Let us focus on a few examples.

Meteorology and coastal defence

The weather has a tremendous impact on our lives. To a large extent, weather is 'produced' at sea, and the distribution of heat stored in the upper layers of the ocean is of great importance for both long-term and daily weather patterns. A good knowledge of meteorological conditions, and of how they are developing above the ocean, therefore makes a substantial contribution to timely prediction of storms and other unfavourable weather. Nowadays, through good measuring networks, and systems for making data available swiftly (in real time or near real time), it is possible to avoid a great deal of human suffering.

However, on a long-term basis it is also important to monitor sea-level changes: it is expected that by 2100 sea-level will have risen about 38–55 cm as a result of the greenhouse effect and the predicted rise of 1.5–6 6 °C in the Earth's temperature. To monitor this trend effectively, and to protect coastlines, we need more than a global network of sea-level stations. It is just as important to estimate the change in sea-level that will occur as a result of wind, atmospheric pressure patterns, rise and fall of land masses, and changes in ocean current patterns; and for these measure-

Box 1: Marine data management: a working definition

First, we need to distinguish 'data' from 'information'. 'Data' are observable, raw 'values' that result from research or monitoring activities; these values can be numerical (as in temperature or salinity measurements) or nominal (as in species lists for a particular region). The term 'information' is commonly used to mean data that have already been processed and/or interpreted results. In that sense, so-called 'metadata', i.e. data about data (e.g. by whom, at what time, where and how the results were collected) can be considered a special kind of 'information'.

Marine or oceanographic data management is the process of entry, quality control, archival and dissemination of research or monitoring data collected in the world's seas and oceans. We usually make a distinction between *operational data* (i.e. data continuously collected by networks of buoys and measuring platforms, transmitted by satellite or radio) and *archival/service data* (i.e. data collected by research teams and research projects, including experimental, field and modelling data). Data collected automatically on board research vessels are considered to be 'semi-operational data'.

ments to be of use, good data management, quality control and fast data availability are essential. In addition, experts expect that rapid warming of the climate will lead to shifts in – and increased intensity of – heat waves, droughts, floods, storms and other severe weather phenomena. Global warming also affects natural climate variability on time-scales of days to decades, by influencing atmospheric and ocean circulation (see below).

Predicting El Niño

El Niño is a large-scale periodic climatic anomaly, typified by a temporary warming of the surface waters of the eastern Pacific Ocean. Because the phenomenon was discovered by fishermen along the west coast of South America and nearly always started during the Christmas period, it was known as El Niño (the Boy Child). Important El Niño events occurred in 1982–83, 1986–87, 1991–92 and especially 1997–98. The name La Niña (the Girl Child) has been given to the cold phase that follows some El Niños (e.g. 1988–89).

It was initially thought that the effects of El Niño were limited to South American coastlines, where they dealt heavy blows to fisheries, but it was soon realized that their impact went much further afield; a strong El Niño is accompanied by heavy rainfall over the centre of the Pacific Ocean, the western part of South America and the southern part of the United States. Droughts then occur in Indonesia, Australia, southern Africa and north-eastern Brazil. All this is caused by fluctuations in the pressure difference beween the Indonesian Low and the South Pacific High, known as the Southern Oscillation (SO). A marked decrease in the pressure difference causes the usually strong easterly winds over the tropical Pacific Ocean to weaken, leading to suppression of upwelling of cold, nutrient-rich water along the coast of South America.

El Niño events affect fisheries, agriculture, ecosystems and weather patterns (and thus human health and safety) far beyond the tropical Pacific. It is estimated that approximately 125 million people were affected by the 1997–98 El Niño event (the worst recent El Niño) and the material damage amounted to approximately US $30 billion. Particularly destructive were the forest fires in Indonesia, the powerful cyclones that struck the west coast of Mexico, and the floods that destroyed harvests in East Africa.

The damage could have been much worse, had the El Niño event not been predicted six months in advance, thanks to the TOGA/TAO network of 72 measuring buoys that became operational in the tropical Pacific Ocean in the early 1990s. These buoys register meteorological and oceanographic data at the surface, and water temperature to a depth of 500 m. Not surprisingly, the timely prediction of such a dramatic phenomenon created considerable 'El Niño hype': many extreme weather events were (wrongly) attributed to El Niño. The fact that prediction of El Niño was made possible by temperature measurements at depth (beyond the reach of satellite-borne sensors) and that the phenomenon was studied on a global level, led to the development and implementation of new and global measuring networks at sea. Between 1990 and 2002, the World Climate Research Programme (WCRP) established the World Ocean Circulation Experiment (WOCE). This mega-project, with its 300 floating buoys and numerous basin-wide hydrographic sections, collected more temperature and salinity measurements over a period of eight years than had been collected during the previous 100 years.

The newest and most ambitious undertaking so far is Argo. This is a global network of (eventually) 3000 autonomous and freely floating profilers that should be operational by 2006. The project has been promoted by the Global Ocean Data Assimilation Experiment (GODAE), the Climate Variability and Predictability Project (CLIVAR) and the global observation systems GCOS (Global Climate Observing System) and GOOS (Global Ocean Observing System). Since the year 2000, Argo floats have been deployed in all the oceans at intervals of ~300 km. A float is submerged to a depth of about 2000 m, is transported by slow, deep currents for about 9 days, then slowly ascends to the surface, all the while measuring temperature and salinity. Having surfaced, the float transmits the collected data to a satellite, and another descent–ascent cycle begins. The average life-span of a float is estimated at four to five years.

Argo data are already available and, after a rigorous quality control phase of five months, will be freely accessible to all; see http://argo.jcommops.org/. This measuring network will not only provide more insight into the ENSO (El Niño–Southern Oscillation) system but will also greatly improve our knowledge of other climatic anomalies (such as those affecting the Arctic and the Antarctic, the Pacific Decadal Oscillation and the North Atlantic Oscillation).

Predictions needed for the safety of shipping

Tides, storms and currents are among the factors that determine the safety of shipping and other activities at sea. Predictions of these, by means of calculations with mathematical models and measurements made from satellites, buoys and other measuring platforms, have become commonplace in the context of shipping. But less ordinary events can also be explained through oceanographic databases. A good example is the occurrence of huge waves which appear from nowhere – accounts of which were often dismissed as 'sailors' tales'. However, it is becoming increasingly accepted that these 'rogue', 'freak' or 'extreme' waves are not only real but are the cause of many unexplained shipping disasters. The project MaxWave (within the EU Framework 5) brought together 11 European research teams to seek a scientific explanation of this phenomenon; see http://w3g.gkss.de/projects/maxwave/. The team also sought to identify the probability of such a 'wall of water' and to investigate how new ships can acquire better protection against such events.

Management of living and non-living resources

Management of living as well as non-living resources requires good knowledge and professional data management. Since the UN Conference on Environment and Development, held in

Box 2: The main players in the management of oceanographic data

• The **Intergovernmental Oceanographic Commission** (**IOC**) of UNESCO was founded in 1960 to promote oceanographic research and contribute towards the establishment of systematic ocean observation platforms (ships and, later, satellites), the necessary technological development and the transfer of knowledge (http://ioc.unesco.org). The Secretariat, as the executing organ of the IOC, is based in Paris and has been headed since 1998 by Dr Patricio Bernal, a Chilean oceanographer. The IOC has 129 Member States, which make up the IOC Assembly. Of these, 36 constitute the Executive Council. As far as data management is concerned, the IOC aims to ensure that oceanographic data and information – collected through research, monitoring and observation – are used efficiently and are distributed to the widest possible audience.

• This objective has been expressed through establishment of the **International Oceanographic Data and Information Exchange** (**IODE**) network that comprises more than 60 oceanographic data centres in as many countries. Most of these are National Oceanographic Data Centres (NODCs) – such as the Flanders Marine Institute, VLIZ – or Designated National Agencies (DNAs). Some of these were given special responsibility for specific regions or data types and are called Responsible National Oceanographic Data Centres (RNODCs). Together, the NODCs, DNAs and RNODCs supply their data to those World Data Centres (WDCs) dedicated to oceanography, which are based at Silver Spring (USA), Obninsk (Russian Federation) and Tianjin (China). The IODE network has also established a number of groups of experts and steering teams to provide advice to the IODE Committee or assist with the implementation of projects. They include the Group of Experts on Technical Aspects of Data Exchange (GETADE; now merged into the ETDMP of JCOMM – see below), the Group of Experts on Marine Information Management (GEMIM) and the Group of Experts on Biological and Chemical Data Management and Exchange Practices (GEBICH).

• The **International Council for Science**, originally the International Council for Scientific Unions (ICSU), was established in 1931 as a worldwide umbrella of scientific councils, academies and societies/institutions (http://www.icsu.org). ICSU maintains a network of 73 national and 27 international member groups and involves itself with everything related to science and society. It mobilizes funds and knowledge, publicizes research through meetings and publications, promotes constructive debates and participation of as many scientists as possible around the world, and facilitates interaction between disciplines and researchers of developed and developing countries. To this effect, ICSU coordinates and initiates important international and interdisciplinary programmes in close cooperation with other international organizations. Examples related to oceanography include cooperation with WMO and IOC in the World Climate Research Programme (WCRP) and with WMO, IOC and UNEP in GOOS and GCOS. ICSU was also instrumental in developing the system of 40 World Data Centres, established during the International Geophysical Year 1957–58 (two of which deal with oceanography; see under IOC above).

• The **World Meteorological Organization** (**WMO**) (http://www.wmo.ch) is a specialized UN agency, established in 1951. Its headquarters are in Geneva (Switzerland), and it was the successor to the International Meteorological Organization (IMO), whose origins date back to 1853. The WMO has 185 Member States, and is responsible for global cooperation in meteorological and hydrological observations and services (including systems for rapid data exchange, standardized observations and uniform publication of observations and statistics). The backbone of WMO is the WWW or 'World Weather Watch', a global data and information network of measuring stations, managed by Member States and using nine satellites, plus approximately 10 000 land-based, 7000 ship-based and 300 fixed and floating measuring buoys with automatic weather stations. The WMO plays a leading role in a number of international programmes and cooperation agreements related to climate change (such as the World Climate Programme which supports GCOS and the Intergovernmental Panel on Climate Change (IPCC); see below).

• Of the three operational observation systems, GOOS and GCOS, mentioned above, are important for operational oceanography. In addition, the climate module of GOOS is identical to the ocean component of GCOS, so the two systems can be considered Siamese twins. GOOS was established in the early 1990s under the co-sponsorship of the IOC, WMO, UNEP (UN Environment Programme) and ICSU. It was established in response to a clear need for a global measuring system, amplified by the call of the World Climate Conference, the IPPC in 1990, and the UNCED Conference in Rio in 1992. Since then a substantial number of regional sub-programmes of GOOS have been created (EuroGOOS, MedGOOS, Black Sea GOOS, GOOS Africa, etc.), and a number of existing initiatives have been absorbed by GOOS. GOOS includes two main groups of operations: (1) measuring systems in the open ocean, specifically to support services at sea, weather prediction, and monitoring of climate change; and (2) measuring systems in coastal areas, aimed at the study of the health and sustainable development of these areas. GOOS was initially established on the basis of existing observing systems, but it also developed its own pilot projects such as GODAE (which includes Argo – see p.21).

• The WMO/IOC **Joint Technical Commission for Oceanography and Marine Meteorology** (**JCOMM**) is a relatively new (1999) intergovernmental body of experts which provides the international coordination, regulation and management mechanism for an operational oceanographic and marine meteorological observation, data management and services system. To a large extent, it unites the common activities of the IOC and WMO and attempts to improve integration of expertise in oceanography and meteorology. Technical aspects of data management are discussed by the JCOMM/IODE Expert Team on Data Management Practices (ETDMP), taking over this role from the IODE GETADE (see above), but expanded to cater also for the needs of the WMO. This initiative also has close ties with the previously mentioned organizations.

• In the north-east Atlantic region, ICES (http://www.ices.dk) has been active since 1902 in the coordination and promotion of marine research, particularly in research related to living resources. Its special Working Group on Marine Data Management (WG-MDM) aims to optimize the data flow between individual research groups, and to develop a data management system that delivers products useful for fisheries policy advice and the management of living resources in the North Atlantic. In this regard, the ICES Oceanographic Data Bank acts as the data centre for OSPAR. The *OSPAR Convention* is an international agreement concerned with monitoring the environmental quality of all marine waters in the north-east Atlantic region (http://www.ospar.org).

Rio de Janeiro in 1992, monitoring of biodiversity has been considered necessary for assessing the health of ecosystems. Many new initiatives have been taken, especially in oceans and seas, to fill knowledge gaps with regard to living organisms.

Management of fishing resources should be based upon the data available. For the north-east Atlantic, ICES (see Box 2) plays a crucial role. Based upon the catch data collected by its member states, ICES annually advises the EU Commissioner for Fisheries about how much of each species can be caught in the coming year. Political negotiations within the European Fisheries Board lead to the so-called TACs (Total Allowable Catches) and the resulting quotas per species and per country.

Exploitation of non-living resources, such as sand, gravel, oil, gas and manganese nodules, is also well documented in databases, which in turn are of great value for managing future use of these resources.

Who is at the helm?

Without attempting an exhaustive review, in Boxes 2 and 3 we highlight a few of the main players in the domain of oceanographic data management, concentrating mainly on physical and biological aspects. A number of projects, organizations and cooperating teams focus on the collection and management of a wide range of operational data and/or other data streams; others specialize in particular areas or activities.

Box 3: Biological marine data

Biological marine data management covers a special group of initiatives and cooperation agreements relating to biological–taxonomic databases. The increased attention given to biodiversity has necessitated the realization of easily accessible and complete species databases, because the concept of 'number of species' is the most practical and widely used measure of biodiversity. Some of the larger and better-known initiatives are OBIS (Ocean Biologeographic Information System: http://www.iobis.org), ITIS (Integrated Taxonomic Information System: http://www.itis.usda.gov) and Species-2000 (http://www.sp2000.org). In addition to catalogues of species, these databases may also contain synonyms, distribution data, and information about ecology, vulnerability, economic use, etc.

OBIS, together with the initiatives 'History of Marine Animal Populations' (HMAP) and the 'Future of Marine Animal Populations' (FMAP) and others, forms the backbone of the 'Census of Marine Life' (CoML) programme. ITIS focusses on the biota of North America and now contains ~ 320 000 species names, of which 186 000 are unique. Species-2000 is a species list with global scope that now has about 860 000 entries, of which ~ 300 000 are unique species. The European Register of Marine Species (ERMS) (http://www.vliz.be/vmdcdata/erms) began as a European MAST project and produced the first extensive list of marine species (~ 30 000) for Europe. In addition, it contains a database of 800 taxonomists in 37 countries, a bibliography of 600 identification guides, and an overview of the collections of marine species available in European museums and institutions. Also noteworthy are the many initiatives of the ETI (the Expert Centre for Taxonomic Identification, based in Amsterdam) which has earned respect through its management of biodiversity information (http://www.eti.uva.nl). Every year, ETI produces about ten CD-ROMs with highly quality-controlled taxonomic information, and for this task it can count on the help of no less than 1500 taxonomic experts worldwide. Since 1991, ETI has produced about 90 CD-ROMs of which about 25 are related to marine/coastal organisms.

Data centres in evolution

Changes in technology and changes in society are both forcing data centres to rethink their role and *modus operandi*. Another trend is the increased interest in biodiversity and the need to set up management and monitoring programmes to study marine (and other) biodiversity. Human-induced world-wide changes, such as global warming, will no doubt affect our living resources; one of the challenges of the new data centres is to integrate biological and physicochemical data and make both data types available for combined analysis. These and other developments were discussed at the 'Colour of Ocean Data' Symposium, held in Brussels in 2002. The last part of the symposium was dedicated to a panel discussion, in which the changing role of data centres was discussed. What follows is a brief overview of the most important trends and issues that were identified.

There is a trend away from the traditional data centre, with its main task of archiving datasets, towards becoming more service-orientated. Data centres can look towards libraries for inspiration to redefine their role; libraries provide expertise and guidance in cataloguing. Archives are grey and dusty, libraries are active and open; data centres should strive to resemble the latter rather than the former. Data management needs an equivalent to the 'Web of Science': a mechanism to bring up a list of relevant, available, quality controlled and peer-reviewed datasets.

Any mechanism for finding data – i.e. 'data discovery' – is meaningless (and very frustrating!) if it is not linked to a system for data distribution, through which the scientist or interested layperson can access actual data. Setting up both data discovery and data distribution mechanisms is made possible by recent developments in internet and database technology.

Some traditional roles of data centres remain important: long-term stewardship of data, integrating datasets, documenting and redistributing datasets, development of standards and standard operational procedures, etc. Datasets often result from particular projects, which usually have a limited time span. Short-term data management, within the time span of the project, is usually not a problem: scientists need data management to produce useful results; moreover, making provisions for data management is often a prerequisite for getting a proposal accepted in the first place. After the project ends, however, there is a danger that detailed knowledge about the collected data can disappear, together with project staff. It is the mandate of data centres to work together with project staff, to ensure that data are properly documented, and that the integrity of the data themselves are safeguarded after completion of the project.

Meta-databases and other methods of data discovery will certainly gain more and more importance as the number of studies, and the number of scientists conducting these studies, increases. Such methods of data discovery, and better communication between and among scientists and data managers, are essential for avoiding unnecessary duplication of effort.

There is a need to create data and information products, not only for other data managers and scientists, but also for policy makers and society at large. These products will assist in increasing the visibility of data centres and demonstrate the usefulness of data management to a larger audience. As such, it may assist in attracting funds for further activities as well as data submissions from scientists.

Unfortunately, marine scientists are generally very poorly informed about data centres and about data and information management procedures. There is a need to investigate how to put data and information management on the curriculum of academic institutions. This would result in a greater awareness of data centres, and an increased quantity and quality of data submissions. Data managers should actively seek collaboration with scientists. Involvement of data managers in the planning of projects at a very early stage, and more input in the development of data collection makes 'Beginning-to-end data management' a reality.

There has to be peer review, as a way of measuring and recognizing progress, for recognizing value and expertise, and as a foundation for standards and accepted procedures. Standards and audit procedures are needed to allow objective peer review. Peer review, in turn, is a way of improving compliance with standards. Countries, or even institutions or scientists, could be tempted to work along principles that were developed locally; obviously, these fit local needs, and are usually much faster to develop, but having a variety of practices can lead to fragmentation and hamper data exchange. Developing standards is a task for the data centres.

Management of physicochemical and biological data has to be better coordinated. The problems of biological and physical data management are different: physics datasets are often high volume and low complexity; biology datasets are low volume but high complexity. The lower level of standardization in biology makes the importance of proper documentation of the datasets even greater. However, commonalities are more important than differences: both biological and physical data management need long-term archives; both need quality control and peer review; managers of both have a responsibility to create data and information products.

Marine data management is – or should be – essentially a global business. Participation of developing countries is essential if we want to build a complete picture of what is happening with our oceans and climate. Several problems hamper this participation. Internet access is difficult in many third-world countries, and where internet access is available, the bandwidth is often very limited, making it virtually impossible to download or upload large volumes of data. Also funds to purchase hard- and software, and expertise to maintain the systems, are factors that are more limiting in developing countries. The data management community should provide platform-independent software that is open source and runs on hardware that is compatible with the technological expertise available. Reliable and stable standards should ensure that data are available in a form that can be handled by these tools. Capacity-building programmes should be organized, making use of these tools and standards.

The future

Managers of marine data are facing major challenges. First, there is the incredible increase in the volume of data, especially in the area of remote sensing. Second, there is the great diversity in the types of data that have to be handled: physicochemical, geological, meteorological and biological data, all have to be integrated, and analyses and information products have to draw on all of them. Last but not least, there is a major discrepancy between the scale at which data are typically gathered, and the scale at which the data and information are needed. With very few exceptions, projects collect data and information on local scales, and over short time-spans. Humanity has brought on itself problems such as global warming and consequent sea-level rise, depletion of fish stocks, and pollution, which have generated a need for data and information on a global scale; integration of all available local datasets is the only way to create a data- and information base to support global decision-making.

Modern data management is inseparable from information technology. Recent developments in technology assist in coping with both the diversity and volume of data flows. The internet provides means to exchange data at no – or very low – cost. Electronic publishing is more and more the method of choice for communicating research results and other information. Database systems are becoming more sophisticated, allowing scientists and data managers to concentrate on subject matter rather than technical nitty-gritty. Computer systems are becoming faster, hard disk and other storage space is becoming cheaper, and information technology is making it possible to conduct data management, and devise information products, that could only be dreamed of just a couple of years ago.

The main challenge for data managers is now to remain in control of developments, and not to let marine data management become technology-driven. Obviously, recent technical developments should be monitored, and put to good use whenever and wherever relevant. But it is more important to continuously re-evaluate what the role of data centres should be, rather than how objectives are being realized. The real issues for data management are standardization, collaboration and enabling knowledge-based decision-making. Obviously, we can do 'more'. But can we also do 'better'?

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Plans for a ship tunnel in Norway

Lars Golmen

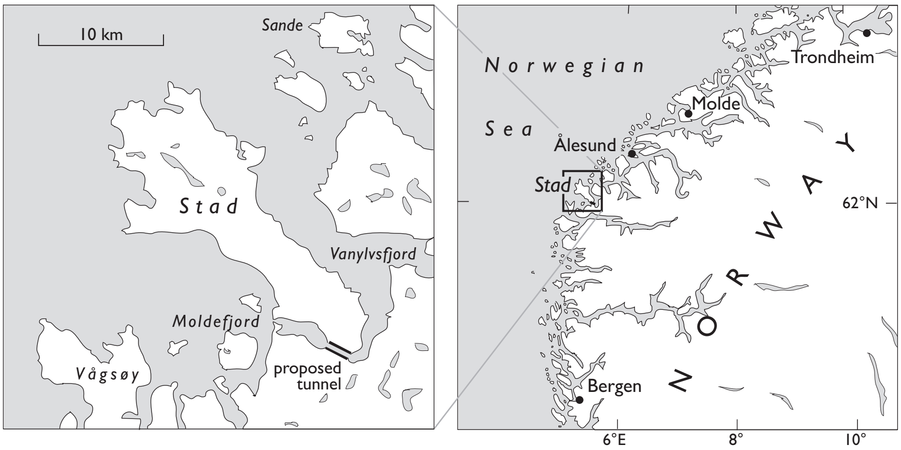
Certain parts of the western and northern coastline off Norway pose a significant challenge for ships during severe weather. One of the major obstacles is the passage west of the Stad headland, midway between Bergen and Trondheim. Many vessels have met their fate in this harsh and exposed area between the North Sea and the Norwegian Sea. During storms, coastal freighters commonly wait in port either side of Stad.

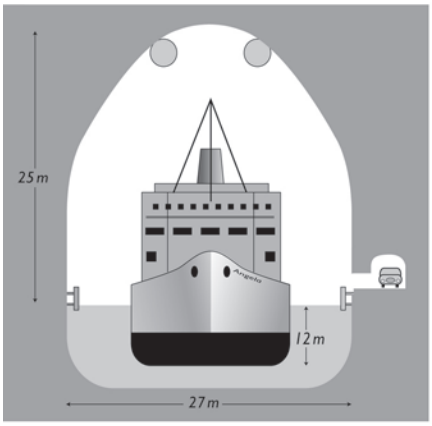
All the incidents and accidents, as well as the uncertainties and the waiting, led to the idea that the way to secure safe and regular passages would be a tunnel through the headland. The idea seems to have arisen during the Second World War when the Nazi occupants investigated means to secure the coastal transport. The idea was revisited in the 1970s by a group including the late Ivar Aanderaa, an industrialist renowned for his oceanographic current meters, which are still in production after 40 years.

Several studies were conducted before 1980, all suggesting that the project was feasible, and foreseeing few technical obstacles. The planned tunnel will connect the Moldefjord, south of Stad, to the Vanylvsfjord to the north, a horizontal distance at sea-level of about 1.8 km.

The tunnel is designed to carry ships of several thousand tonnes, but not the biggest carriers. The width will be 27 m, the height of the roof will be 25 m or more above sea-level, and the water depth will allow a draft of 12 m. Significant amounts of rock will have to be excavated and disposed of, but other than that, the project is regarded as straightforward in terms of construction and engineering. Construction costs will be around 870 million NOK (~ €100 million).

The pre-feasibility studies included measurements of hydrography, currents and tides in the two fjords to be connected. The major issue to be investigated was the risk of strong currents inside the tunnel, possibly peaking at times of harsh weather when the tunnel would be most needed. Numerical model studies showed that such risks would occur when south-westerly or north-westerly winds pile up water on one side or the other, and on rare occasions the sea-level gradient could set up a current of 1.5–2 m s^{-1} (3–4 knots) inside the tunnel. Otherwise, the tunnel should be navigable all year round, allowing regular and timely passage of fast commuter craft, passenger boats





Above *Location of the proposed tunnel.*
Right *Artist's impression of the tunnel. The round objects near the roof are ventilation shafts. Traffic will be regulated so that it is in one direction at any given time.*

and cargo freighters, and fast and safe carriage of goods such as fish products from the large Norwegian aquaculture and fishery industry, as well as swift relocation of equipment (booms etc.) in the event of an oil spill on the coast.

At present, even large modern ships may encounter problems at Stad. In December 2003 a brand new coastal steamer lost both engines 2–3 km off Stad in 6–8 m waves in the middle of the night. The 136-m long ship drifted steadily towards the cliffs, the drift slowed only by the anchors. 150 passengers and crew waited in lifeboats ready to be launched. Only 100 m away from disaster, the engines fired again and the ship was able to manoeuvre to safety. Although the tunnel plans are not yet approved by the government, recent incidents like this, and the general pressure towards safer maritime traffic, may be paving the way for this unique project to be launched soon.

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Limiting biological invasions of aquatic organisms

Stephan Gollasch

Aquatic species colonize new habitats either by natural means (e.g. distribution by currents) or via human-mediated vectors (e.g. shipping and aquaculture). As far as northern Europe was concerned, the first invasion of non-indigenous species as a result of human activity might well have been that of the North American soft shell clam *Mya arenaria,* which was probably introduced with solid ballast as a result of Viking voyages to North America. The introduction of alien species outside their native distributional range is considered to be one of the most important anthropogenic threats to the biodiversity of the world's oceans, and has resulted in negative consequences for both ecology and economies. International forums have recognized this problem and regulations have been drafted accordingly. This article provides an overview of existing regulations relevant to biological invasions, with particular reference to Europe, and is directed to science policy makers, politicians, lawyers, science administrators and interested biologists; it is intended as a basis for discussion, and does not provide an interpretation of international law. As shipping and ballast water form one of the most important vectors of anthropogenically mediated biological invasions, I have concentrated on these, but for purposes of comparison, intentional species introductions for (say) aquaculture purposes are briefly included.

Negative impacts of biological invasions have frequently been reported from almost all of the world's seas and oceans. The total number of non-indigenous aquatic species in northern Europe was estimated in 1998 to exceed 100, including fish, algae, molluscs and crustaceans (cf. Figure 1), of which the majority were unintentionally introduced. Successful invaders tend to spread, and may change the natural environment by competing with native species or predating on them. As a result they may threaten the functioning of ecosystems, and affect public health and economic activities such as tourism, fishing and aquaculture.

Natives of China and Korea, mitten crabs reached German waters via ballast water, and are now found throughout Europe

Figure 1 *Chinese mitten crabs (*Eriocheir sinensis*) spread throughout northern Europe in the 1920s and 1930s. They spend most of the lives in freshwater environments, where their burrowing can cause serious erosion. They mate in tidal estuaries, where the eggs and young develop; juveniles actively migrate upstream towards freshwater systems.*

As mentioned above, a major cause of a unintentional introduction of species is release of ballast water. Species have been transported with ballast water and associated sediments ever since the 1870s when water began to be commonly used as ship's ballast, for stabilization and trim, and to submerge the propeller. Ships' ballast pumps usually have their intake opening below the water-line near the bottom of the ship. Aquatic organisms are pumped on board when ballast water is taken up, and are frequently transported across natural migration boundaries, i.e. between oceans, and across salinity barriers (e.g. between freshwater ports). Most organisms die in the ballast tanks during the first days of the voyage, but some individuals survive voyages of several months' duration. Upon arrival, the organisms are discharged along with the ballast water (Figure 2).

Organisms transported in ships' ballast include truly planktonic taxa and benthic species that have a larval form which is free-living in the water column. According to shipping studies, more than 1000 different taxa have been found in ballast tanks, ranging from fish to unicellular algae (including forms known to cause harmful algal blooms). The majority of these taxa are algae and coastal invertebrates, such as crustaceans, gastropods and bivalves.

Unilateral voluntary recommendations and mandatory regulations aimed at minimizing the introduction of species via ballast water have been implemented in various regions throughout the world. New Zealand and Australia were the first countries to implement voluntary ballast-water guidelines in the late 1980s and early 1990s. Indeed, most regulations are of a voluntary nature and currently favour exchange of ballast water in the open ocean.*

Ballast-water exchange may be done by: (1) emptying and refilling the tank at least three times; (2) applying the overflow technique (Figure 3) where water is pumped into ballast tanks allowing an overflow on deck, until three times the volume of the tank has been pumped through; or (3) the dilution method, where extra pipe-work allows a continuous addition of water to the tank while the same amount of water is discharged, so that the water level in the ballast tank does not change. In contrast to the overflow method, the dilution method can be used for partially filled ballast tanks.

At present, only a few European countries recommend voluntary exchange of ballast water in mid-ocean areas.

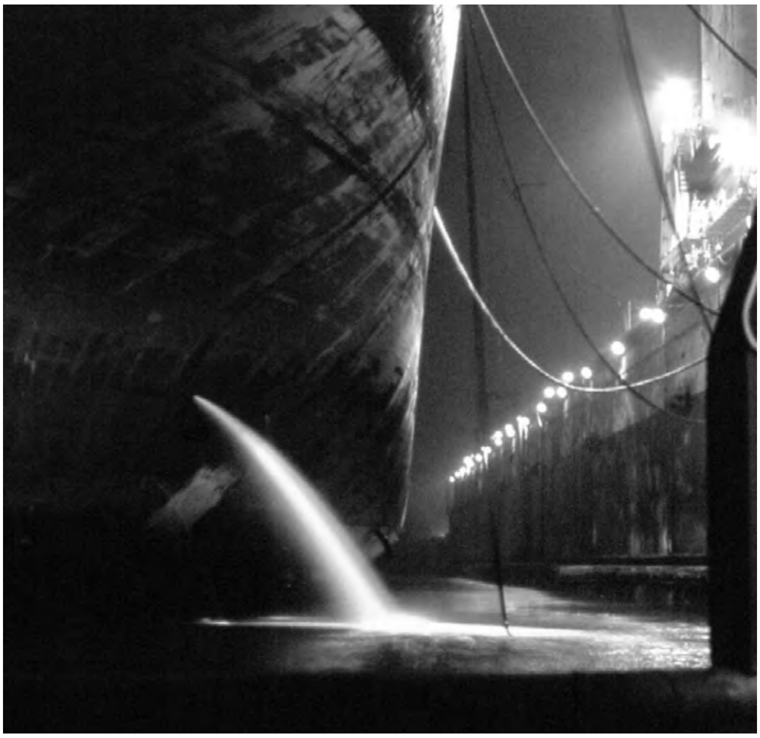

Figure 2 *Ballast-water release from an ocean-going merchant vessel, after dry-docking in the Port of Hamburg, Germany.*

When ballast water is released, so are organisms living in it

Legal instruments

Internationally agreed legal instruments may be binding or non-binding. Binding instruments are usually mandatory agreements between States, such as treaties or conventions. Non-binding instruments ('soft-law') take the form of resolutions such as guidelines and action programmes.

The following international instruments relevant to the unintentional introduction of aquatic species are listed chronologically. The lists are not fully comprehensive, but provide an overview of current legislation.

Voluntary international instruments

Worldwide, there are a number of non-binding regulations and recommendations, and not surprisingly, their success depends on the extent to which the relevant authorities act on them. Some of these regulations do not refer to specific vectors such as ballast water, and these are covered first, followed by instruments that specifically address ballast water and other vectors.

Voluntary general instruments

As early as the 1970s, the International Council for the Exploration of the Sea (ICES) considered species invasions to be a problematic issue. It established the Working Group on Introductions and Transfers of Marine Organisms (WGITMO), which focusses on planned introductions (e.g. oysters for use in aquaculture) and unwanted imports of associated disease agents and parasites. In 1994–95, ICES developed a Code of Practice on the Introduction and Transfer of Marine Organisms. The Code recommends the application of appropriate quarantine measures in donor and recipient countries to avoid the introduction of non-target species (e.g. disease agents and pathogens). An updated and revised version of the Code was published by ICES in 2003 on www.ices.dk. This Code includes all concerns expressed in the previous Code of Practice, follows the precautionary approach to minimize the spread of exotic species, and covers genetically modified organisms in greater detail than the earlier version.

In 2000, the Species Survival Commission (SSC) of the World Conservation Union* published guidelines for the prevention of biodiversity loss caused by alien species. These guidelines were intended to increase awareness of the problem and alert States to the fact that preventing the spread of alien species is a priority issue requiring national and international action. They aimed to minimize the number of unintentional introductions and prevent unauthorized introductions of alien species, and encouraged development, implementation and improvement of suitable eradication and control programmes. This would involve developing a comprehensive framework for national legislation and international cooperation to limit introduction of alien invasive species, as well as their eradication and control. The guidelines encouraged relevant research and development and sharing of an adequate knowledge base to address the problem of alien invasive species worldwide.

Voluntary ballast-water instruments

in 1973, the International Maritime Organization (IMO) – the United Nations body that deals with shipping issues – created the Marine Environment Protection Committee (MEPC). Australia was the first country to bring the ballast water

*Some countries (e.g. Argentina and Chile) require chemical treatment (chlorination) of ballast water when there are outbreaks of human pathogens (e.g. cholera) in the ballast-water uptake area.

* Formerly the International Union for Conservation of Nature and Natural Resources, and still referred to as the IUCN.

problem into focus and in the early 1990s played a key role at the IMO in proposing the development of mechanisms to control the release of ballast water. MEPC formed the Ballast Water Working Group (BWWG) to evaluate information and consider solutions proposed by the Member States and by non-governmental organizations. The BWWG concluded that voluntary guidelines were the appropriate first step in addressing this problem. It recommended an exchange of ballast water in mid-ocean areas, as far as possible from any shoreline, in order to considerably reduce the number of organisms and taxa inside ballast tanks. Mid-ocean organisms, pumped onboard during the water exchange, are unlikely to survive coastal conditions.

As safety is of paramount importance it was stipulated that mid-ocean exchange of ballast water should only be undertaken at certain sea states and if cargo conditions permit. The MEPC adopted the guidelines by resolution in 1991, and in 1993 they were adopted by the IMO Assembly as a resolution entitled 'International Guidelines for *Preventing* the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges'. However, it was recognized that complete prevention of organism release cannot be achieved, and in 1997 this was replaced by Resolution A.868(20) 'Guidelines for the Control and Management of Ships' Ballast Water to *Minimize* the Transfer of Harmful Aquatic Organisms and Pathogens'. This resolution intends to 'assist Governments and appropriate authorities, ship masters, operators and owners, and port authorities, as well as other interested parties, in minimizing the risk of introducing harmful aquatic organisms and pathogens from ships' ballast water and associated sediments while protecting ships' safety.' In the resolution, the IMO proposed guidelines to limit the movement of organisms by ballast water world-wide. The guidelines recommended:

- informing ships of areas where ballast-water uptake should be avoided due to the presence of harmful algal blooms and known unwanted contaminants;
- precautionary procedures to be adopted when taking on ballast water in shallow areas;
- exchange of ballast water at sea as far as possible from the coast;
- ballasting with freshwater;
- discharging ballast water and sediments to onshore facilities (if available); and
- provision for ballast-water reporting forms.

The guidelines further recommend avoiding taking on ballast in shallow areas and at night when deep-living organisms may migrate towards the sea-surface and be more likely to be pumped onboard.

The BWWG at IMO has since developed a mandatory IMO Ballast Water Management Convention as a stand-alone instrument (see below).

The United Nations Conference on Environment and Development (UNCED), held at Rio de Janeiro (Brazil) in 1992, resulted in the *Convention on Biological Diversity* (see below), the Rio Declaration on Environment and Development, and Agenda 21. The Rio Declaration consists of 27 key principles providing guidance for future development of national and international legal decision-making, and actions aimed at achieving both socio-economic development and environmental protection. Among the 27 principles are: the Prevention Principle, the Precautionary Principle, and the Polluter-Pays Principle.

Regarding prevention, reduction and control of degradation of the marine environment as a result of sea-based activities, Agenda 21 calls upon all States to better implement and even strengthen existing conventions, and to support the work of the IMO (see above) and other agencies in developing international instruments to protect the marine environment from shipping-related pollution.

In the mid-1990s, the ICES/IOC (International Oceanographic Committee)/IMO Working Group on Ballast and Other Ship Vectors (WGBOSV) was initiated. This group deals with unintentional species introductions via ships. Annual meetings update members on newly recorded ship-mediated biological invasions, and on impacts of invaders, and offers opportunities to initiate concerted international activity. The group further recommends appropriate actions to its parent committees (i.e. ICES, IOC and IMO).

The issue was tackled at the Fifth North Sea Conference held in Bergen (Norway) in 2002. The text of Article 42, agreed at the Conference, is given in the box opposite (top right).

The overflow technique is one way of exchanging ballast water in the open ocean

Figure 3 *Ballast-water exchange using the tank overflow technique, in which the tank is flushed out by pumping through three times its volume of seawater.*

Binding international agreements

The following instruments are not all strictly focussed on the marine environment, but the broader ones are included for completeness.

- The *RAMSAR Convention* (*Convention on Wetlands of International Importance Especially as Waterfowl Habitat, 1971*) requires Contracting Parties to wherever possible address the environmental, economic and social impact of invasive species on wetlands within their jurisdictions. Contracting Parties are further urged to 'review existing legal and institutional measures and, where necessary, adopt legislation and programmes to prevent the introduction of new and environmentally dangerous alien species and the movement or trade of such species within their jurisdictions'.
- The *Bonn Convention for the Conservation of Migratory Species of Wild Animals* (1979) urges Contracting Parties 'to the extent feasible and appropriate, to prevent, reduce or control factors that are endangering or are likely to further endanger the [indigenous] species, including strictly controlling the introduction of, or controlling or eliminating, already introduced exotic species.'
- The *Bern Convention on the Conservation of European Wildlife and Natural Habitats* (1979) recommends 'each Contracting Party to strictly control the introduction of non-native species'. Parties should initiate regional cooperation to coordinate the control of invasive species.
- Chapter XII of the 1982 *UN Convention on the Law of the Sea* (UNCLOS) focusses on protection and preservation of the marine environment and requires that 'States shall take all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of technologies under their jurisdiction or control, or the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto.'
- The 1992 *Convention on Biological Diversity* (*CBD*) is the first international agreement obligating States to conserve and use their biological resources sustainably. It states that 'each Contracting Party shall, as far as possible and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species.' The jurisdictional scope of these obligations applies also to the biodiversity in neighbouring and other countries.

In 1995 the second meeting of the Conference of the Parties to the *CBD* was held in Jakarta (Indonesia). The *Jakarta Mandate on Conservation and Sustainable Use of Marine and Coastal Biological Diversity* includes living modified organisms resulting from modern biotechnology and recommends applying the precautionary approach.

- The OSPAR Convention (*Convention for the Protection of the Marine Environment of the North East Atlantic, 1992*), ratified 1998, states that decisions relating to international shipping, and the resulting spread of alien species, should be left to the IMO. However, the OSPAR Commission was requested to express its concerns to the IMO and to rely on decisions taken by IMO Member Parties to achieve appropriate responses.

Article 42 of the Fifth North Sea Conference (2002)

To prevent, reduce and mitigate adverse effects on the ecosystem and indigenous species from the introduction and transfer of non-indigenous species via ships' ballast water and sediments, the Ministers agree:

i) to actively support the development of the *International Convention for the Control and Management of Ships' Ballast Water and Sediments,* and work towards its finalization in 2003, and its rapid entry into force;

ii) to take coordinated action within IMO to establish adequate mitigation and control measures for the North Sea under the framework of the coming pre-said *IMO Convention*, and to support OSPAR's work on regional matters regarding ballast water;

iii) to take urgent coordinated steps to reduce the problem of spreading of non-indigenous invasive organisms to and within the North Sea in accordance with international law and in order to fully implement IMO Guidelines (Resolution A.868(20)), in the light of the forthcoming *International Convention for the Control and Management of Ships' Ballast Water and Sediments*, and decide upon national and/or regional measures by, if possible, the end of 2004, taking into account the progress within IMO. Such measures could, *inter alia*, include monitoring programmes, information exchange, early warning systems, combating actions, control and enforcement; and

iv) to enhance and support actively research on and the development of treatment technologies, decision support systems, and other issues related to preventing the spreading of non-indigenous organisms via ships' ballast water and sediments and to cooperate in those activities.

- The *Convention on the Law of Non-Navigational Uses of International Watercourses* (1997) is the basic document of international water law. Part 4 of the Convention, entitled 'Introduction of Alien or New Species', states:

> Watercourse States shall take all measures necessary to prevent the introduction of species, alien or new, into an international watercourse which may have effects detrimental to the ecosystem of the watercourse resulting in significant harm to other watercourse States.

- As mentioned earlier, the IMO BWWG has developed a stand-alone Ballast Water Management Convention (i.e. this new Convention is not annexed to an existing IMO Convention). Initially the MEPC was requested to develop legally binding provisions entitled 'Draft Regulations and Code for the Control and Management of Ships' Ballast Water and Sediments to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens' with the intention of creating a new Annex to MARPOL 73/78* – MARPOL provisions deal with pollution from ships, including oil, noxious liquid substances in bulk, harmful substances carried by sea in packages, sewage from ships, garbage and air emissions. Subsequently, however, it was decided not to regard ballast water as a pollutant for the purposes of MARPOL, and preparation of the stand-alone IMO Ballast Water Management Convention began.

The IMO Ballast Water Management Convention

The *International Convention for the Control and Management of Ships' Ballast Water and Sediments* was adopted at a Diplomatic Conference at IMO Headquarters, London, on 13 February, 2004. The Diplomatic Conference was attended by representatives from 74 IMO Member States,

*MARPOL 73/78 = *The International (IMO) Convention for the Prevention of Pollution from Ships, 1973*, as modified by the relevant Protocol of 1978.

one Associated Member, and two observers from intergovernmental organizations (IGOs), as well as representatives from 18 non-governmental organizations (NGOs).

The Convention includes many elements that are also present in the relevant IMO Resolution A.868(20) mentioned above. In addition, it aims for standard guidelines on ballast-water management and includes provisions for technical solutions to the problem, and the possibility of port entry requirements or coastal state prescriptions. In this context, ballast-water management includes water exchange, treatment and discharge to (land-based) reception facilities.

In the case of ballast-water exchange in mid-ocean, the Convention adds to the requirements outlined in IMO Resolution A.868(20) by requiring a minimum water depth of 200 metres and a distance of at least 200 nautical miles (n.m.) from the nearest land. Ships that cannot meet these requirements need to exchange the water as far as possible from the nearest land (at a distance of at least 50 n.m.) in a minimum water depth of 200 m. The concept of regional implementation further includes ballast-water discharge control areas and ballast-water uptake/exchange areas.

Most IMO Member States agreed that it is preferrable to have a universal global approach in shipping regulation. However, it was recognized that for certain areas, regional implementations according to international law may be necessary to adequately address particular circumstances. Nevertheless, variations in the implementation of international regulations, or unilateral legislation on a geographical scale smaller than that of the North East Atlantic region, could create extra problems and would therefore not be beneficial.

For regions like the north-east Atlantic, cooperation between States is essential. Article 13 of the the Convention ('Technical Assistance, Cooperation, and Regional Cooperation') states that:

> … Parties with common interest to protect the environment, human health, property and resources in a given geographical area, in particular, those Parties bordering enclosed or semi-enclosed seas, shall endeavour, taking into account characteristic regional features, to enhance regional co-operation, including through the conclusion of regional agreements consistent with this Convention. Parties shall seek to co-operate with the Parties to regional agreements to develop harmonized procedures.

Special Considerations for Regional Seas

Scientific studies have shown that in shallower regional seas (e.g. shelf seas such as the North Sea) ballast-water exchange is not an effective way of removing organisms. As a result, the number of organisms in ballast water is relatively high and trials have shown that there may even be more organisms inside ballast tanks after an exchange of water than before. Consequently, ships calling at (say) North Sea ports may need to exchange their ballast water in deeper regions such as the open Atlantic, or apply alternative ballast-water management techniques.

Inner-European and domestic shipping within the North Sea cannot employ ballast-water exchange measures according to the IMO regulations, as either water depth or distance from shore would not meet the requirements. Also, it is stated in the IMO Convention that ships shall not be required to delay or deviate from their intended voyage in order to comply with any particular requirement for ballast-water exchange. As a result, most European coastal shipping would be excluded from ballast-water exchange requirements, mainly for practical reasons. However the risk of introducing species persists. It is therefore recommended that ballast water is discharged to reception facilities, or is required to be treated prior to release in European waters; alternatively, European ballast-water exchange zones need to be identified.

Treatment of ballast water involves using mechanical, physical or chemical processes to extract, inactivate or otherwise render harmless, ballast-water organisms during, or prior to, release of the water. Treatment measures need to be proven environmentally sound, to ensure that they do not cause more problems than they solve. This is especially true for chemical treatment where ballast water may need to be decontaminated prior to release.

Two basic ways are being considered for identifying ballast-water exchange zones. One is to identify areas where ballast-water operations (exchange of water, discharge of water) are permitted; the other is to define areas where ballast-water operations are prohibited. Either way, regional agreements are essential.

It is questionable whether exchange zones for ballast water can easily be identified in northern Europe, as most European waters are shallow-water bodies (e.g. the North Sea). However, it may be feasible to establish ballast-water exchange zones in the open Atlantic off western Europe. Ships from overseas (and the Mediterranean) intending to discharge ballast water originating outside northern Europe could be asked to carry out a water exchange in these zones. However, short regional voyages will have to be addressed separately. One might assume that short-distance or domestic traffic would not promote species introductions as the organisms in question would spread by natural means anyway. This is certainly the case for many marine organisms, but certain short-distance shipping routes should not be excluded from any ballast-water requirement: ballast water moved between freshwater ports in Europe (e.g. St Petersburg to Hamburg) would allow freshwater species to spread. In these cases, ballast-water treatment may be an appropriate approach to reduce the risk of species invasions.

The text in Section C of the IMO Ballast Water Management Convention includes provision for additional measures in case parties wish to add to the basic requirements of the Convention. It clearly states that affected neighbouring countries should be consulted, indicating the need for a regional approach. It further recommends the implementation of 'early warning systems' to notify mariners of areas where ballast-water operations should be avoided.

The Convention further states that all ballast-water management areas should be consistent with international law, i.e. with UNCLOS: 'Any additional measures adopted by a Party or Parties shall not compromise the safety and security of the ship and in any circumstances not conflict with any other convention with which the ship must comply.' The establishment of ballast-water management zones would not limit the rights and duties of a government under international law, nor the legal regimes of straits used for international shipping.

Particular Sensitive Sea Areas (PSSAs)

PSSAs are unique marine habitats which have to conform to certain IMO requirements. Initially, this environmental protection initiative focussed on the prohibition against discharging oil-contaminated water. However, its extension to protect PSSAs from ballast-water discharges has not been discussed at IMO.

The Wadden Sea, located in the south-eastern North Sea, off the coasts of Denmark, Germany and the Netherlands, is an example of a unique marine habitat. It is one of the world's most important tidal wetlands and is characterized by high biological productivity and high natural dynamics. With various resource-users (e.g. fishing, shipping and tourism) there is potential for conflict of human interests and a need for conservation of nature. To protect and conserve the environment of the Wadden Sea, the trilateral Wadden Sea Plan, involving cooperation between Denmark, Germany and the Netherlands, was adopted in 1997. Additionally, parts of the area are identified as Wetlands of International Importance (Ramsar Areas), as Bird and Habitat Directives areas, and as Man and Biosphere Reserves. Furthermore, the progress report of the 5th International Conference on Protection of the North Sea (Bergen, 2002) identified 60 Sites of Community Importance (SCI) for protection in the North Sea. These sites are mostly located in coastal regions and cover about 900 000 hectares.

A proposal to identify the Wadden Sea as an IMO-approved PSSA was submitted during MEPC48 and adopted at MEPC49 in 2003. After that, the north-western European seas as a whole (with the exception of the Baltic) were proposed, with the approval of the IMO. Then all countries with a Baltic coastline (except those under Russian jurisdiction) prepared a joint proposal to classify the Baltic as a PSSA. At the most recent meeting of MEPC (MEPC51 in March/April 2004) several new PSSAs were adopted, including the Baltic – one of the very few brackish seas in the world.

Measures to protect PSSAs may include: identification of certain areas to be avoided by tankers or other ships carrying hazardous cargoes; traffic separation schemes; no-anchoring areas; mandatory piloting requirements; and vessel traffic-management services. The IMO will adopt individual measures to protect particular PSSAs at upcoming meeings of MEPC.

Recommendations

Biological invasions are of global concern. Although a global uniform and mandatory ballast-water regulation is a desirable tool it should be noted that in certain areas, including regional seas, additional measures might be necessary to protect the environment from future species introductions with ballast water. Nevertheless, limiting biological invasions could become 'Mission Possible' if certain actions are taken. These include:

- **A Europe-wide awareness campaign**

The campaign should cover the problems caused and the risks posed to the environment and economies, and should be addressed to all relevant stakeholders. It should promote the development and implementation of relevant regulations.

- **Regional agreements**

These could promote a more comprehensive strategy in policy-making and in designing scientific and technical studies to focus on minimizing unintentional introductions into European waters.

- **A European 'Non-Native Species Council'**

Based on the model of the US National Invasive Species Council, this body could: facilitate research and avoid duplication of research efforts; assign responsibilities to appropriate bodies on a national and international basis and promote their cooperation; provide technical and scientific advice to governments; and aid the decision-making process. The European coordinating body could include representatives of European governments and universities and ministerial departments concerned with legal aspects and relevant scientific research.

- **A 'Ballast Water Tax'**

Funds gathered by the tax could be used to finance ballast-water research, in particular to improve ballast-water treatment systems with a view to further reducing the number of organisms being discharged. (The tax would be levied on the basis of the volume of ballast water discharged, but might be extremely difficult to calculate.)

Outlook

Much work needs to be done, and implementation of the IMO Ballast Water Management Convention is critical. Significant outstanding issues include:

- approval of guidelines for ballast-water treatment systems (and guidelines for prototype-testing);
- guidelines for sampling to assess whether a vessel is in violation of the Convention (Port State control);
- a procedure to approve active ballast-water treatment substances (e.g. chemical treament);
- design, construction standards and operational guidelines for ballast-water exchange;
- ballast-water and sediment reception facilities;
- risk assessment;
- designation of ballast-water exchange areas.

A review of ballast-water management technologies, and how effective they are at removing, inactivating or rendering harmless organisms in ballast water, will be carried out by MEPC before 1 January 2006. Governments are requested to consider developing appropriate working groups to ensure implementation of the Convention as soon after ratification as possible, to protect our waters from biological invasions and their unwanted ecological and economic impacts.

Stephan Gollasch is a marine biologist with many diverse interests. He was involved in the first European programme sampling ballast water, tank sediments and hull-fouling. Today, he works as an independent consultant, and is Chairman of ICES WGITMO and ICES/IOC/IMO WGBOSV.

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Climate Change and Biological Response in Mediterranean Sea Ecosystems

– a need for broad-scale and long-term research

Carlo Nike Bianchi and Carla Morri

The effects of climate change on marine biota are well known to palaeontologists but were more or less neglected by marine ecologists until the 1970s. Marine ecologists generally assumed that marine ecosystems were naturally stable, and that most changes (seasonal cycles apart) were probably caused by humanity; their natural variability was therefore often neglected. This was particularly true for the Mediterranean Sea, where research has traditionally been directed toward the identification and description of different marine ecosystems, rather than on their dynamics.

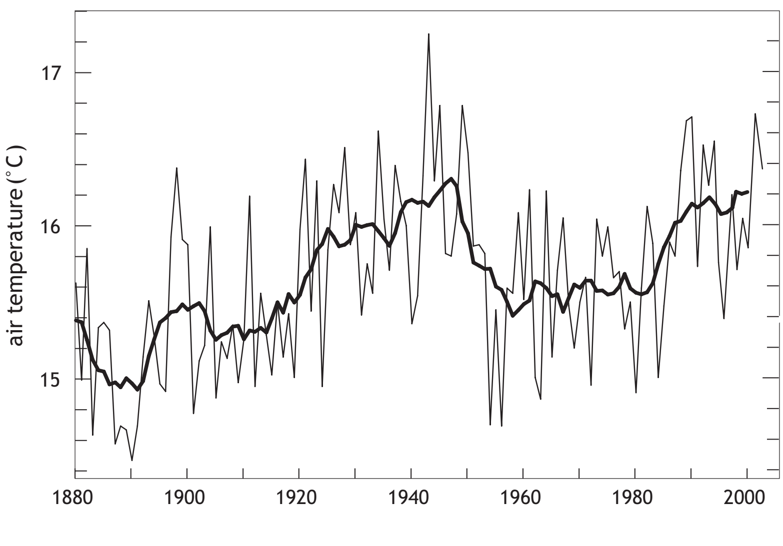
Studying the dynamics of marine ecosystems in order to understand their variability requires historical, long-term data. While a number of such data series are available for northern European seas, little exists for the Mediterranean. Fishery statistics are often the only time-series of biological data available, data on plankton and especially on benthos being still rarer: as these data only began to be collected in recent times, the various time-series cover at best only the last few decades.

Many Italian marine scientists are presently involved in a national research project called SINAPSI (Seasonal, INterannual and decAdal variability of the atmosPhere, oceanS and related marIne ecosystems) funded by the Ministry of University and Scientific Research (AdP MURST-CNR, L. 95/95). Here we report on some of the biological highlights emerging from the initial results.

Since 1880, the coolest periods in the north-western Mediterranean have been prior to 1920 and in the 1960s and '70s

Figure 1 *Trend in air temperature (annual means, °C) at Genoa, 1880 to 2003. Heavy line = running averages over 11-year periods.*

(From data of the Meteorological Observatory of Genoa)



Climate versus anthropogenic change

Distinguishing environmental stress due to climate change from that due to human pressure is often difficult. A good example of this is the regression of the meadows of *Posidonia oceanica*, a seagrass species endemic to the Mediterranean Sea. Four other seagrass species are found in the Mediterranean but none forms meadows as large or of comparable ecological importance. At present, *P. oceanica* meadows are showing alarming signs of degradation, especially in the northern parts of the Mediterranean. This degradation may be explained either by pollution, resulting in greater water turbidity and hence diminished plant vitality; or by natural decline of the plant which is believed to have had its climatic optimum around 6000–2750 years BP when the regional climate was warmer than at the present day, after which it started to cool. Regression of *P. oceanica* meadows has definitely been accelerating in recent decades: for example, in the case of the Ligurian Sea (north-western Mediterranean) it has been estimated that nearly 30% of the original surface area of *P. oceanica* was lost in the 1960s, during the period of rapid urban and industrial development along the coast of Liguria. Those years, however, also corresponded to a cold phase in the secular temperature trend (Figure 1).

Another Ligurian Sea example comes from the Magra estuary. The Magra is a small river flowing down the Apennines and entering the Ligurian Sea a little to the east of the town of La Spezia (see Figure 3(a) opposite). There, benthic communities were monitored over a 7-year period, from 1987 to 1993. Major changes in these communities, including a decreased abundance of organisms, were observed in 1988 and 1991: it is tempting to relate the observed changes to the activity of a new sewage treatment plant (started in 1988, completed in 1990–91), but major fluctuations in the temperature trend were observed in exactly the same years (Figure 2).

The difficulty in distinguishing between climatic and human influences means that caution must be exercised when examining changes in marine ecosystems. Furthermore, anthropogenic influences and climatic change can combine in their effects on the marine biota.

Last but not least, we are becoming aware that humans are now directly influencing the climate. Oceans are warming in response to increased atmospheric carbon dioxide and other greenhouse gases – a result of human activities. This means, of course, that biological changes related to climate fluctuations can no longer be considered 'natural', and distinct from those caused by pollution or other direct anthropogenic causes.

Climate change and shifting biogeographic boundaries

Temperature fluctuations may be expected to cause changes in species distributions. These will be particularly obvious in areas that are close to biogeographic boundaries (i.e. at the limits of regions inhabited by different flora and fauna). It has been said that climatic shifts induce biogeographic shifts. Monitoring biogeographic boundaries should therefore give an unambiguous signal of climate change, as predicted global warming will probably make southern species extend their range northward. This is apparently what is happening within the Mediterranean Sea, where the occurrence of warm-water organisms has recently increased in northern areas such as the Ligurian Sea.

The Ligurian Sea, situated in the north-east corner of the western Mediterranean (cf. Figure 3), is one of the coldest areas of the Mediterranean Sea. Accordingly, the flora and fauna of the Ligurian Sea are characterized by a strong diminution of subtropical elements and by a more marked presence of boreal species typical of cold temperate waters. Paradoxically, episodic entry into the Ligurian Sea of warm-water species from the warmer Tyrrhenian Sea to the south, has been recorded mostly in cold years.

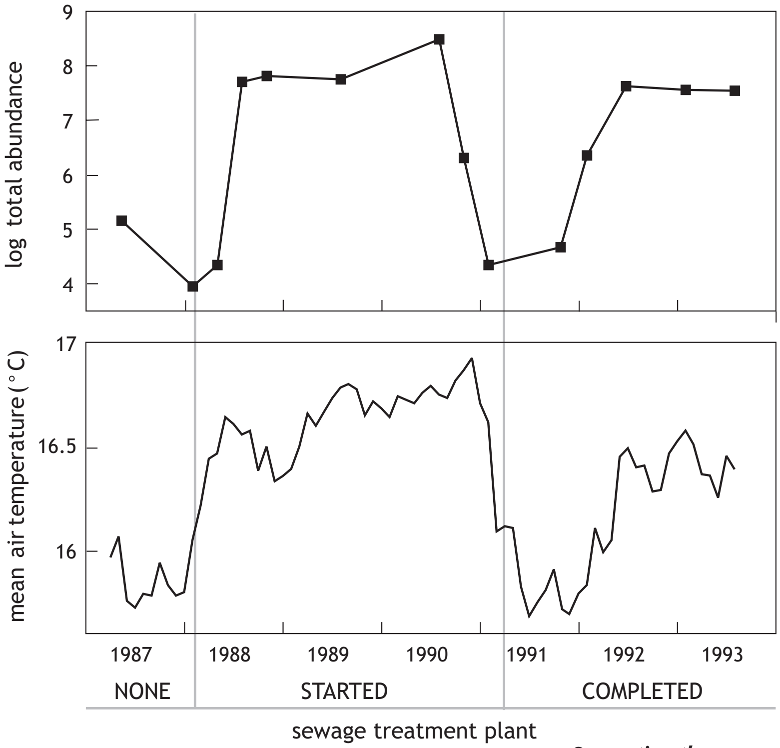
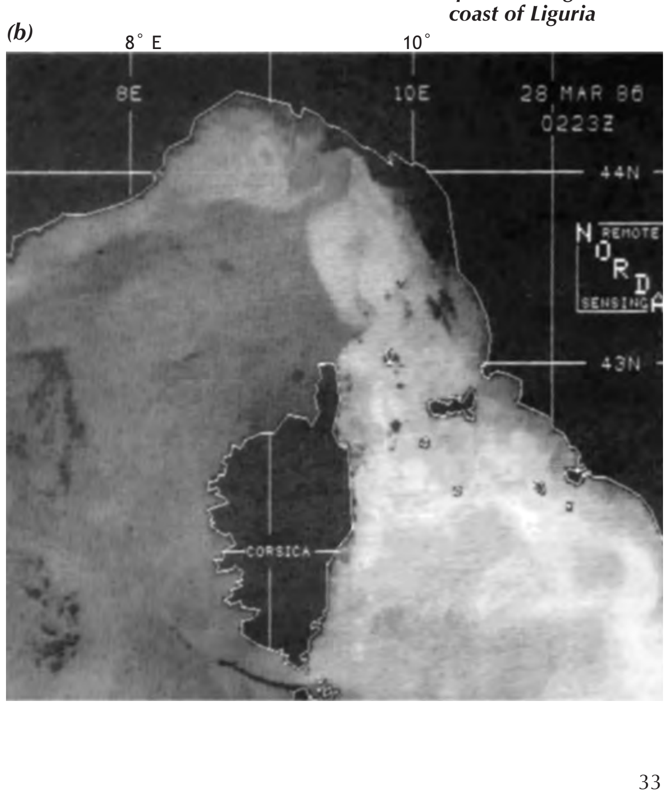


Figure 2 *Biotic, climatic, and anthropogenic change from 1987 to 1993, as related to benthic communities in the Magra estuary.* ***(a)*** *Trend in abundance (natural logarithm) of benthic organisms (black squares correspond to sampling dates).* ***(b)*** *Air temperature (°C); each data point represents the mean of the previous three months. The bar along the bottom shows the timing of the construction and start of operation of a large sewage plant.*

Separating the possible effects of climatic change from those caused by human acivities is not easy

Figure 3 ***(a)*** *Geographical setting of the north-western corner of the Mediterranean, showing much of the Ligurian Sea and the northern part of the Tyrrhenian Sea, and the main current systems.* ***(b)*** *Satellite infra-red thermal imagery (AVHRR NOAA 9, 28 March, 1986) revealing details of the circulation pattern in the region (lightest areas are the warmest).*

The northward-flowing Tyrrhenian Current carries warm-water species along the coast of Liguria



This apparent paradox is explained by the peculiar pattern of water and heat exchanges between the Tyrrhenian and Ligurian basins, mediated by the northward-flowing Tyrrhenian Current (Figure 3(a)). Seasonal cooling and evaporation of Ligurian Sea surface water results in it sinking and flowing away from the basin towards the south-west. This loss of water from the region draws warmer water in from the Tyrrhenian Sea: the more intense the Ligurian Sea winter cooling, the larger the volume of warmer water carried northward by the Tyrrhenian Current, and the greater the probability that warm-water species are transported into the Ligurian Sea. Survival of warm-water species in cold years is unlikely, and this explains the rarity of findings in the last one-and-a-half centuries. In a few cases, warm-water species have succeeded in establishing adult pseudopopulations (i.e. groups of organisms unable to reproduce).

This scenario has changed in the last two decades: discovery of warm-water species in the Ligurian Sea has become more frequent and nearly continual since the mid-1980s, even when winter temperatures have been high. Physical oceanographers have recently found evidence of a warming trend in Ligurian Sea water, and Ligurian Sea surface-water temperatures have been shown to correlate with air temperatures taken at the Meteorological Observatory of Genoa (cf. Figure 1). Genoa air temperature shows a warming trend comparable with that already known for the Northern Hemisphere. It is hypothesized that seawater warming allows the formerly sterile pseudopopulations in the Ligurian Sea to reproduce, thus providing independence from larval supply by the Tyrrhenian Current and allowing stable populations of warm-water species to become established.

Similar northward expansions of the geographical range of warm-water species have been observed in many areas outside the Mediterranean, such as the English Channel, off Madeira, and off southern California.

Changes within resident populations

It is common knowledge that individual populations change over time. The suggested causes for such changes of abundance within populations usually include vagaries in recruitment success, disease, predator–prey relationships, etc. However, in some cases, changes in populations have been proven to be related to climate. A case of particular interest is provided by those marine organisms, both invertebrates and algae, that lay down skeletons composed of calcium carbonate which persist after their death. The growth of these carbonate structures is strongly influenced by temperature and other climatic factors, so that coral skeletons (for example) record climatic variations.

Corals and other constructional organisms may themselves also play an active role in climate change, since the process of biocalcification interacts with the carbon cycle in the ocean. There are no coral reefs in the Mediterranean Sea, but there are many types of biogenic constructions, made by various organisms. Three invertebrate species in particular have recently been studied with the aim of estimating their carbonate production: the serpulid tubeworm *Ficopomatus enigmaticus*, the bryozoan *Pentapora fascialis,* and the scleractinian coral *Cladocora caespitosa*. Initial results (Table 1) seem to indicate that their production of calcium carbonate is within the range of that of most reef corals ($0.4–60\,kg^{-2}m^{-2}yr^{-1}$).

A large colony of *Cladocora caespitosa*, more than 60 years old, was found living in the eastern Ligurian Sea. Retrospective analysis of its skeletal growth through X-radiography showed that higher growth rates coincided with a warmer period in the 1940s, and lower ones with a colder period in the 1960s and '70s (Figure 4). Although other factors, such as colony senescence, might be invoked to explain changes in growth rate, these changes may be an indication of increased calcification in warmer years. This deduction agrees with the palaeoecological information, which indicates that *C. caespitosa* was more abundant – and its formations more conspicuous – during the warm periods of the Quaternary, especially during the Tyrrhenian stage (125 000 years BP), showing high subtropical affinity. It might therefore be supposed that if the present seawater warming continues, *Cladocora caespitosa* will play a greater role in a more and more 'tropical' Mediterranean Sea. In reality, coincident with the positive anomalies of sea-surface temperature recorded in recent summers, this species underwent a mass mortality, comparable with those observed in the tropics (Figure 5, opposite). Cases

Table 1 *Initial data on calcium carbonate production by three bioconstructional benthic invertebrates in the vicinity of La Spezia in the eastem Ligurian Sea (cf. Figure 3(a)).*

Species (and higher taxon)	***Ficopomatus enigmaticus*** (Polychaeta Serpulidae)	***Pentapora fascialis*** (Bryozoa Ascophora)	***Cladocora caespitosa*** (Cnidaria Scleractinia)
Habitat	brackish water	rocky shelf	shallow rocky sea-bed
Size of colony or indiv.	5 cm tube-length	10 cm diameter	15 cm diameter
$CaCO_3$ content	0.06 g per tube	$0.5\,g\,cm^{-3}$	$0.7\,g\,cm^{-3}$
Abundance density	145 000 individuals m^{-2}	7 colonies m^{-2}	1.5 colonies m^{-2}
$CaCO_3$ standing stock	$8.7\,kg\,m^{-2}$	$1\,kg\,m^{-2}$	$3.5\,kg\,m^{-2}$
Linear growth	$3.5\,cm\,yr^{-1}$	$3\,cm\,yr^{-1}$	$0.3\,cm\,yr^{-1}$
$CaCO_3$ production	$6\,kg\,m^{-2}$	$2.8\,kg\,m^{-2}$	$1.4\,kg\,m^{-2}\,yr^{-1}$

of mass mortality apparently correlating with high temperatures were also recorded in other organisms, such as sponges and gorgonians.

Change is continual …

From these few examples, mainly from the Ligurian Sea, it seems obvious that marine ecosystems are subjected to continuous change in species distribution, diversity and species dominance, as well as in recruitment, production and growth of populations. Marine communities do not fluctuate around hypothetical typical configurations: they just change, not only on geological time-scales but also on human generational or even decadal scales.

The idea that marine ecosystems are intrinsically stable probably has to be abandoned, and the meaning of stability needs to be revisited once more. Stability implies two independent concepts: *resistance* (the tendency to withstand a perturbation) and *resilience* (the ability to return to the same equilibrium point after perturbation).

Resistance has to be seen in many instances as nothing more than the persistence over many years of the adults of long-living species. These might have successfully settled during an episodic event and, once fully grown, have been able to resist minor disturbances; but they will give place to other individuals (maybe of a different species) after another episodic event, such as a disturbance strong enough to kill them. Accordingly, the well-established concept of climax – a stable community state in equilibrium with the regional climate – has been accompanied or replaced by expressions such as 'polyclimax' or 'multiple stable points'.

Resilience, on the other hand, is a remnant of the 'balance-of-nature' philosophy, which has deeply influenced biological thinking for decades. The recovery of a perturbed community depends on the largely unpredictable arrival of larvae and propagules from outside, rather than on an orderly process of recolonization leading to the same species assembly as was there before becoming re-established. Resilience is thus a non-concept when viewed (as it usually is) in a demographic perspective; it probably still has meaning when the global properties of the ecosystem, such as productivity or biomass, are taken into account. It is conceivable that the total biomass of an ecosystem remains relatively constant, but that over time, species vary their contribution to the total biomass. Claims that ecosystems are both stable and unstable need not be paradoxical: rather, they may reflect analyses at different analytical scales. Similarly, the recognition that change is a rule in ecosystems requires us also to consider stability at the appropriate time-scale.

There is a growing body of scientific literature demonstrating that most of the observed change in marine ecosystems is linked to climatic variation, but much more insight is needed to understand patterns and processes fully. Climate change can influence marine communities by a combination of: (1) a direct effect on the organisms (direct influence of temperature, causing changes in survival, reproductive success, dispersal patterns, and behaviour); (2) effects mediated by biotic interactions (conferral of competitive advantage to one of a pair of overlapping species); and (3) indirect effects through ocean currents (changes in climate may alter circulation patterns and current speeds).

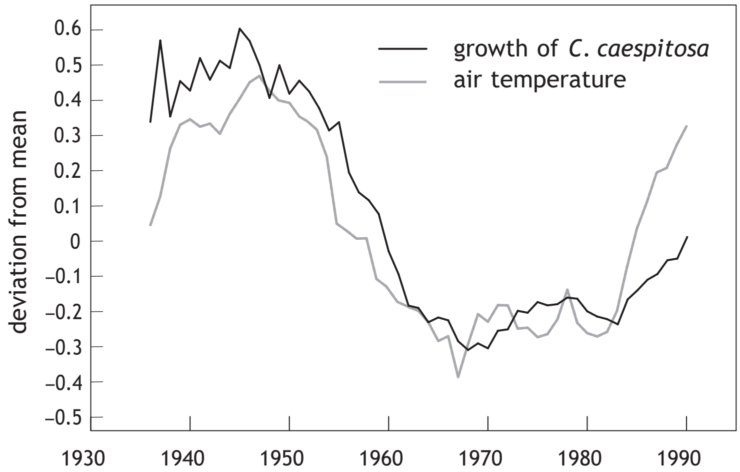


Figure 4 *Trends in temperature and growth of a 60-year old colony of the scleractinian coral* Cladocora caespitosa *from the Ligurian Sea. Both plots trace the respective 11-year running average of the deviations from their mean value.*

Growth rates of Cladocora caespitosa seem to be closely related to temperature

The studies on bioconstructional species mentioned earlier serve as an example of (1), the direct effect of temperature fluctuations on growth and carbonate production. These potentially immortal carbonate organisms are 'witness' to climatic fluctuations and may even play a role in regulating future change. They also provide information relating to (2), in that they are likely to gain competitive advantage over non-carbonate marine plants in warmer periods. On the other hand, the case of southern species in the Ligurian Sea is a striking example of the importance of (3) indirect effects. Marine ecologists emphasize the role of physical transport processes in structuring marine communities, and the expression 'hydrodynamic biological oceanography' has been coined to convey that variations in the distribution and abundance of organisms in marine communities are intimately related to

In the warm summer of 1998, there was a mass mortality of corals in the Ligurian Sea

Figure 5 *A colony of* Cladocora caespitosa *off La Spezia, the upper part of which died in August 1998. (The rule is 15 cm long.)*

physical processes, either directly through obvious constraints on the dispersal and survival of individuals, or indirectly by affecting the intensity of other biological and physical controls. This means that – without minimizing the importance of direct biotic interactions in shaping populations and communities – marine biological processes should be considered in the context of the physical setting and the relevant space- and time-scales.

Climate change is sometimes viewed as one of the most important threats to marine life. On the other hand, climatic fluctuations may act positively on biodiversity, favouring the coexistence of species potentially redundant from a functional standpoint and thus allowing the formation of species-enriched assemblages. Glacial–interglacial cycles have acted as a diversity pump on an evolutionary scale, so that species having either cold–temperate or (sub)tropical affinity can be found together in the present-day Mediterranean Sea. More recent climatic fluctuations may play the same role on an ecological scale. Diversity is probably the tool ecosystems adopt to face environmental fluctuations: a flexible species composition may allow ecosystems to maintain their functioning unaltered. It may sound paradoxical, but in ecology, change promotes stability, whereas stasis is an unnatural condition.

A logical consequence of the idea that marine ecosystems are intrinsically dynamic is that snapshot case studies, the most commonly funded kind of research, are of limited usefulness compared with long-term monitoring. A better knowledge of what is going on in the Mediterranean Sea requires continued research and monitoring in areas of science currently unfashionable with funding agencies: systematics, biogeography and taxonomy. Specialists in these disciplines who retire are not being replaced by young students; thus, while biodiversity problems are growing, we are losing expertise in biodiversity.

While there is no doubt that the biota of the Mediterranean Sea is changing, it is impossible at present to foresee to what extent this change will affect the trophic web and the general functioning of marine ecosystems. To understand the change in Mediterranean Sea ecosystems, it is essential to start monitoring biodiversity at a broad geographic scale. Neither species nor ecosystems recognize national boundaries, nor do climatic or even human impacts. An internationally co-ordinated network would be essential to long-term research projects. Studies have to use similar approaches and implement easily comparable methods, and need to encompass a monitoring period that corresponds to the expected lifetime of the dominant organisms and the time-scale of the most important factors that influence them. Funding and other constraints often force ecologists into three-year projects at maximum: few natural patterns are of such short duration, major changes in biota occurring on longer cycles. With a short-term approach to ecological monitoring and research, attempts to understand ecosystem change, both natural and human-induced, will always be likely to end in frustration.

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Ecotoxicology
and the marine environment

value, uncertainties and challenges

Claude Amiard-Triquet and Jean-François Pavillon

At the end of 1999, the French National Centre for Scientific Research (CNRS) carried out an investigation into what society expects from the scientific community. Not surprisingly, the general public was most interested in health and disease, particularly AIDS – 57% of the population wanted to know whether it will be possible to find a vaccine. Second in the list of public concerns were environmental issues (drinking water, 38%; transgenic organisms, 30%; nuclear energy, 30%). The question of water quality was well considered at the institutional level, with the publication in October 2000 of European Directive 2000/60/EC establishing a framework for a community policy; however, this ambitious text has engendered a need for research into the best tools for attaining the aims of the Directive.

At the interface of ecology and toxicology, and relating to both the environment and health, ecotoxicological research aims to improve our knowledge of the fate and effects of chemicals that reach the environment as a consequence of agricultural practices, industrialization and urbanization.

The deleterious effects of pollutants were first revealed to the public through spectacular events such as oil spills, but more insidious impairments are also at work. Developed under the pressure to cope with both increased inputs of 'traditional' contaminants (e.g. metals, hydrocarbons and nutrients) and the presence of a large range of new artificial molecules (e.g. pesticides, persistent organic pollutants, veterinary and human drug residues), the application of ecotoxicology has in practice preceded understanding of the fundamentals of the science. So, do European systems of education and research allow us to face the challenge of providing knowledge indispensable for good integrated management of coastal areas with a view to sustainable development?

The past and the present

Environmental concerns have been emerging progressively since the Second World War. For decades, the introduction of pollutants into the environment involved substances naturally present, such as metals, hydrocarbons, nutrients and organic matter, with changes being only at the level of quantities released. Since the Second World War, changes have been both quantitative and qualitative, with the emergence of a huge number of synthetic chemicals – a tendency which continues at the beginning of the third millenium.

The impact of both natural and synthetic chemicals has been revealed through a series of dramatic events. DDT – a pesticide highly beneficial in forestry and in the eradication of insects that act as vectors of illness – was recognized as responsible for the impairment of reproduction of top bird predators. It was demonstrated that this effect was the consequence of 'biomagnification' of DDT in food chains. Biomagnification is a particular mode of chemical bioaccumulation in living beings which leads to concentrations increasing with the trophic level of the individuals. Biomagnification of mercury, particularly the organic form methyl mercury, was responsible for the 'Minamata disease', characterized by impairment of the central nervous system, which in 1963 affected perhaps thousands of people in Kyushu Island, Japan, killing tens of them and leaving hundreds more disabled, especially fishermen and their families who subsisted mainly on sea-food. The methyl mercury contamination was traced to effluents from factories using mercury compounds as catalysts in plastic production (http://cisat.isciii.es/supercourse/lecture/lec0361/019.htm).

The first oil spill to give rise to both Europe-wide concern and scientific attention was that associated with the wreck of the *Torrey Canyon* in 1967, which affected the coast on both sides of the Channel. This was also an occasion when the deleterious effects of detergents were clearly documented. In such cases, the source of the problem was obvious. In the cases of DDT and methyl mercury, scientists played an important role in demonstrating the link between the deleterious effects observed in biota, including our own species, and the presence of specific contaminants in the environment, as well as showing how these contaminants reach top predators.

The basic scheme followed in risk assessment was thus established :

source ➛ exposure ➛ incorporation ➛ effect

A given chemical is emitted from a *source*, which is either well defined (as in the case of industrial effluent) or diffuse (e.g. agricultural pollution). It is then distributed in the environment, diffused and dispersed in the water column, adsorbed onto suspended or deposited particles that may be living (microalgae) or inert (clay, organic debris), leading to the *exposure* of living beings to a large range of contaminants in different components of the environment. Depending on environmental and biological factors, chemicals may be *incorporated* into living beings from water, sediment and through the food chain. Once incorporated in the tissues of biota, chemicals can exert their noxious *effects*.

How best to protect the marine environment?

Two decades ago, the approach envisaged was relatively simple. First, it was necessary to establish precisely the relationship between the dose of any compound liable to reach the environment and the effect on different classes of aquatic organisms: microalgae, annelids, molluscs, crustaceans, fish, etc. Toxic doses had to be compared with concentrations of chemicals of interest in sites potentially exposed to pollution, and it was assumed that the quality of the environment would be guaranteed, provided that environmental concentrations remained well below toxic doses. This strategy was refined to serve as a basis for risk-assessment of new products coming onto the market, taking into account the quantities to be produced and used, and the risk that a larger or smaller fraction was liable to enter the environment. These principles were applied in European regulations intended to protect human beings and their environment. To obtain the best toxicological data and the best chemical assessment of environmental concentrations, much work was carried out, by biologists working on the standardization of toxicity tests, and by chemists in the field of validation of analytical determinations based on internal and external quality controls (i.e. standardization of reference materials and international intercalibration exercises). However, it soon became clear that the problem was much more complicated than at first envisaged, and a closer look at the relationship between the dose of a given contaminant and its effect raised many questions.

Some considerations about the 'dose' …

We mentioned above that a contaminant may be incorporated into biota from water, sediment and/or food, so ideally these different routes should all be considered, but in reality it would be impossible to carry out so many complicated tests. Standardized tests take into account mainly water-borne chemicals, despite the fact that many potentially risky contaminants are poorly water-soluble. For those chemicals that are biomagnified in the food chain, it is evident that this procedure underestimates the risk. For sediment-dwelling species, the value of these tests is debatable since sediment is the aquatic 'compartment' in which the largest quantities of most environmental chemicals are stored.

In the case of water and food, as well as sediment, there is also the question of the 'bioavailability' of contaminants present. The global concentration of a given contaminant has little ecotoxicological significance because the uptake in biota can vary dramatically from nearly nothing to huge concentrations, depending on its physico-chemical characteristics. This is one of the major reasons why experimental results can hardly ever be extrapolated to environmental situations. In the natural environment, many factors influence the chemistry and bioavailability of contaminants, including the presence of organic matter and suspended particles, and the existence of salinity gradients etc.; also important are interactions between different classes of chemicals – a factor which is practically never taken into account in toxicity tests and is nearly impossible to determine for the tens of thousands of substances introduced into the marine environment.

To counteract these difficulties it has been proposed that it is more meaningful to consider *incorporated doses* (i.e. concentrations present in the tissues of exposed organisms), as these of necessity take the bioavailability of the contaminant into account. However, although this is an improvement it is not a complete solution, for the following reasons:

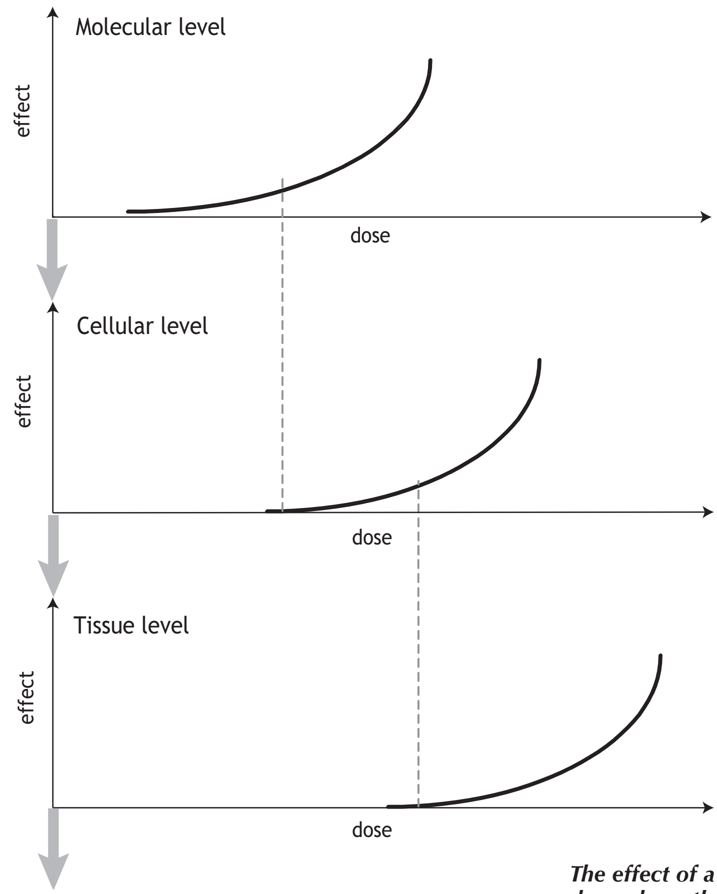
- Incorporated contaminants may be 'detoxified', as in the case of metals which are stored (at least partly) in the tissues of most invertebrate organisms as mineral structures and do not interfere with metabolism even if present at high doses (e.g. silver sulphide, high levels of which can be stored in oysters without any deleterious effect on them).
- Other contaminants, including carcinogens, can exert their effect on tissues and then be eliminated. The development of cancer is the result of cumulative effects of successive exposures, without particularly high levels ever accumulating in tissues.
- Moreover, incorporated doses are no longer comparable to chemical concentrations in the environment, which makes it difficult to propose threshold levels in order to protect biota against noxious effects.

… and the 'effect'

The second part of the relationship 'dose versus effect' is also a matter for debate. In standardized tests, the toxic effect that is quantified is generally very extreme, e.g. death shortly after exposure. Such acute effects are not likely to occur in the natural environment except in the case of an accident. Though dramatic, accidents account for only a limited proportion of the chemicals introduced into the marine environment, and it is therefore very important to assess chronic (i.e. long-term) effects. The problem is that the large range of possible effective doses results in a large range of biological effects (Figure 1).

Biochemical changes in organisms can be observed at even very low doses of chemicals in the surrounding medium. Moreover, some of these

Figure 1 *The relationship between doses of chemicals and their effects. The dose needed to have a noticeable effect increases at successive levels of biological organization. The figure could be extended downwards to show individual, population, and so on.*



changes are relatively specific to certain classes of chemicals, and are used in the European Biological Effects Quality Assurance in Monitoring Programmes, BEQUALM, as a first step in their use in biomonitoring the quality of the marine environment (http://www.bequalm.org/). Some of these changes reveal a biological adaptation to chemical stress rather than a noxious effect (e.g. the production of detoxificatory proteins), which is why Lafontaine and colleagues (see Further Reading) have termed these substances 'biomarkers of defence'. By contrast, impairments such as inhibition of a neurotransmitter (e.g. acetylcholinesterase) and DNA damage would be called 'biomarkers of damage'.

Even in the case of biomarkers indicating damage, what is the ecological value of such information? If environmental contamination affects only some macro-molecules, it may have no consequence at the level of the cell or tissue. With increasing doses, and more macro-molecules being affected, cellular or tissue impairments are likely to occur. But again, if a sufficient number of cells are still functioning, the individual will be able to cope with the chemical stress. This argument may be made at successive levels of biological organization, from the individual to the population, the community, and finally the ecosystem. At each step, the dose needed to induce an effect is increased; current knowledge is consistent with the scheme shown Figure 1, at least at sub-organism levels.

At supra-organism levels, the time factor becomes important (Figure 2). Effects at the level of populations and communities become noticeable after years or tens of years. In such a situation, it is not really possible to attribute observed effects to a specific stress because there have generally been a number of environmental changes, which potentially have interacted. At the other end of the scale, biochemical changes, some of which are relatively specific, provide early and sensitive indices of environmental stress due to chemicals. However, while effects on population and communities have a high ecological relevance, it is less clear what ecological value there is in monitoring biochemical changes which might be counteracted by the many regulatory and detoxificatory processes at work in living beings. Bridging the gap between sub-organism responses and effects occurring at higher levels of biological organization is one of the major challenges for future ecotoxicology.

Some key pointers for future research

'The missing biomarker link'

This subheading, borrowed from a recent paper by Wim De Coen and Colin Janssen (see Further Reading), expresses the aim of work being done to determine the best way to validate any extrapolation of responses at the sub-organism level to

The effect of a toxin depends on the size of the dose …

… and the time-scale under consideration

A toxin initally acting at the molecular level may eventually have noticeable effects on communities and ecosystems

Figure 2 *Responses at different levels of biological organization become apparent after different periods of remaining latent. The term 'biotransformation' means the conversion of contaminants into different forms by living beings (see text overleaf).*

(After Adams *et al.*, 1989)

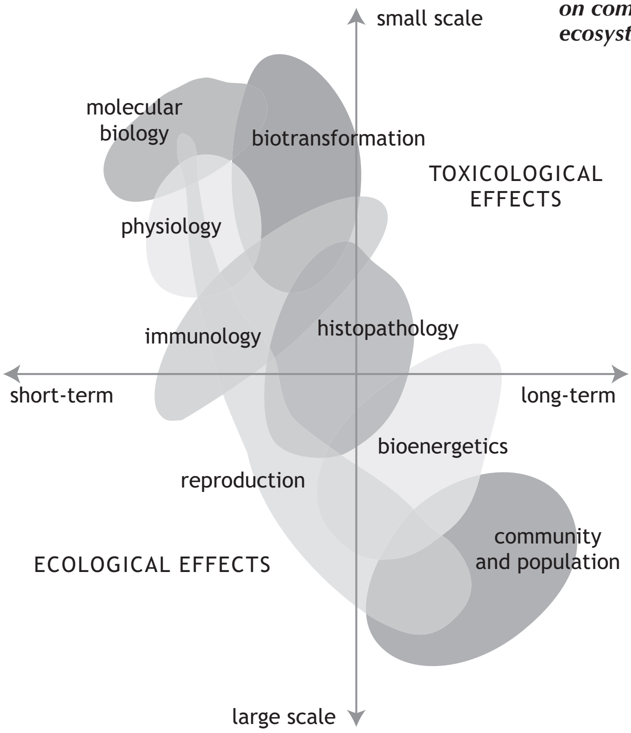
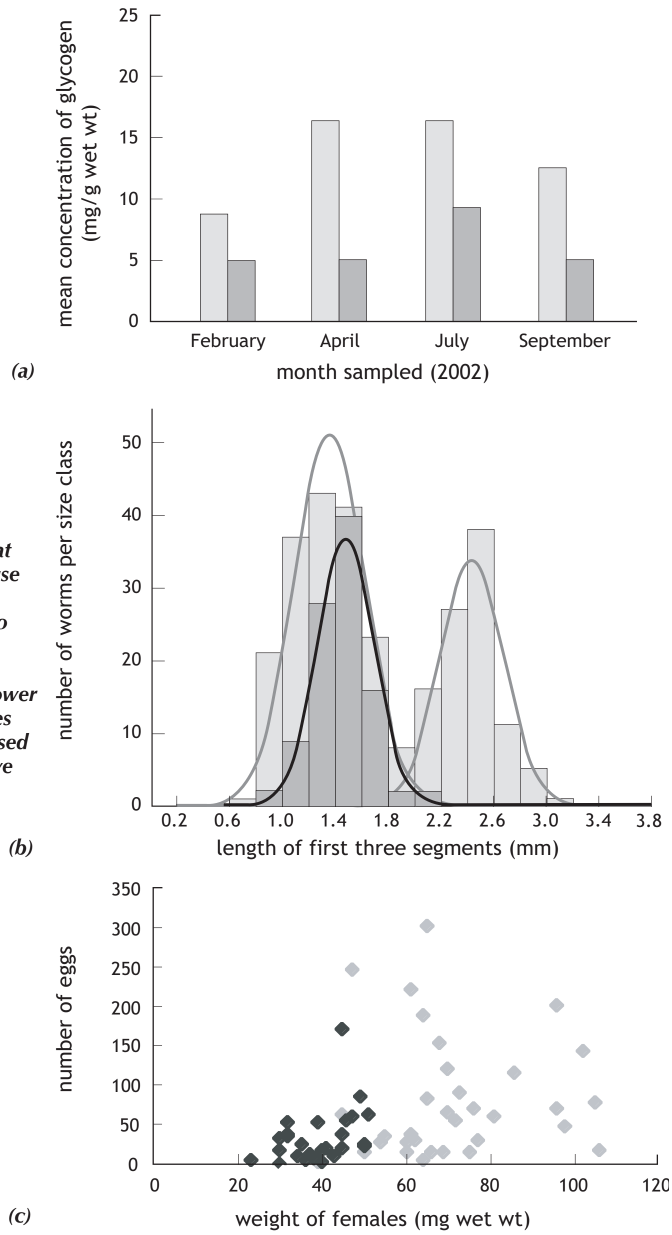


Table 1 *Some biomarkers which may reveal threats of ecological damage (After BEEP, Coordinator: Philippe Garrigues; http://beep.lptc.u-bordeaux.fr/)*

Measurable changes	Possible causes	Biological significance
Acetylcholinesterase (AChE) inhibition*	Inhibition by pesticides, metals	Neurotoxic effects with consequences for behaviour
As DNA adducts*	Genotoxic compounds (PAHs, nitro- and amino-organic compounds)	Index of genotoxic effects Predictor of pathology
Endocrine disruption Imposex in gastropods* Intersex in crustaceans Histology of gonads	Various chemicals, both organic and inorganic	Reproductive disturbances
Embryo sex ratio* (biological model: eelpout, viviparous fish)	Hormone disruption	Reproductive success

*Subject to the intercalibration exercise within the BEQUALM Programme.



Studies of ragworms indicate that increased use of energy resources to cope with toxic stress results in lower growth rates and decreased reproductive success

effects occurring at higher levels of biological organization. Within the framework of the European 'concerted action' BIOMARE (Coordinator: H. Hummel; www.biomareweb.org), ecologists and ecotoxicologists debated which biomarkers might be most powerful for revealing threats of ecological damage. Of a large selection of biomarkers studied in another European programme, BEEP, the most useful are those which reveal neurotoxic effects with consequences for behaviour, and any toxic effect linked with reproduction (such as genotoxicity and endocrine disruption) (Table 1). Some of these tools are well developed, and are already included in external quality control procedures at the European level (as in the BEQUALM Programme), but others still need to be improved or developed.

As emphasized by De Coen and Janssen, because most of an organism's energy budget is used for growth, reproduction and basal metabolism, increased energy expenditure in basal metabolism to cope with toxic stress will lead to a reduction in growth and reproduction. Thus it seems that studies of energy metabolism constitute an interesting research avenue that involves revisiting pioneer works such as those devoted to the scope for growth. Preliminary work carried out within the framework of the French National Programme of Ecotoxicology (PNETOX) has shown striking agreement between variations in energy reserves, growth and reproduction in a key estuarine species (Figure 3).

Genetic effects are not limited to direct damage to DNA; indirect effects have also been revealed, such as the selection of resistant genotypes in populations chronically exposed to chemical stress. Although temporarily beneficial, these genetic variations can reduce the adaptability of 'resistant' organisms to future environmental changes. The rapid development of genomics might, in the near future, allow the use of genetic effects as biomarkers to be integrated into environmental monitoring.

Remembering the 'bio' in biogeochemical cycles

The extent to which living beings are exposed to contaminants depends on the fate of those contaminants in the environment, where exchanges between sediment and the water column are of major importance. This is because, as mentioned above, although the bulk of most environmental chemicals are stored in sediments, toxicity depends strongly on the extent to which the contam-

Figure 3 *Comparison of the status of the ragworm* Nereis diversicolor *from the polluted Seine estuary (data in dark grey) and the comparatively clean Authie estuary (data in light grey).* ***(a)*** *At the clean site, the level of glycogen (and other energy reserves, not shown) was higher.* ***(b)*** *Animals were observed to be larger at the clean site than at the polluted site (size based on the length of the first three body segments) (there were two size groups at the clean site, of which only one had an equivalent at the polluted site).* ***(c)*** *The larger, heavier females produced more eggs.*

(Data from UCO/CEREA, Angers, France, and the Natural History Museum, London, within the framework of PNETOX)

Figure 4 *The burrowing worm* Nereis diversicolor *in sediment of the Authie estuary. Note the contrast between paler, well-oxygenated sediment lining the burrows and the surrounding dark anoxic sediment. The high density of this species, indicated here by the number of burrows, means that it plays an important role in both the physicochemistry and the ecology of estuarine mudflats.*

(Photo by courtesy of Ludovic Bailly-Chouriberry)

inant can be remobilized in soluble form. Despite an abundant literature on this topic, in most cases the role of biota has been rather neglected, even though some components of biota play a key role in the fate of chemicals. For example, the role of bacteria in nutrient cycling has been clearly established for decades, but we also need to recognize the important role played by microorganisms in the biogeochemical cycles of chemical stressors. They are responsible for the so-called 'biotransformation' of contaminants, including the biodegradation of organic chemicals such as detergents and some pesticides, or the complexation of inorganic contaminants. Biodegradation helps eliminate certain classes of pollutants but it must be kept in mind that it is a set of complex reactions, and intermediate products of degradation can be as toxic as the parent molecule, sometimes more so. One of the complexation reactions that has been investigated in great detail is the methylation of metals. In the case of mercury, it has been demonstrated that bioaccumulation and toxicity are considerably greater for methyl mercury than for mercury as metal. These examples suggest that a more comprehensive study of the role of bacteria is essential.

Another functional group, also very important in the fate of sediment-bound chemicals, consists of all those organisms that live within the sediment and rework it continuously as they make their burrows and circulate water and oxygen through them as they do so, changing the physical and chemical conditions which govern the chemistry of contaminants. This bioturbation has given rise to stimulating studies involving macrofauna, including the ragworm *Nereis diversicolor*, the density of which can reach several hundreds to several thousands of individuals per m^2 in estuarine and coastal mudflats (Figure 4; cf. Figure 3). It is necessary to go further and take into account the meiofauna (size < 0.5 mm) which are responsible for many of the biogenic structures in the top few centimetres of mudflats, those in which physicochemical reactions are most active.

Modelling the fate and effects of contaminants

It is evident that a complete ecotoxicological evaluation for all of the tens of thousands of substances which enter the marine environment would be an impossible task. We therefore have to use the most relevant data available, even if imperfect, to assess environmental risk. In Europe, approaches to assessment are guided mainly by the OSPAR Strategy on Hazardous Substances, taking into account EC requirements.*

*Commission Directive 93/67/EEC on risk assessment for new notified substances and commission regulation No. 1488/94 on risk assessment for existing chemicals.

Burrowing animals such as ragworms influence the fate of contaminants by affecting physical and chemical conditions in the sediment

The Technical Guidance Document (TGD) in support of European regulations for the marine environment (not yet published) is a revised and adapted version of that for the inland environment, published in 1996 (http://ecb.jrc.it/existing-chemicals/). Marine risk assessment starts with *exposure assessment*, the final objective being the calculation of Predicted Environmental Concentrations (PECs) for both the aquatic and the sediment compartments, at local and regional scales. Model calculations integrate estimates about the mode of release (intermittent or continuous, through point or diffuse sources), characterization of environmental compartments, partition coefficients,† and abiotic and biotic degradation rates (with particular attention to the influence of the chemistry of seawater). PECs thus derived may be compared with selected measured data (when they exist – for many chemicals it is technically and financially impossible to analyze ultra-traces) to decide the environmental concentration to be used for risk characterization.

The other part of the approach is *effect assessment*, used to derive Predicted No-Effect Concentrations, or PNECs. The ecotoxicity of chemicals in freshwater organisms is much better documented than that in estuarine and coastal organisms, and in some cases no data are available for the latter. Although the TGD proposes strategies to cope with this situation, many uncertainties have been identified, leading to the use of very large safety margins, which could be reduced if we had sufficient data for ecologically relevant saltwater species. PNECs are also derived for sediment organisms, but partition coefficients allow a preliminary screening of substances likely to bind to sediment. Partition coefficients are also used in effect assessment for bioaccumulation and so-called secondary poisoning, i.e. contamination through the food chain. Special attention is paid to PBTs (Persistent, Bioaccumulative and Toxic substances). The environmental compartments are then assessed at local and regional spatial scales by comparing the PECs and the PNECs for representative species at different trophic levels.

Although it is less costly and time-consuming than a complete ecotoxicological evaluation, modelling environmental risk for a given sub-

† Partition coefficients describe the relative concentrations of contaminants that are found in different environmental compartments at equilibrium.

stance remains a considerable task. An approach that can help significantly is development and use of Quantitative Structure–Activity Relationships, or QSARs, a method which has given rise to an important literature, particularly in the field of human toxicology. Structure–activity relationships are based on the axiom that a chemical's structure is correlated with its physical, chemical and toxicological properties. Thus QSARs may be used to predict physicochemical behaviour of contaminants and their fate and effects in the environment. The usefulness of QSARs technology is particularly evident when it is used to predict the toxicity of untested chemicals simply on the basis of their chemical structures, but it is also important in promoting a more efficient use of chemical-testing resources (as pointed out by John Walker, who has edited a special issue of the journal *Environmental Chemistry and Toxicology* devoted to the latest developments in this field; see Further Reading). New techniques and software have allowed widespread use of QSARs in toxicological sciences. However, if it is to gain regulatory acceptance, this approach needs to be based on sound principles and high quality data (cf. ECETOC (2002) in Further Reading). The main limiting factor is the quality of experimental data available, many datasets being heterogeneous because they have been produced in different laboratories with different protocols. If a model is based on lower quality data, it will have a poorer statistical value and be more likely to lead to inaccurate predictions. Clearly, the use of QSARs will continue to evolve as biogeochemical and toxicological understanding advances.

By way of conclusion

The research priorities suggested above correspond with several of the points listed in the framework of the Long-Range Research Initiative (http://www.cefic.be/lri), promoted by international chemical industries. This research programme, which both responds to and adds to scientific knowledge in the light of regulatory and societal development, focusses on bridging the gap between research and policy and will help industry to react quickly and effectively to emerging concerns.

Ecotoxicologists have a lot to do. They must:

- Develop mechanistic studies to obtain the fundamental knowledge needed to improve regulations aimed at preserving the environment.
- Propose operational procedures which will help in assessing the ecological status of marine environments.
- Provide tools for biomonitoring, with a view to detecting signals of early degradation, allowing prompt protective action, or to assessing the recovery of sites after remediation.

A major question which is not being tackled by planned ecotoxicological research is that of interactions between contaminants. The US Environmental Protection Agency (EPA) recently published a *Framework for Cumulative Risk Assessment* (http://cfpub.epa.gov/ncea/raf) which takes into account the fact that ecosystems are impacted by a number of pollutants through different media. The potential importance of interactions between different stressors was discussed at a workshop on the European Technical Guidance Document convened by the ARC.* Here, the point was made that although field studies allow interactions to be taken into account, interest in this approach is limited because it is practically impossible to interpret observed effects in terms of the different pollutants present. No clear strands have been proposed for future research, and input of scientists in the Framework of the US EPA, and the European regulations, is likely to be limited.

Because of the magnitude and social importance of the task, the community of environmental chemists and ecotoxicologists need to focus their energy on major problems, some of which have been highlighted in this article. Unhappily, despite the fact that ecotoxicology is a relatively young science, it seems that the memory of established knowledge is already fading. For instance, it is surprising that biomagnification of metal-containing compounds is a matter of debate among members of the Society of Environmental Chemistry and Toxicology (*SETAC Globe,* Vol. 4, Nos. 3 and 4) given that reviews published in the 1980s established that, except for mercury and caesium-137, trophic transfer does not lead to biomagnification, a situation termed 'biodiminution' by Wen Wang (see Further Reading). This is probably because young researchers use computerized literature sources and thus miss papers published two or three decades ago. Student researchers are often told that the literature more than ten years old is obsolete, but when research is based on sound techniques (e.g. quantification of radionuclides or metals), the relevant papers are still valid (and it is counter-productive to waste time and research funds redoing the work).

According to Finn Bro-Rasmussen (former President of the EU Scientific Committee on Toxicology, Ecotoxicology and Environment), 'the current lack of knowledge is hampering our evaluation of chemicals and products and is at the centre of public insecurity and uncertainty regarding chemicals'. This is true but needs to be refined. Results have now to be incorporated into theory with a view to:

- on the one hand, organizing and using knowledge for predictive purposes, allowing 'preventive health care' for ecosystems, by analogy with human health experience;
- on the other hand, developing innovative science, generating new ideas and discoveries rather than adding more and more details to well-established paradigms.

For more on this topic, see *Ecotoxicology: a hierarchical treatment*, particularly Chapters 1 and 13 (contributions by Newman and Schindler in the Further Reading list).

*ARC = Cellule mixte IFREMER/INERIS d'Analyses des Risques chimiques en milieu marin, Nantes, 4 Feb.and 21 March 2003)

Further Reading

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A Virtual Institute of Marine Ecotoxicology?

Jean-Francois Pavillon

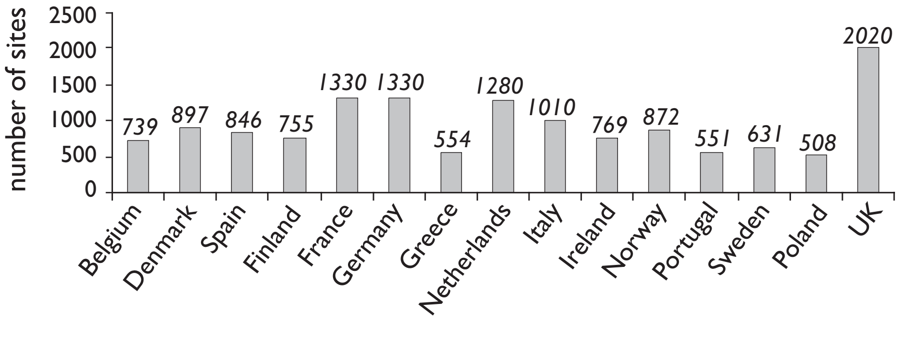
There are relatively few national marine ecotoxicology programmes in Europe, but a search on the web led me to 14 092 websites. These were found using the key words 'marine ecotoxicology', 'programme', plus the country in question. Adding 'research' as a key word only had a small effect. In fact, the webites that were found relate not only to research programmes, but also to education, reports, articles, information about laboratories and research centres, some bibliographical lists, directories etc.

It is very difficult discover information about research programmes in marine ecotoxicology because they are generally included in much larger environmental programmes devoted to the study of the evolution or transformation of marine ecosystems exposed to pollutants. For instance, the European Action BIOMAR devoted to biodiversity has identified links between ecology and ecotoxicology, whereas BIOCOMPS focussed on the impacts of biodiversity changes in coastal marine benthic ecosystems. Some European Programmes, like BIOSET (BIOSensor for Environmental Technology) have a predominantly technical character and do not deal only with the detection of pollutants. Other programmes are distinctly ecotoxicological, such as the NOW Stimulation Programs System which involves a number of countries: Austria, Belgium, Finland, Germany, Netherlands, Poland and Sweden; yet others have a mainly applied character, such as the National Marine Ecotoxicology Analytical Control (UK). In France, the PNETOX (National Program of Ecotoxicology) includes both marine and terrestrial environments. Others focus on a particular species and/or a particular physiological function, for instance the SLOPE/IUPAC Project on endocrine disruption in marine fish.

European marine ecotoxicology is extremely varied, and involves specialists and laboratories with great potential, but it has problems existing as a science in its own right. Perhaps it will be necessary to create (on the web) a Virtual Institute of Marine Ecotoxicology, the mission of which would be to bring together information on, for example:

- programmes of worldwide research in the field of marine ecotoxicology;
- existing reports;
- specialized laboratories and researchers.

But – as everyone knows – it is a question of funding.



Number of European Marine Ecotoxicology programmes per country, as identified by a web search up to mid-2003

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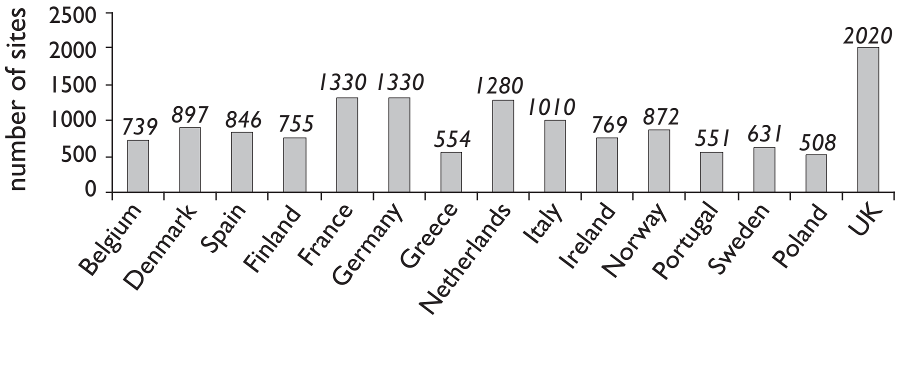

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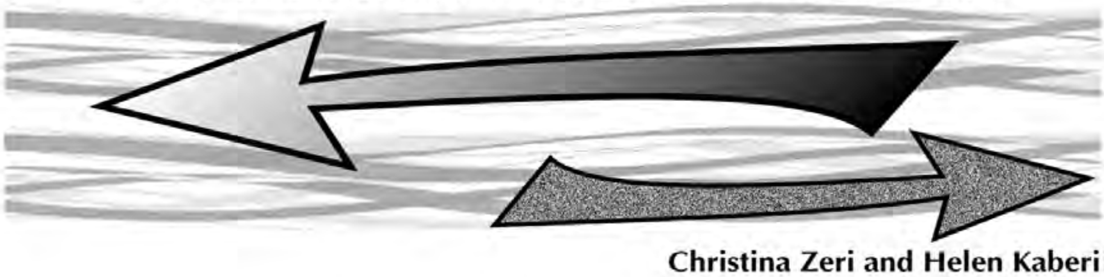
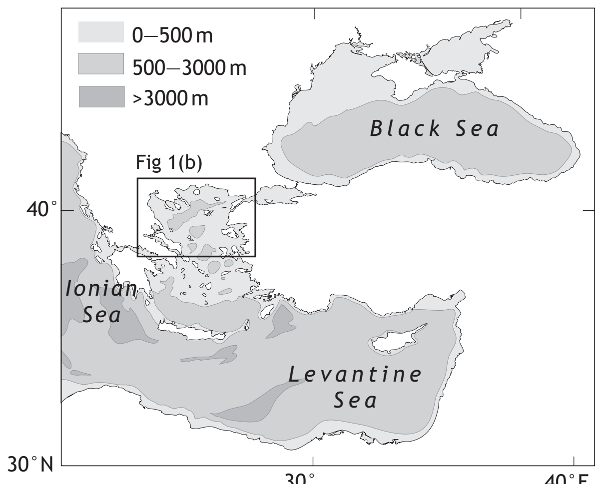
THE INFLUENCE OF THE DARDANELLES OUTFLOW ON THE BIOGEOCHEMISTRY OF THE NORTHERN AEGEAN



Christina Zeri and Helen Kaberi

The effect of human activities on the oceans is a subject of great public interest. In the case of enclosed basins such as the Black Sea and the Mediterranean, prolonged and intensive human activity in the surrounding regions has resulted in significant environmental impact in the form of coastal and marine degradation and increased risk of more serious damage. Urbanization, disposal of industrial and domestic wastes, intensive agriculture and animal husbandry, soil degradation and desertification are a few of the causes of this degradation.



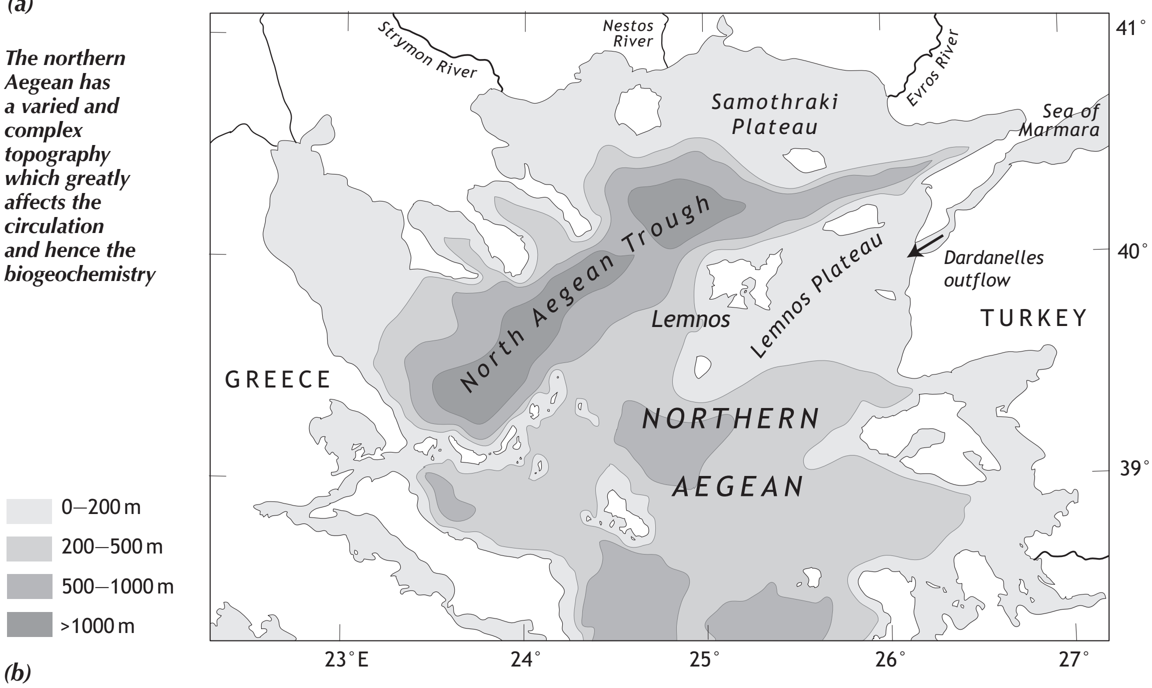
(a)

The Black Sea and the northern Aegean: an interconnected system

The natural and anthropogenic substances that reach the open sea from the coastal zone and the overlying atmosphere include nitrogen and phosphorus compounds from fertilizers or combustion processes, heavy metals, terrestrial organic matter, radionuclides, aromatic hydrocarbons, pesticides and synthetic organic compounds from oil, or from industrial or domestic sources. Some of them, such as

Figure 1 ***(a)*** *The geographical setting of the area under discussion, showing the Black Sea linked to the northern Aegean via the Sea of Marmara and the Dardanelles.* ***(b)*** *The bathymetry of the northern Aegean Sea.*

The northern Aegean has a varied and complex topography which greatly affects the circulation and hence the biogeochemistry



(b)

lead, mercury, cadmium and chlorinated hydrocarbons, are potentially harmful to marine biological systems. Others, such as nitrogen, phosphorus and iron, are nutrients that can enhance marine productivity. It is therefore necessary to understand the various pathways followed by these substances in marine biogeochemical cycles and their effects in both time and space.

The Black Sea ecosystem, in particular, has been seriously damaged during recent decades, especially along the north-west shelf of the Black Sea, where the Danube outflow represents 77% of the total discharge and is the main source of nutrients and pollutants. The region is notable as an area of high productivity, high carbon flux and sedimentary storage. Its degradation has led to diminishing fishery resources and a decrease in the potential for recreation and tourism. Recent economic decline in the industrial and agricultural sectors of the surrounding countries has led to some improvement in the health of the north-west shelf, compared with previous decades, but the area continues to be of major ecological concern.

At the same time, the Mediterranean Sea – which is connected to the Black Sea via the Dardanelles, the Sea of Marmara and the Bosphorus – has been receiving increasing pollution loads from various sources. Although a lot of effort has been put into understanding and quantifying the scale of the environmental problems in both areas, little is known about their impact on an inter-basin scale. There are large uncertainties concerning the fluxes and budgets of nutrients and pollutants from the Black Sea into the eastern Mediterranean, and their impact on the local marine environment. Furthermore, although the role of the Sea of Marmara as a source or sink of organic and inorganic substances is relatively clear, the processes and mechanisms that govern this role are not adequately understood. An improved understanding of the natural processes governing the interconnection of the two seas is essential for assessing the impact of nutrient and pollutant transport from one basin to another. Only if the natural variability is thoroughly understood can accurate prediction of the effects of human influences, and their potential mitigation, become possible.

Although both the Black Sea and the Mediterranean face similar environmental problems, they have remarkably different physical and biogeochemical characteristics. A two-layer flow dominates the water-exchange pattern in the two straits and the Sea of Marmara. In the upper layer, brackish Black Sea Water (BSW) flows into the Sea of Marmara through the Bosphorus and then into the northern Aegean Sea through the Dardanelles; in the lower layer, high salinity Mediterranean water (Levantine Intermediate Water, LIW) flows to the Black Sea. The overall result is a net flow from the Black Sea to the Aegean. Knowledge of the biogeochemical processes occurring in the northern Aegean Sea is of great importance for understanding interactions between the Mediterranean and Black Sea ecosystems.

Recent research

Over the past decade, major advances have been made in understanding the biogeochemical processes that control ecosystem functioning in the northern Aegean Sea. This was made possible through national and EU-funded programmes, such as the MATER project ('Mass Transfer and Ecosystem Response'), KEYCOP ('Key Coastal Processes in the mesotrophic Skagerrak and the oligotrophic northern Aegean Sea: a comparative study'), and INTERREG I ('Inter-regional pollution studies in the North Aegean Sea'). These important programmes have provided insight and significant information about many key issues; they began by establishing a basic understanding of circulation and mixing patterns, biogeochemical fluxes of various substances, and an assessment of the trophic conditions in each area.

So, what have we learnt about the influence of Black Sea waters on the functioning of the northern Aegean ecosystem?

Hydrographic effects

The northern Aegean Sea is characterized by irregular bottom topography (Figure 1(b)). Two shelf areas (depth < 200 m), the Samothraki Plateau in the north and the Lemnos Plateau in the north-east, are separated by the North Aegean Trough, which runs north-east–south-west. Within the Trough, there are three main depressions reaching a depth of 1500 m. The area receives freshwater from many of the rivers drain-

A short history of the northern Aegean–Black Sea link

Map of the Dardanelles drawn by J.N. Bellin (1764)

During the last glacial period, the Black Sea and the Sea of Marmara were two isolated freshwater lakes. About 12 000 years ago, toward the end of the glacial period, the Earth grew warmer and the vast sheets of ice that sprawled over the Northern Hemisphere began to melt. As a result, the Aegean Sea became deeper and salty water passed through the Dardanelles and filled the Sea of Marmara. What happened later is still not clear. It is the subject of two contradicting theories, which nevertheless agree that a two-layer flow was established about 7000 years ago. The Mediterranean swelled, and seawater pushed through the Bosphorus, displacing freshwater towards the Aegean. Thus the Black Sea, the Sea of Marmara and the Aegean Sea became interconnected by a two-layer flow.

The current flowing from the Black Sea to the Mediterranean has long been known to sailors and fishermen, and was described by the Greek Apolonios in the third century BC. The deep countercurrent was discovered in 1680 by Marsigli, who proved its existence by collecting water samples from surface and deep layers.

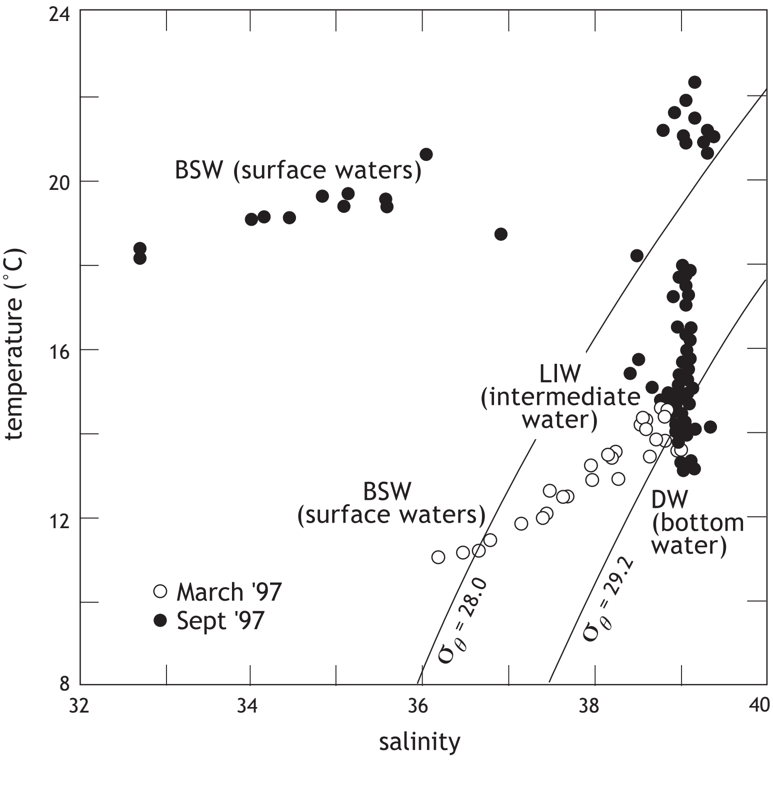
ing the Balkan Peninsula, as well as large amounts of brackish water from the Black Sea via the Sea of Marmara. It has been estimated that river runoff contributes approximately 8 $km^3 yr^{-1}$, and that the volume of brackish surface waters flowing out through the Dardanelles varies between 100 and 1200 $km^3 yr^{-1}$. Maximum river flow occurs from February to May (550 $m^3 s^{-1}$), while the largest net outflow through the Dardanelles occurs in late spring and summer (300 $km^3 yr^{1}$).

The freshwater inputs combined with the sea-bed morphology result in the formation of a particular water column structure, in which three major water masses can be identified. Black Sea Water (BSW) originating at the Dardanelles, with a low salinity (initially < 30 p.s.u.) and low temperatures (8–22 °C), is detectable at the surface (0–50 m). During winter, BSW flows along the northern coast of the island of Lemnos (Figure 1(b)); at that time of the year it bifurcates, forming branches flowing to the north and to the south; by contrast during summer, after passing through the Dardanelles, BSW flows to the south-west. This distinct surface water mass is modified as it is transported either north or south of Lemnos, by mixing with warm and saline waters of Levantine origin. The resulting surface mixed layer is identified by its low density ($\sigma_\theta < 28.0$). Levantine Intermediate Water (LIW) ($28.0 < \sigma_\theta < 29.2$) occupies the whole northern Aegean at depths greater than 50 m and less than ~ 400 m. Below 400 m depth, circulation is restricted by the bottom topography and the various basins are filled with dense saline waters ($\sigma_\theta > 29.2$), referred to as North Aegean Deep Water (DW). A temperature–salinity diagram including data from two representative periods is shown in Figure 2.

In winter, surface waters in the northern Aegean are considerably cooler and generally more saline than in summer

Figure 2 *T–S diagram for waters in the northern Aegean, for March and September 1997. Three water masses are distinguishable: BSW = Black Sea Water, at the surface; LIW = Levantine Intermediate Water; DW = North Aegean Deep Water. Water with* $\sigma_\theta < 28.0$ *corresponds to the surface mixed layer. In March 1997, the variation in temperature is much less, and the data points are more concentrated.*

(From Zeri and Voutsinou-Taliadouri, 2003)

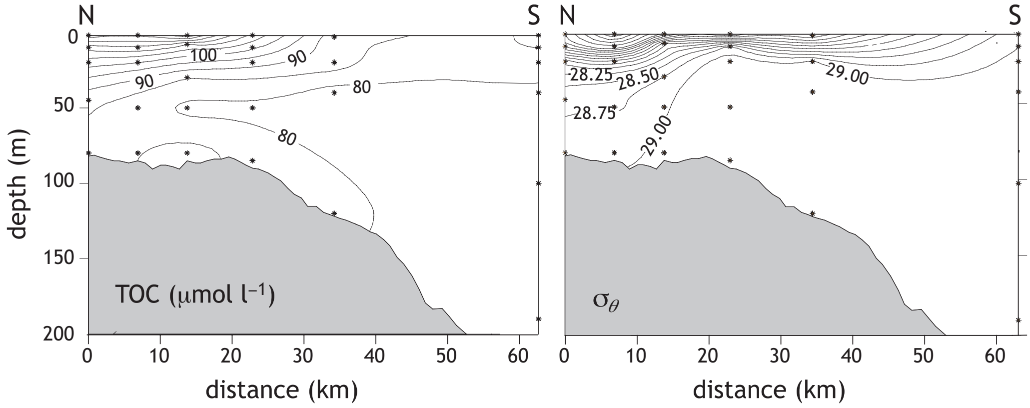


Although climatic conditions prevailing in the northern Aegean during winter favour the formation of dense water, deep-water formation has not taken place since 1993. Recent results have shown that the shallow layer of brackish water originating at the Dardanelles outflow consumes a large fraction of the air–sea heat exchange, thus acting as an insulator for the underlying denser and more saline waters of Levantine origin. The low temperature of the surface water further reduces the heat loss to the atmosphere during extreme cold events. Thus, deep-water formation in the northern Aegean depends not only on atmospheric conditions over the region, but also on the thickness and hydrographic characteristics of the surface layer of BSW, which are directly related to the magnitude of the Dardanelles outflow.

Effects on nutrients and productivity

Nutrient exchanges at the two straits reflect the water exchange pattern, so that nutrient inputs from the Sea of Marmara to the Aegean are 4–5 times greater than exports via the underflow, resulting in a net mass transfer of nutrients from the Black Sea towards the Mediterranean via the straits. Interestingly, although nutrients are supplied to the Black Sea via rivers and the atmosphere in inorganic form (NO_3^- and PO_4^{3-}), the increased inputs to the northern Aegean via the Dardanelles outflow are the organic forms of nitrogen (dissolved organic nitrogen = DON) and phosphorus (dissolved organic posphorus = DOP). The fluxes of dissolved inorganic forms of nitrogen and phosphorus entering the northern Aegean through the Dardanelles are less important than believed in the past: the organic forms decay only slowly *en route,* whereas there is a net decrease in mean inorganic nutrient concentrations as a result of consumption in the Marmara basin. This scenario is confirmed by the significantly higher total organic carbon (TOC) values observed in the low salinity upper layer of the northern Aegean (Figure 3). The processes controlling the transformation of nutrients from inorganic to organic forms are not yet fully understood. Budget calculations for the northern Aegean Sea, based on empirical models constructed according to the LOICZ biogeochemical modelling guidelines, have shown that the system acts as a net sink for dissolved inorganic nitrogen (DIN) and dissolved inorganic phophorus (DIP) and as a net producer of organic matter, because primary production exceeds respiration.

The eastern Mediterranean has been characterized as one of the most oligotrophic (least productive) areas of the world. Nevertheless, recent results from the projects mentioned earlier have shown that within the eastern Mediterranean basin there is a gradient in oligotrophy from north to south, with waters of the northern Aegean being relatively more productive than those in the southern Aegean.



Black Sea Water with high concentrations of organic carbon can be observed to the east of the island of Lemnos

Figure 3 *North–south sections across the Lemnos Plateau showing the distribution of density (σ_θ) and total organic carbon (TOC). The low-density Black Sea Water exhibits high concentrations of organic carbon.*

(From Krasakopoulou, et al., 2001)

Effects on pollutant transport

As discussed above, shelf areas receive high loads of pollutants from terrestrial sources and are enriched in pollutants relative to oceanic waters. Pollutant transport on an inter-basin scale is a subject of great interest, especially in the case of the Black Sea–northern Aegean system. The particular example of trace metal transport is discussed below.

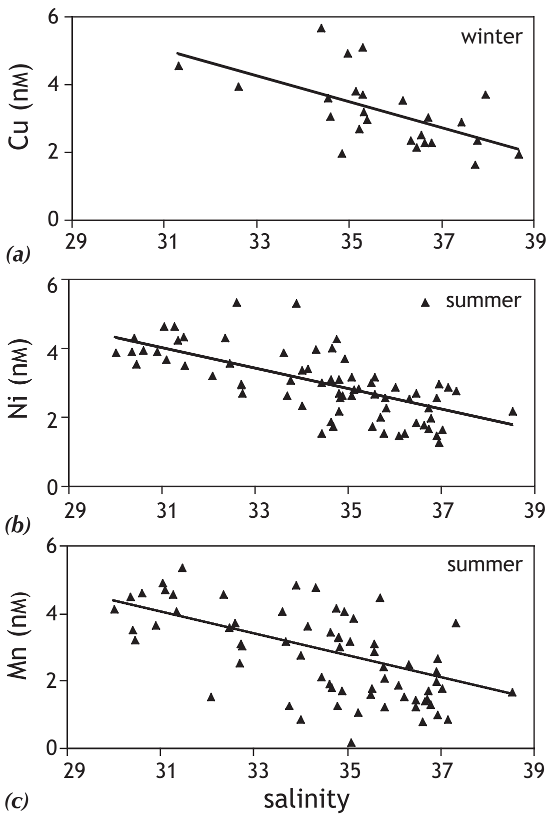
As well as deep basins, the northern Aegean has an extensive coastal zone (Figure 1(b)). Little is known about how dissolved trace metal concentrations in the northern Aegean compare with those in the Dardanelles and the Sea of Marmara. However, it is known that the aerobic surface waters of the Black Sea, and hence the outflow to the northern Aegean, are relatively enriched in trace metals.

Since the surface layer in the northern Aegean is a mixture of riverine water, Black Sea Water (BSW) and Levantine Intermediate Water (LIW), trace metal relationships with salinity will show to what extent mixing affects their distribution. In Figure 4, trace metal concentrations are plotted against salinity in the surface mixed layer ($\sigma_\theta < 28$). The relationships shown in Figure 4 suggest that waters with low salinity and high metal concentration, such as river water and BSW, mix conservatively with (i.e. have a straight-line mixing relationship with) high salinity–low-metal-concentration waters of Levantine origin. These relationships are what one would expect, given the hydrography of the area: BSW, rich in trace metals, enters the northern Aegean from the east and flows northward or southward, mixing with LIW, which is poor in trace metals, coming from the south. Riverine waters, with high metal contents, enter the system from the north and meet the already modified BSW + LIW water mass moving northwards.

However, it should be stressed that in the northern Aegean, the water outflow from the Dardanelles is much greater than the local riverine inputs. An improved estimate of the relative importance of these inputs can be obtained if trace metal concentrations in the surface water mass are compared with those in 'pure' BSW and LIW (top part of Table 1, overleaf). From the salinity values of the surface water mass ($\sigma_\theta < 28.0$) and of pure BSW and LIW, it can be established (Table 1) that the surface water mass in the northern Aegean has an average composition of 21% BSW and 79 % LIW during summer, and is 14%

Figure 4 *Correlations between trace metal concentration and salinity in the upper ($\sigma_\theta < 28.0$) mixed layer ($p > 0.05$) for waters in the northern Aegean. The trace metals are:* ***(a)*** *copper;* ***(b)*** *nickel, Ni;* ***(c)*** *manganese, Mn.*

(From Zeri and Voutsinou–Taliadouri, 2003)



Plots of S versus trace-metal concentration show mixing between low salinity, trace-metal-rich river water + BSW, and high salinity, trace-metal-poor Levantine waters

BSW and 86% LIW during winter. Using these results, together with trace metal data for Black Sea surface waters (BSW) and for the intermediate layers of the northern Aegean (LIW), Cd, Cu and Ni concentrations can be calculated for the surface mixed layer of the northern Aegean. The generally good agreement between measured and predicted values, as listed in Table 1, suggests that Cd, Cu and Ni are conservatively mixed between the major water masses (BSW and LIW), i.e. there

Table1 *Characteristics of 'pure' Black Sea Water and Levantine Intermediate Water, and a comparison between measured and calculated trace metal concentrations in the surface mixed layer (σ_θ < 28.0) of the northern Aegean.*

	Salinity	Cd (nM)	Cu (nM)	Ni (nM)	Mn (nM)
Characteristics of 'pure' BSW and LIW					
BSW*	18.06 ± 0.62; *n* = 5	0.078 ± 0.018	5.6 ± 1.16	9.4 ± 0.91	12.5 ± 5.0
LIW+ (summer)	38.77±0.33; *n* = 87	0.092 ± 0.027	2.51 ± 0.76	5.46 ± 1.71	4.10 ± 2.06
(winter)	38.28 ± 0.55; *n* = 60	0.042 ± 0.027	2.18 ± 0.75	4.84 ± 1.72	2.94 ± 3.40
Average composition of surface layer in summer					
Calculated (21% BSW + 79% LIW)		0.088	3.14	6.26	5.83
Measured†	34.44 ± 2.09; *n* = 71	0.107 ± 0.038	3.63 ± 0.90	7.46 ± 1.83	14.6 ± 7.1
Average composition of surface layer in winter					
Calculated (14% BSW + 86% LIW)		0.047	2.67	5.49	4.31
Measured†	35.73 ± 1.63; *n* = 6	0.047 ± 0.020	2.74 ± 0.91	6.22 ± 1.41	5.97 ± 4.07

*Haraldsson and Westerlund (1991) †Zeri and Voutsinou-Taliadouri (2003)

Note: The concentration of a trace metal depends on the concentrations in the two components, and the relative proportion of the two components. BSW generally has the higher concentration of trace metals, except in the case of cadmium; LIW has higher concentrations of trace metals in summer, but more of it is mixed up into the surface mixed layer in winter.

is little influence from other inputs or processes. Therefore, the relationships described above are controlled largely by the presence of BSW in the area; as such, they show that BSW acts as a source of metals in the northern Aegean. Whether other pollutants such as organic compounds behave near-conservatively during mixing of Black Sea and Levantine waters has not so far been investigated.

What questions remain unanswered?

Recent research has shown that the biogeochemistry of the northern Aegean depends largely on the charactersitics of the Dardanelles outflow. However, the information gathered so far concerning the impact of the outflow on deep-water formation, nutrient availability and pollutant transport in the northern Aegean has shown that important questions remain unanswered. The processes controlling evolution of the characteristics of Black Sea waters as they travel towards the eastern Mediterranean are still not clear. Why is the input of inorganic nutrients limited, even though a considerable volume of water originating from the highly eutrophic Black Sea enters the Aegean? What are the biogeochemical processess that control the change from inorganic to organic forms of nutrients? Do pollutant loads from the Black Sea reach the northern Argean unmodified? The answers to the above questions wll fill important gaps in knowledge crucial for managing future human impact on the Mediterranan Sea.

Further Reading

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