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Bio-ecological Observations in Operational Oceanography

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Cover picture

Large image: "A water perspective of Europe", courtesy of Swedish Meteorological and Hydrological Institute. The white lines show the watershed boundaries between the different catchment areas flowing into the regional seas of Europe.

Inset image: Height of the sea surface in the north Atlantic and Arctic simulated by the OCCAM global ocean model, courtesy of David Webb, James Rennell Division, Southampton Oceanography Centre.

Bio-ecological Observations in Operational Oceanography

Report of the third Workshop of the EuroGOOS Scientific Advisory Working Group

organised by EuroGOOS and ICES

6-8 April 2000 at the National Institute of Coastal and Marine Management / RIKZ, Den Haag, The Netherlands

With support from European Commission Directorate General Research

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Preface

The Workshop on "Bio-ecological Observations in Operational Oceanography" was held from 6 - 8 April 2000 in Den Haag, Netherlands. It was organised by the Scientific Advisory Working Group of EuroGOOS in conjunction with ICES and also received funding from EU Directorate General XII, Research.

EuroGOOS is the Association of European national agencies for developing operational oceanographic systems and services in European seas, and for promoting European participation in the Global Ocean Observing System (GOOS). EuroGOOS was set up in 1994 and has now 31 Members from 16 countries.

The Global Ocean Observing System is planning to co-ordinate, strengthen, and harmonise the national and international efforts to assess and predict the marine environment and thus to effectively improve operational oceanography world-wide. Operational oceanography can be defined as the activity of systematic and long-term routine measurements of the seas, their interpretation, and the rapid dissemination of operational products (typically forecast, nowcast, hindcast).

To establish a scientific base to guide the Euro-GOOS Plan, the Scientific Advisory Working Group was set up. It initiated a series of work-shops under the motto "Extending the Limits of Predictability". The first workshop on "Predict-ing the Ocean for the 21st Century. Optimising the Observations Network for the Atlantic and Adjacent Seas" took place 8-9 March 1999 in Rome and was attended by 45 participants from 13 countries. Its broad objectives aimed at developing operational oceanography in scope (physics to ecology), in accuracy (evaluation of modules) and in extent of prediction period (via data assimilation, coupling of ocean-shelf and marine-atmospheric models).

The second workshop on "Ocean Atmosphere Shelf Sea Coupling" took place in Norrköping, Sweden, 14-15 September 1999 with 13 partici-pants. Based on BOOS, the Baltic Ocean Ob-serving System, issues discussed during this workshop included nested modelling, air-sea exchanges and how it is influenced by ice, and coupling protocols.

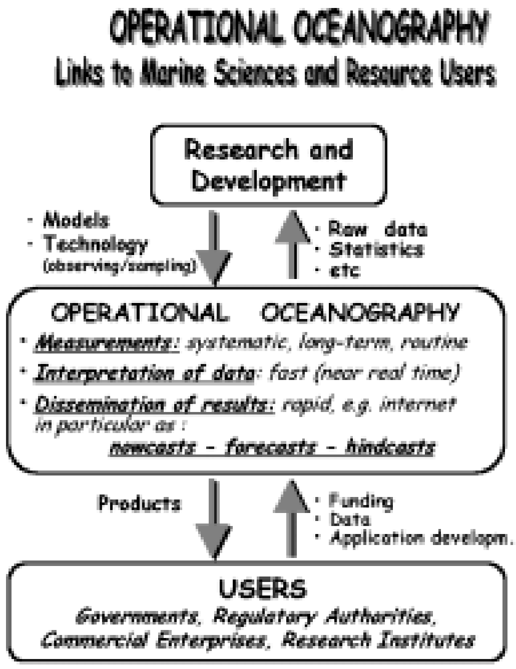

Figure 1. Elements of operational oceanography

The present workshop is the third in the series. Its aim is to broaden the focus of EuroGOOS from climatic/physical operational oceanography by including biological variables and to advance an ecosystem approach for ocean monitoring. The workshop was attended by 35 participants from 11 European countries (see Annexe 2).

The workshop was organised in four sessions dealing with user requirements, sampling tech-nology, anthropogenic and climatic influences on ecosystems, and ecosystem modelling. At the end of the workshop participants discussed and formulated recommendations to a European Ocean Observing System focusing on future demands for bio-ecological products, the emerging requirements for monitoring technol-ogy, and improved scientific understanding of specific processes.

The organisation of this report follows the structure of the workshop rather closely by having a chapter for each session, containing the summaries of presentations followed by a session synthesis. The final chapter summarises the recommendations of the workshop.

We thank Sally Marine for copy editing and layout of this report.

Executive Summary

EuroGOOS and ICES organised a workshop on "Bio-ecological Observations in Operational Oceanography" (held in The Hague, 6-8 April 2000). The goal of this meeting was to advance an ecosystem approach for ocean monitoring by describing existing surveys, technologies, and concepts of bio-ecological oceanography and by discussing strategies of how to meet present and future user requirements in this sector. The workshop covered user requirements, sampling technology, anthropogenic and climatic influences on the ecosystems, and ecosystem modelling.

Workshop participants recommended that user involvement in the sampling strategy should be given high priority. Identified users were: the scientific community, environmental and public health agencies, coastal managers and decision makers, the public in general, fisheries and aquaculture business, shipping and tourist industry, and the navy. Participants recognised a need for further user requirement surveys as well as for an improvement of the interaction between marine scientists/operational agencies and politicians/ public. In addition, it was felt that a contribution of stakeholders to sampling and monitoring could reduce costs and improve acceptance of operational oceanography.

Sampling strategy should include different monitoring types and schemes. Cost reduction of expensive monitoring could be achieved through the improvement of error models and through a responsive sampling strategy. Participants suggested that progress of the bio-ecological monitoring technology could be achieved through the improvement of existing and development of new bio-sensors, through a standardisation of the most common methods, and advances in the use of remote sensing for the assessment of primary productivity.

Workshop participants agreed that improvement and development of impact indicators for the monitoring and control of pollution in coastal environments should be prioritised, and that a common definition, harmonisation and standardisation of the most important indicators must be achieved.

Another major point of discussion evolved around ecosystem considerations for fish stock assessment that will require new type of data. Workshop participants recommended that scientific efforts to identify those ecological variables and models that have a significant effect on fish distribution and abundance should be greatly increased. The importance of spawning areas for fish monitoring was recognised and adequate research recommended. It was also felt that non-commercial fish species deserve more attention than they are given at present.

Improvement and extension of bio-ecological data analyses was deemed necessary. Participants suggested the establishment of data analyses centres and of quality criteria for parameters, methods, processes, and model results. Strengthening the co-operation among modellers from different institutions and regions was seen as the only way to develop indispensable bio-ecological operational models. Such models should be based on identified user requirements. Among the processes deserving more attention from a bio-ecological operational perspective, were transport and ecosystem models, benthic processes, and benthic-pelagic interaction.

Participants strongly recommended improvement in building and using long-term databases. They suggested the initiation of such databases in hitherto neglected areas (e.g. Mediterranean, Black Sea) and advised that systematic collection of biological data should be performed by national and international agencies. In addition, easier access to databases was judged necessary and the establishment of a "data analyses and data mining" software depository recommended. The "Continuous Plankton Recorder" was specifically commended for quality and accessibility.

Workshop participants identified a number of products from bio-ecological monitoring, some of which already result from existing models. They recommended emphasising visualisation of data analyses and model results in order to ensure wide use and easy access to operational oceanographic products. Among the products mentioned were: High quality data sets for scientific research (e.g. primary productivity); early warning systems for harmful algal blooms, oil spills, etc.; habitat mapping for different benthic organisms; measurement of fluxes and transport tracking of hazardous substances and nutrients; monitoring and forecasting of stratification patterns; size of physically defined feeding areas for many fish species; and many others.

1 Introduction

Among the ocean sciences, it has been physical oceanography that until now contributed most to the GOOS aims. Ocean climate forecasting is well prepared to meet the GOOS challenge combining advanced measurement techniques with growing theoretical and practical modelling capabilities. Although fish stock assessment as carried out by the members of ICES represents one of the oldest operational marine activities, biological operational oceanography is generally not as advanced. This is a result of the difficulties involved with the development of automated sampling techniques, and understanding of the complex fluctuations and distribution of many living organisms. As Dik Tromp emphasised in his welcome speech to the Workshop participants, bio-ecological operational oceanography or the link between physics, water quality and biology is the most difficult task yet encountered by EuroGOOS.

Three (of five) GOOS modules, LMR (Living Marine Resources), HOTO (Health of the Ocean), and Coastal GOOS, aim at establishing the means to protect the environment and meet the objectives of Agenda 21, the Biodiversity Convention (see GOOS 1998), and the Water Framework Directive. EuroGOOS surveys show a great unfulfilled demand for water quality data, primary productivity, health-related, and fisheries related data. Finally, new sensors and new models make bio-ecological forecasting feasible now for the first time.

So far, the GOOS modules mentioned have set a general frame of variables, products and possible users for their work but have not proceeded to specify the strategies needed to acquire particular products (see IOC publications 1996, 1997, 1998a, 1998b, 1999a, 1999b). This specification is, however, ongoing. Within GOOS modules, a number of international research and development projects take place that focus on very different aspects of the marine environment: HOTO has a pilot project in Brazil on "Rapid Assessment of Marine Pollution" (RAMP), whereas the LMR module has a more regional focus and concentrates on fisheries in co-operation with FAO.

Keith Brander, official ICES representative at the workshop, stated that ICES is determined to play an active role in GOOS. He mentioned a number of activities relevant to GOOS that are carried out by ICES at present, such as the international bottom trawl surveys and the maintenance and building of data bases. The ICES Steering Group on GOOS additionally listed a number of ways in which ICES could assist, including (a) working with EuroGOOS to establish integrated operational oceanographic monitoring in the North Sea to address ecosystem and fisheries requirements, (b) exploring the feasibility of a similar approach in Barents Sea, Nordic Seas and Labrador Sea, and (c) nominating representatives on living marine resources to the appropriate GOOS panels.

The goal of the Workshop on "Bio-ecological Observations in Operational Oceanography" did not only consist in describing a number of state-of-the-art techniques of bio-ecological monitoring but also to discuss the status of interpretation and modelling of bio-ecological data including possible future trends. It is expected that the results of the Workshop will contribute towards an increasing awareness of biological oceanography and its possibilities. This should encourage research and promote the increased integration of biochemical observations in the ongoing operational oceanographic programs. The design of a permanent operational oceanographic observing system depends upon scientific understanding of marine physical and biological processes, possession of competent technology, and a knowledge of what is required by potential users of the information. The recommendations of workshop participants to GOOS and EuroGOOS and those supporting the Global Ocean Observing System take into account present and predictable user requirements as well as present knowledge on marine ecosystem processes. The recommendations are set out in full in Chapter 6 of this Report.

Where recommendations of this Report require existing components of EuroGOOS to deliver new products for use by the bio-ecological community, this request will be transmitted immediately to the relevant body. Where new observations or data types need to be developed, these observations will be scheduled and implemented, in collaborations with ICES and other bodies, when technically permitted. This is a new frontier.

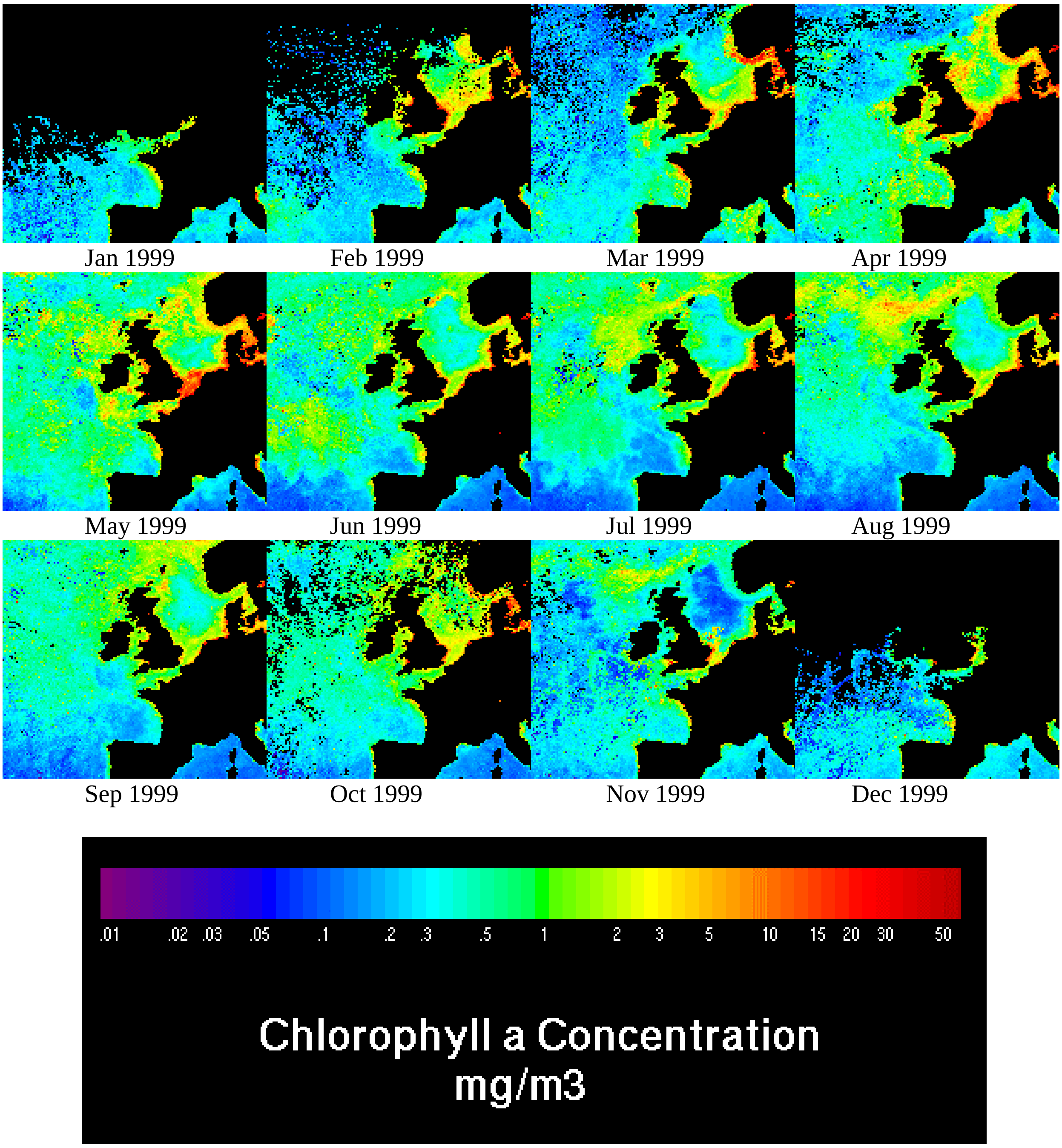

Figure 2: Bio-ecological products showing monthly monthly composites of chlorophyll a distribution in the North Sea from SeaWiFS data. Plymouth Marine Laboratory - Remote Sensing Group involvement within SEAMAR (http://www.ieo.es/seamar/seamar.htm).

The authors would like to thank the SeaWiFS Project (Code 970.2) and the Distributed Active Archive Center (Code 902) at the Goddard Space Flight Center, Greenbelt, MD 20771, for the production and distribution of these data, respectively. These activities are sponsored by NASA's Mission to Planet Earth Program.

2 Users of Bio-ecological Products and their Data Requirements

2.1 Summaries of presentations

Bio-ecological data requirements identified by GOOS/EuroGOOS

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Operational Oceanography can be defined as the activity of systematic and long-term routine measurements of the seas and oceans and atmosphere and their rapid interpretation and dissemination. GOOS and its regional programmes, such as EuroGOOS, are promoting the development of an internationally co-ordinated operational oceanographic system (IOC, 1998).

Five Modules have been set up by GOOS focusing on different aspects of such a system: 1) Climate Monitoring, Assessment and Prediction, 2) Assessment and Prediction of the Health of the Ocean (HOTO), 3) Monitoring and Assessment of Living Marine Resources (LMR), 4) Coastal Seas Management and Development (Coastal GOOS), 5) Marine Meteorological and Oceanographic Services (IOC 1998a). HOTO concentrates on anthropogenic activities and their effects on the ocean environments, LMR wants to provide information on the state of living marine resources and ecosystems, and Coastal GOOS aims at quantifying perturbations and stresses to coastal ecosystems as well as detecting and predicting their effects on people, coastal ecosystems and living marine resources, and coastal marine operations.

The HOTO, LMR and Coastal GOOS Panels are each developing strategies for the development and implementation of their respective products and have already suggested a number of variables and products to be included in GOOS. LMR identified possible users for products from this sector, most prominently regulatory agencies, environmental organisations, wildlife reserves, tourism and sports fishing, climate change and other research, and private sector organisations impacting the environment (IOC 1998b). Recently, EuroGOOS has performed a data requirement survey in 6 European countries (Fischer & Flemming 1999) and found that variables from the Biogeochemical group were requested by 40% of all participants, mainly by research institutes, environmental organisations, the private food sector (especially aquaculture), and the services sector. Overall, the six most frequently requested biogeochemical variables were phytoplankton composition, suspended sediments, chlorophyll, nitrate, phosphate and oxygen. It should be noted that no trophic levels beyond zooplankton were included on the list. Data products from GOOS are needed on different spatial and temporal scales that depend very much on the application for which they are needed as well as on the type of variable that is being requested. This is reflected in the results of the EuroGOOS Data Requirement Survey. In contrast to other variables, the highest demand for biogeochemical data products is in the estuarine environment and relatively long forecast periods tend to apply to many variables from this group, especially to harmful substances (e.g. PAHs). In spite of the difficulties involved in measuring many biochemical variables, average variable accuracy requested is not lower than that of physical variables. However, spatial as well as temporal resolution required for biogeochemical operational products tend to be coarser than for other products whereas no differences in vertical resolution can be detected between physical and biogeochemical variables.

Data and technology requirements for water quality assessment

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Government needs for data are policy driven at national, European or international level. Apart from a desire to ensure that current operational monitoring programmes meet present needs changes in the approach to data collection are likely to be required in the future to meet changing policy needs. For example, the emergence of requirements for an ecosystem approach to environmental management and the setting of ecological quality objectives will require a review and possible changes in current practice. There is likely a need to measure a wider range of variables and also to include measurement of rates as well as state variables. Further, there is an awareness that low-frequency ship-based observations do not resolve environmental and ecosystem variability at the appropriate spatio-temporal scales for present needs. An integrated approach using a range of sampling strategies and platforms will be required to meet the future needs.

The design of an effective operational monitoring programme needs to address questions concerning choice of measured variables but equally important are the scales of variability to be encountered. Matching the spatio-temporal resolution of the sampling strategy to scales of variability of the parameter or process of interest is a critical step. No single platform (mooring, drifting buoy, survey vessel, ferry) can resolve all the likely spatio-temporal scales of interest and as a result an integrated observing strategy is likely to be required. Current and future sampling strategies will be described together with a description of environmental variables that may be measured using readily available automated sensors and samplers. Future measurement needs will be identified in terms of platforms and new measurement requirements and the possible candidates to meet those needs.

Marine biological indicators: EEA's data needs and assessments

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EEA’s work in general on data collection, indicator development and reporting and the networking within EIONET (is presented. Activities of the ETC/MCE and EEA on marine data collection from Member States and Marine Conventions, the development of marine indicators, the development of thematic maps and GIS, the Inter-regional Forum with Marine Conventions and marine assessments are shown. Finally, the future aims and activities of EEA on marine data flow, the Water-Framework Directive, EEA-reporting and the harmonisation with similar activities of Marine Conventions are outlined.

Coastal users' data requirements (aquaculture and small-scale fisheries)

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Aquaculture has grown over the past 3 decades from about 5 million tonnes in 1973 to over 36 million tonnes in 1998. It includes seaweed, shellfish, crustacean, and finfish culture and utilises a variety of culture systems (e.g. onshore tank and pond facilities, inter-tidal and submerged units, offshore floating or submerged structures). Aquaculture depends on good water quality and suffers from domestic and industrial pollution in many parts of the world.

All aquaculture systems require continuous monitoring for farm management and for environmental management. In addition, a full year monitoring of water quality, climate, and biological conditions is needed prior to installing an aquaculture operation. Important variables are:

- currents,
- extreme weather conditions
- cold spells early warnings (e.g. super-cooling effects in northern climates)
- temperatures and salinity changes
- oil spills and their near shore drift to predict which farming units may be affected (shellfish and finfish farming) and to initiate timely rescue measures. Usually a 10 hr warning time should be sufficient for most floating structures (e.g. modern single-anchored cages) or pre-harvest stocks (cages, raft-cultures, etc)
- algal bloom warnings and predictions on their drift direction and temporal development. This would greatly assist shellfish and finfish farms to secure their operation by either lowering the cages on long-lines below the bloom layer, or by stopping fish feeding 10 hours prior to the full-bloom development (to reduce respiratory requirements of fish during bloom exposure when gills are temporarily damaged).

Such monitoring programmes could - to some extent - incorporate the farms themselves which would enhance the cost-efficiency of trend monitoring. Farmers are on the spot every day and could provide a variety of regular measurements. In return, they would receive essential information about relevant parameters which influence their long-term management and investment decisions.

The escape of farmed fish into the wilderness is a common problem in finfish culture (e.g. salmon) and is regarded as an environmental threat as cultured fish can interbreed with wild con-specifics and thus deplete the genetic fitness of natural populations. Tight control measures are necessary to prevent escapes or to recover escaped fish. Modern tracking methodologies (electronic tagging) can help in this context and may also offer new opportunities in understanding the factors influencing recruitment in straddling stocks while at the same time guiding fisheries scientists and managers to design better sampling strategies on site.

Modern shipping can cause problems to fisheries and aquaculture through the transmission of harmful exotic species via ballast water and hull fouling. This has already led to changes of species diversity along many coasts with dramatic consequences to aquatic resource users and to human health. About 80% of the world's cargo is transported by ships. Table 1 clearly indicates that most of the important ship types carry a substantial amount of ballast water while at sea and most of it is released inshore. Estimates suggest that at present the total volume of ballast water reaches a volume of 10 to 12 billion tonnes a year while more than 3000 species are in intercontinental transit daily. Offshore ballast water exchange (which is thought to reduce species survival rate) is considered to be a possible solution but it requires monitoring (remote sensing) and forecasting of algal bloom events (inshore and offshore) to prevent the uptake of biologically “contaminated” water.

Finally, the number of coastal resource users is increasing world-wide. These users go far beyond fisheries and aquaculture. While these are in need of specific information about the sea and seashores, they may also be considered possible partners in modern inter-linked monitoring systems that finally are integrated into larger expert systems for Integrated Coastal Zone Management strategies.

Vessel type	Ballast volume
ULCC > 300,000 t	30%
VLCC > 200,000 t	30%
Suezmax Tankers (120,000-200,000 t)	30%
Aframax Tankers (80,000 - 120,000 t)	30%
Older and/or smaller tankers	20%
Chemical tankers	20%
LNG/LPG tankers	25-30%
OBO's and Ore/Oil tankers	30 %
Northsea Shuttletankers (60,000-120,000 t)	40-50 %
Balk carriers Capesize	20%
Bulk carrier Panamax (60 - 80,000 t)	20 %
Bulk carriers Handysize (20 - 60,000 t)	20 %
General Cargo	10-15 %
RoRo's	20-25 %
Vehicle carriers	20-25 %
LASH vessels	30 %
Containervessels	10-25 %
Post Panamax container vessels	30-35 %

Table 1. Major types of modern ships and their average ballast volume relative to the size of the ship (modified after IMO)

Data requirements for living resources management

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ICES
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The type and quality of data required for management of living resources depends very much on the type of management which is being used and on the objectives of the management system. Within the ICES area the main form of management is by annual limits on the total allowable catch (TAC) for many commercial fish species. This requires information from the fishery, but also increasingly from other sources, particularly research vessel surveys. The principal kinds of information from these sources have been described in previous GOOS reports. The duration of stock assessment time series for ten fish species in ten areas is shown in Table 2. As the objectives of fisheries management are widened to include other components of the marine ecosystem, so the data requirements will change. It is also likely that information about the marine environment will be used to an increasing extent in the assessment of fish populations.

AREA	cod	G'land halibut	haddock	hake	herring	scad	plaice	saithe	sole	whiting
Celtic Sea	1988						1977		1971	1982
E Eng Channel							1980		1982	
Faroe	1961		1961					1961		
Iberia				1982		1985				
Iceland	1955							1962		
Irish Sea	1968				1972		1964		1970	1980
Kattegat	1971						1987		1984	
NE Arctic	1946	1970	1950					1960		
North Sea	1963		1963		1960		1957	1967	1957	1960
W Scotland	1966		1965		1976			1972		1965

Table 2. Earliest year for which stock assessment (output) data are available

2.2 Session synthesis

Biological data requirements do not stop at the observation of single parameters but rely on the understanding of bio-ecological processes as well as the matching of temporal and spatial sampling scales to the scales of variability in the parameter or process of interest. Workshop participants voiced concern over the relatively high costs of biological monitoring at finer spatio-temporal scales requiring high resolutions. The high economic value of coastal ecosystems, however, might help to justify monitoring expenses. They also felt the need for a common definition of biological or ecological indicators to avoid the vagueness of the term "water quality" that varies with different agencies.

A significant task in environmental assessment will be the improvement of existing and development of new impact indicators. Customary indicators usually do not convey much about the actual effect that chemical pollutants have on biological components in a particular ecosystem. Indicators are of great value to environmental assessment as they allow a rough judgement on the state of an environment by serving as a kind of filter for very complex interactions. As the processes influencing an indicator, however, are mostly poorly understood, the sole use of indicators can lead to an oversimplified and dangerously false view of the actual events. Participants therefore recommended that indicators should be supplemented by raw data. For environmental assessment, one of the difficulties encountered by the European Environmental Agency (EEA) appears to be the poor reporting of biological parameters by many coastal European countries (in contrast to chemical parameters). Also, the quality of data reported is not even throughout Europe resulting in questionable indicators for many regions. EuroGOOS might be able to incorporate some of the most important biological and chemical coastal variables in co-operation with EEA to improve this situation (an existing example for the operational monitoring of biological and chemical data is the Ferrybox programme in the Baltic Sea).

Aquaculture is among the major coastal resource exploitation businesses in some European countries and its importance is rising rapidly. Fish farms essentially need short-term (24 hours) warning of hazardous conditions, such as oxygen depletion, high waves, extremely low surface temperature, toxic algal blooms, and oil spills, in order to take appropriate measures to save their animals. A well-known problem of aquaculture is the escape of farmed organisms into the wilderness that can result in a loss of biodiversity in wild stocks and which must therefore be monitored somehow. Abundant food supply to cage farms also attracts wild fish, a fact that can be used by scientists in stock assessment. Another important user group of coastal seas is the shipping industry. Through the discharge of ballast water (an estimated total of 12 billion tons per year), huge amounts of sediment and exotic species from far-away places are released to coastal environments, which, for example, can cause toxic algal blooms to develop or new species to be introduced. Control of this requires monitoring and forecasting of algal bloom events.

Fish stock assessment has a long history with operational scientific data collections reaching back half a century in ICES (see Table 2). Due to the cost, the frequency and resolution of survey sampling for fish stock assessment is low, typically 6-12 months intervals and a grid interval of about 70 km. In order to maintain continuity, the type of data sampled today has not changed since the 1960s and the models used are still based on single species allowing for no or only little interaction with the environment. It is widely felt among the fish stock assessment community that this is inadequate and should change.

An ecosystem approach would require new types of data to be integrated into fish stock assessment under the conditions that (a) the data acquisition in terms of time and costs is operationally feasible, (b) their effects on fish stocks are scientifically credible, and (c) these effects are significant enough. (Such parameters [whether expressed as states or rates] are still to be determined and the models linking them to fish stock development to be created). It was felt by workshop participants that fish stock assessment could benefit from good estimates of primary productivity and its variability. (As large-scale variability of primary production is determined by its small-scale variability, it would be sensible to start with small-scale assessment.) Fish stocks are generally not influenced in a linear way by environmental variables and are often event-driven, which has to be taken into account for modelling. Predictions of extreme environmental conditions, e.g. low phytoplankton abundance, and very low or high temperatures or lack of oxygen, might be helpful in this context; the high short-term variability of most such conditions require a careful sampling design with a high temporal resolution. Operational oceanography has concentrated on the observation of surface variables whereas many commercially important fish species are demersal, therefore more complete inclusion of bottom variables (e.g. bottom oxygen in the Baltic Sea) into operational oceanography might prove beneficial for the assessment of benthic species.

The impression gained from the EuroGOOS data requirement survey was that at present only specific user groups (especially from the research, food and environment sectors) actually request bio-ecological data products, and that these tend to concentrate on a few, mainly phytoplankton-related variables (e.g. primary productivity, nutrients, etc.). This result was probably partly influenced by the emphasis of the survey on physical variables and by the present difficulties and high costs involved in operational monitoring of biochemical and biological variables which might have prevented many respondents to request such products. The workshop, however, made clear that a number of important applications have very specific and varying bio-ecological data requirements. A survey that is specifically directed at users of biological operational oceanographic products could assess those needs in more detail. In addition, scientists might be able to help users identify needs that they themselves are not able to see. At present, the following bio-ecological data products (forecasts and analysed data) are of interest to existing and potential users of GOOS:

- Nutrients
- Suspended sediments
- Eutrophication
- Harmful algal blooms
- Temperature (max/min)
- Exotic species
- Oxygen (profile, bottom)
- Chlorophyll, Phytoplankton
- Toxic substances, oil slick
- Wave height
- Background physics

Workshop participants also expressed the necessity for better contact with users of biological operational oceanographic data products and especially the education of potential users. EU directives could help national governments to become users of such products in order to improve human health, environmental protection, aquaculture, and fisheries management.

The usefulness of involving stakeholders in the data collection as demonstrated by ferrybox projects (see below) was greatly appreciated by workshop participants and it was suggested more than once that users should be approached and asked to contribute to the operational sampling of biological, chemical and geological data. Sectors mentioned explicitly in this context included the aquaculture industry that could contribute towards water quality assessment in coastal zones and the shipping industry that already contributes to measuring relevant plankton parameters (ferry box projects, see below) and could perhaps also be involved in ballast water monitoring. Other possible sectors that could have an interest in actively contributing towards bio-ecological operational oceanography are the fishing industry, oil industry, harbour and port authorities, and others. In summary, the sectors that were seen as possible drivers (either as initiators or as data contributors) of a bio-ecological operational oceanography were:

- Governments (nation./local)
- European Union
- International conventions (OSPAR, HELCOM)
- Shipping (ballast water, antifouling)
- Aquaculture business (water quality)
- Ports and harbours (water quality)
- Fishery regulation
- Media and public (websites)
- Public health, Bathing water
- Land pollution control
- Marine parks
- Scientific research

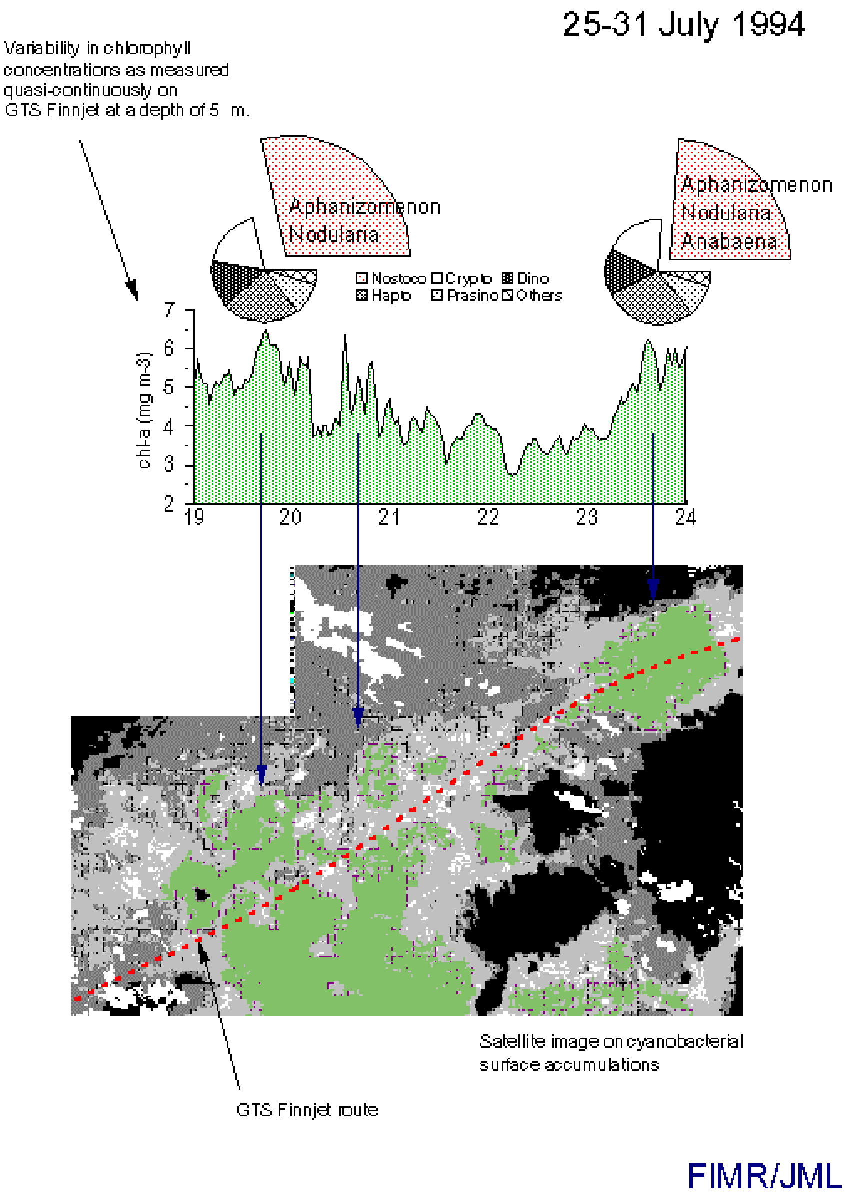

Figure 3. Product from Finnish Alg@line system, available on the internet: http://meri.fimr.fi

3 Sampling and Assessment of Aquatic Communities and Processes

3.1 Summaries of presentations

Nutrients assessment and applications

David Hydes
Southampton Oceanography Centre
Southampton, United Kingdom

Measurements of concentrations of nutrient have two functions in a GOOS context. One is in determining the concentrations of nutrients that are immediately available to support primary production in a given area, the other is to provide information that can be used to help understand the short and long range transport and biogeochemical processes that control the supply of nutrients throughout the year. A range of autonomous analysers are now available that have successfully transferred wet chemical methods from the laboratory to remote sampling stations and moored data buoys. The development of systems for use on ships of opportunity presents a new challenge, both from the point of view of obtaining data of sufficient resolution but of also meeting the safety aspects of their operation. The requirements for such systems will be discussed as well as some of the potential ways forward. Examples will be presented of how nutrient data may be combined within in a current "FerryBox" study of plankton dynamics on the South Coast of the UK, and how nutrient measurements may be useful on a wider scale.

'FastTracka' - Fast Repetition Rate Fluorimetry

John Attridge & John Atkins
Chelsea Instruments Ltd.
West Molesey, United Kingdom

Fast Repetition Rate Fluorimetry (FRRF) is an extension of conventional fluorimetry that allows the photosynthetic activity of phytoplankton to be measured in both sea and fresh water environments. In this talk the principle behind FRRF will be described in more detail and illustrated by its implementation in Chelsea Instruments 'FastTracka' fluorimeter.

A conventional chlorophyll fluorimeter will simply indicate the concentration of fluorophore in the sample. This can arise from chlorophyll in living phytoplankton, chlorophyll released from dead micro-organisms and other compounds that fluoresce at the measurement wavelengths. Using FRRF it is possible to discriminate a time dependent fluorescence signal arising from chlorophyll actively participating in photosynthesis from a dc background signal from non-active compounds.

Figure 4. Fast Tracka. Fast repetition rate fluorimeter. Chelsea Instruments.

The measurement is achieved by firing a rapid sequence of low energy flashes into the sample. Energy absorbed by a photosynthetic light-harvesting complex will be transferred to a photosynthetic reaction centre to initiate a cycle of photosynthesis. While this happens the reaction centre is 'closed' and cannot receive any more energy and any excess will be dissipated as heat or fluorescence. Therefore, an increase in fluorescence signal will be recorded with each subsequent flash until all the reaction centres are closed and the signal stabilises to a maximum value. This 'saturated' fluorescent signal is all that a conventional fluorimeter will record. Analysis of the FRRF response enables the following parameters to be determined that cannot be obtained by conventional methods:

- photochemical quantum efficiency;
- efficiency of light harvesting;
- concentration of active photosynthetic reaction centres;
- proportion of reaction centres closed due to ambient light;
- time constants associated with electron transfer within the photosynthesis mechanism.

Investigating these parameters we are finding applications that include the study of primary production, carbon fixation in the oceans and early algae bloom detection.

Rationale and requirements for global ocean observing of in situ optical properties

Jim Aiken
Marine Laboratory
Plymouth, United Kingdom

Biological production drives all the processes in the oceans that relate to natural resources, fisheries and the air-sea exchange of CO_2 and other biogenic gases, which are implicated in the natural and anthropogenically-forced greenhouse effect and climate change. Ocean colour is the water leaving radiance (Lw) or the light reflected (R) from the water after selective scattering by particles and absorption by dissolved compounds and particles (principally phytoplankton and their photosynthetic pigments) at visible wavelengths (400-700 nm). Reflectance (R,λ) relates to the ratio of the back-scatter coefficient (bb,λ) and absorption coefficient (a, λ) for all the constituents.

Phytoplankton pigments (principally chlorophylls and carotenoids) absorb photons at visible wavelengths which are used in the photosynthetic process. Conceptually, there exists a functional relationship between optical properties and the bio-optical signatures of sea water and phytoplankton production. Coupling large-area satellite remotely sensed observations of ocean properties (colour, temperature, currents etc) with measurements of process rates and parameter values can provide data to model and predict the effects of pelagic production on the global biosphere and the responses of oceanic ecosystems to climate change.

Both optical properties and photosynthetic parameter values will vary seasonally and across ocean basins and the shelf seas, so measurements must cover the full range of bio-optical provinces. Measurements are needed of optical properties, water constituents and photosynthetic parameters.

IOPs: scattering (b, λ), back-scatter coefficient (bb,λ) and absorption coefficient (a, λ) of phytoplankton and particles.

AOPs: Reflectance (R,λ), the water leaving radiance Lw(λ), the downwelling irradiance Ed(λ), the Solar Irradiance Es(λ), and the diffuse attenuation coefficients Kd,u(λ).

Water constituents: concentrations of phytoplankton pigments, particles (inorganic and biogenic) and dissolved organic compounds (DOC, yellow substances or gelbstoff).

Photosynthetic parameters: Pmax, Ik, α, σps2, and τ (from the fast repetition rate fluorometer, FRRF).

Remote sensing of primary production variables in coastal waters

Roland Doerffer
GKSS Forschungszentrum, Institute of Hydrophysics
Geesthacht, Germany

The generation of advanced earth observation satellites, which have been launched recently (NASA's TERRA) or will be launched in the near future (ESA's ENVISAT) provides the potential for remote measurements of variables, which are of importance to estimate the primary production of coastal waters. Using imaging spectrometers such as MERIS on ENVISAT it will be possible to map the concentrations of phytoplankton chlorophyll and of suspended matter, which is the main factor for light attenuation in coastal waters e.g. of the North Sea. Further variables which are of interest for determining PP and which can be derived from satellite data are the sea surface temperature, diurnal time series of the attenuation of PAR by clouds and an estimate of the stratification or vertical mixing using wind / wave data. However, critical is the knowledge of the parameters describing the Production versus PAR (PI) curve. The presentation will discuss a scenario how all these variables can be measured in the future and can be combined by simple models to produce time series maps of primary production of coastal waters.

Ten years of operational monitoring of phytoplankton blooms and eutrophication in the Baltic Sea - experiences using ship-of-opportunity technique, satellite imagery and ecological models

Juha-Markku Leppänen & Mikko Kiirikki
Finnish Institute of Marine Research / Finnish Environment Institute
Helsinki, Finland

The Gulf of Finland has eutrophied during the last decades. Plankton biomass has increased and toxic phytoplankton blooms are common. The ecosystem of the Baltic Sea is also highly fluctuating: strong seasonality, small-scale variation in hydrography, and patchy distribution of organisms require that sampling strategy should cope with various spatial and temporal scales in the ecosystem.

The Finnish Institute of Marine Research has run a comprehensive algal monitoring and alarm system, Alg@line, since 1990. It has been developed in order to record reliably the intensity and incidence of patchy phytoplankton blooms and especially harmful and potentially toxic ones.

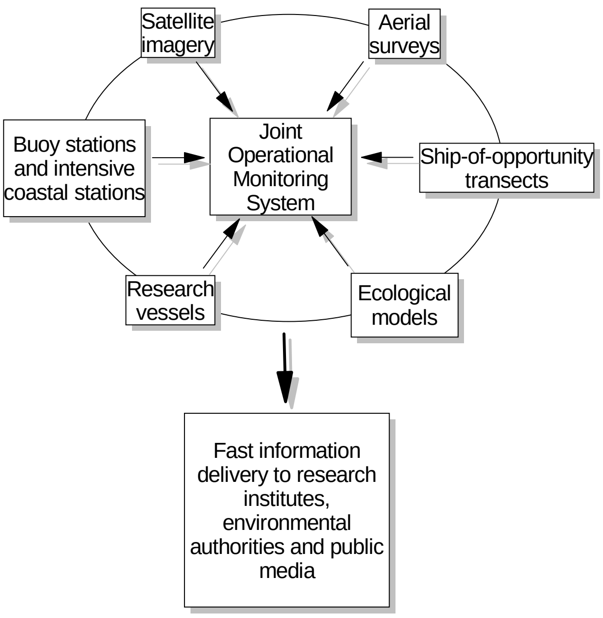

Figure 5. Concept of the Operational Monitoring System for the Gulf of Finland

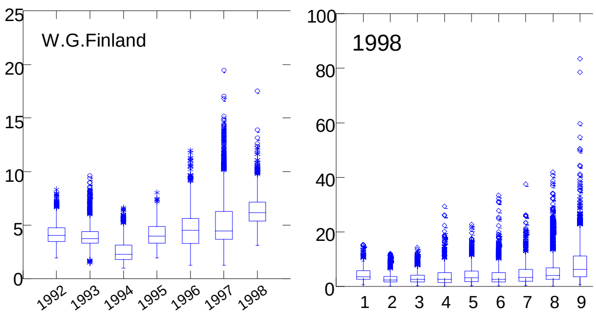

Figure 6. Left: annual variation in the summer concentrations of chlorophyll a (mg m^{-3}) in the Gulf of Finland. Right: Regional variation in the spring concentrations of chlorophyll a (mg m^{-3}) in the Baltic Sea (1= Travemünde, 2= Mecklenburg Bight, 3= Arkona Sea, 4= Western Bornholm Sea, 5= Northern Bornholm Sea, 6= Western Gotland Sea , 7= Eastern Gotland Sea, 8= Northern Baltic Proper and 9= Western Gulf of Finland)

Alg@line monitors the fluctuations in the Baltic Sea ecosystem in real-time using several approaches (Fig. 5). It combines high frequency automated sampling onboard several merchant ships with satellite imagery, aerial surveys, buoy recordings and traditional sampling onboard research vessels and at coastal stations. Ecosystem models are at the moment at pre-operational stage. The core of the system is the ship-of-opportunity recordings on ferries. Presently, Alg@line has analysers and sample collectors on five ships.

The analysers on ferries record surface water quality with high spatial (ca. 150 m) and temporal (ca. 1 day) resolution. The systems provide on-line information on the variability in phytoplankton, hydrography and nutrients. Now a Continuous Plankton Recorder (CPR) device is operational in the Baltic Sea, too.

The forecast system links information from the monitoring systems to mathematical models. Today, the ecosystem model is able to produce early warning forecast for toxic blue-green algal blooms and to make prediction on the long-term development of the ecosystem with various loading scenarios.

The information based on the unattended recordings on the ships is available on a specific Web site, Alg@line Database, providing information in Finnish, Swedish, Estonian and English. The web address is http://meri.fimr.fi.

The Alg@line system has proved to be able to give almost continuous on-line information on the rapidly fluctuating Baltic Sea plankton ecosystem. It is also capable to collect data to analyse long-term changes in the plankton biomass and species composition (Fig. 6 and 7).

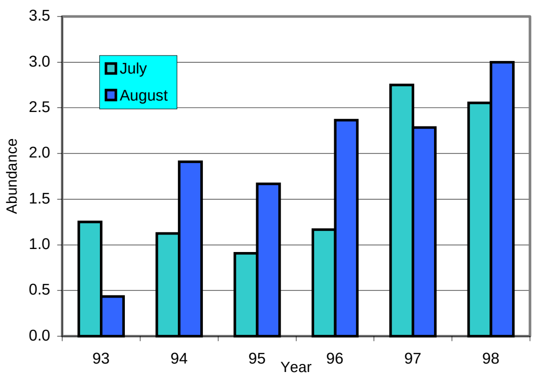

Figure 7. Annual variation in the abundance of the toxic blue-green alga Nodularia spumigena in the northern Baltic Proper and the western Gulf of Finland

Persistence and variability of phytoplankton assemblages. Implications for monitoring

Marta Estrada
Institut de Ciències del Mar. CSIC.
Barcelona, Spain

The dominance of a particular species or the precise composition of the phytoplankton community at a certain place or time may be, in practice, impossible to predict. Even in apparently well-mixed environments, interactions with physical, chemical and biological factors may allow the coexistence of numerous competitors and may generate large oscillations and chaotic behaviour of species abundance. Thus, in the context of issues like harmful algal problems, limitation of phytoplankton monitoring to only one or few species of interest, may impair efforts to find useful regularities in the variability of the concerned populations. The consideration of functional groups of phytoplankton provides a basis for simplification of the real world and may help to improve our predictive capability relative to the dynamics of the system. Functional groups (functional types or life-forms) are non-phylogenetic classifications based on physiological, morphological or other traits, and can be defined as groupings of organisms that respond in a similar way to recurrent patterns of selective factors. Functional groups can be operationally characterised using a variety of approaches. One of them is the use of multivariate statistical techniques to detect recurrent patterns in the composition of phytoplankton communities at particular places or times. Taxa within a recurrent assemblage share a similar ecological response and can be examined for common traits characterising a functional group. This contribution discusses the applicability of the functional group concept in the context of GOOS and presents some examples of identification of recurrent phytoplankton assemblages in marine ecosystems.

Benthos Sampling in European Waters

Heye Rumohr
Institut für Meereskunde an der Universität Kiel
Kiel, Germany

Monitoring the fauna of the seafloor is one of the most reliable means to determine environmental quality since the stationary benthos integrates changes of the marine environment over time and shows effects even when the actual causal event could not be measured. Benthos sampling methods have been always very conservative and little was changed after the first quantitative attempts by C.G.Joh. Petersen in 1909. Grabs have replaced dredges, which nonetheless give still valuable information on rare and larger species. Coring devices are the most popular technology in recent deep-sea and general research activities. Newly designed special gear to collect the „overlooked fauna“ i.e. rare and large epi- and infauna gave a new momentum in the sampling scene. Much has been done to make data from various benthos samplers more reliable and comparable particularly with respect to the fact that data are stored in international data banks and are used by other people than the data originators (intercalibrations, intercomparisons, ring tests, quality assurance). There have been nevertheless attempts to overcome the shortcomings of traditional sampling. These methods are destructive and do not allow repetitive information retrieval from the same spot. Imaging methods (photo, video, sonar) have gained more importance since they are non-destructive and cover various scales from mm to decametres. They need, however, traditional samples for verification and groundtruthing. There are new approaches to use echosignals for larger scale mapping and classification of the seafloor. The combination of traditional methods with modern imaging and classification methods provide new types of data which allow us to judge the environmental quality status of the seafloor and its fauna with more precision and spatial validity.

Status quo of fish monitoring and assessment

Norbert Rohlf
Institut für Meereskunde
University of Kiel, Germany

Many stocks in the North Sea and the Atlantic are subject to assessment and thus to monitoring. Data on distribution of target species, age composition and maturity as well as on abundance of early life stages are of main interest. Most of these data are collected during acoustic surveys, young fish and egg/larvae surveys on an annual (e.g. herring in North Sea) or periodical basis (e.g. three year modus for mackerel/horse mackerel). A combination of the different sources of information is used to identify the state-of-the-art of the stock in the assessments and can be used as a scientific background for fisheries politics and management (e.g. settling of fishing quotas or TACs).

Predictions on developing year-class strength and stock sizes depend on fishing pressure as well as species interaction and physical factors and thus implicate increasing kinds of variance with time. A better understanding of ecological processes combined with a powerful modelling will be helpful in assessment quality. At least some of the surveys can be regarded as a platform for collection of additional ecological information (e.g. zooplankton abundance, food availability) or to combine existing databases with information from other projects and sources in process studies.

Towards absolute abundance estimation of fish and zooplankton; main challenges in acoustic methodology

Egil Ona and Roald Saetre
Marine Institute
Bergen, Norway

The most important fish stocks in the North Atlantic are now monitored and assessed using data from acoustic surveys. The stock abundance is generally given as indices, rather than in absolute numbers. If absolute stock abundance is to be specified, both bias and precision needs to be studied. The talk will focus on the three most important sources of bias in acoustic abundance estimation, vessel avoidance, target strength and identification. Some new methods for such investigations will be shown, and new, promising acoustic methods for measuring zooplankton size and abundance will be briefly presented.

3.2 Session synthesis

Operational oceanography requires regular, preferably automated, measurements taken by low-cost and robust instruments. Remote sensing, optical, acoustical, and chemical in-situ sensors are all of interest in this context and have to be evaluated for each ecosystem component. Many biological processes are driven by physical and chemical environmental changes and measurement of temperature, salinity, turbulence, currents, sedimentation, nutrients, etc. are essential for the reliable assessment and prediction of biological components. Automated technology is indispensable in operational oceanography to ensure the high frequency sampling necessary to capture the high temporal and spatial variability of biological ocean components.

In-situ sampling is currently the main assessment procedure for most biological and chemical ocean variables including water quality and nutrient assessment. Biosensors are still a developing technology that must be thoroughly tested in the field and examined in terms of reliability, cost, accuracy, and precision. Optical sensors are currently used in the measurement of primary productivity. An example for a new generation of optical in-situ sensors is fast repetition rate fluorometry that can be used to estimate primary production rates

The Ichthyoplankton Recorder – a video recording system for in-situ studies on small scale plankton distribution patterns

The ichthyoplankton recorder is a towed underwater video recording system and can be operated at speeds of 3 to 5 knots. A highly sensitive video system is integrated into the cod end of a Gulf III type high speed zooplankton sampler. A CTD probe as well as sensors for flow and light attenuation are attached to the sampler. The system is designed to detect fish fry, their food organisms and their predators in the size range from 0.5 to 20 mm on small temporal and spatial scales and operates with conventional periphery devices. The video information as well as the environmental data are transferred via a single conductor cable to a S-VHS recorder and to a PC, respectively, on board of the research vessel.

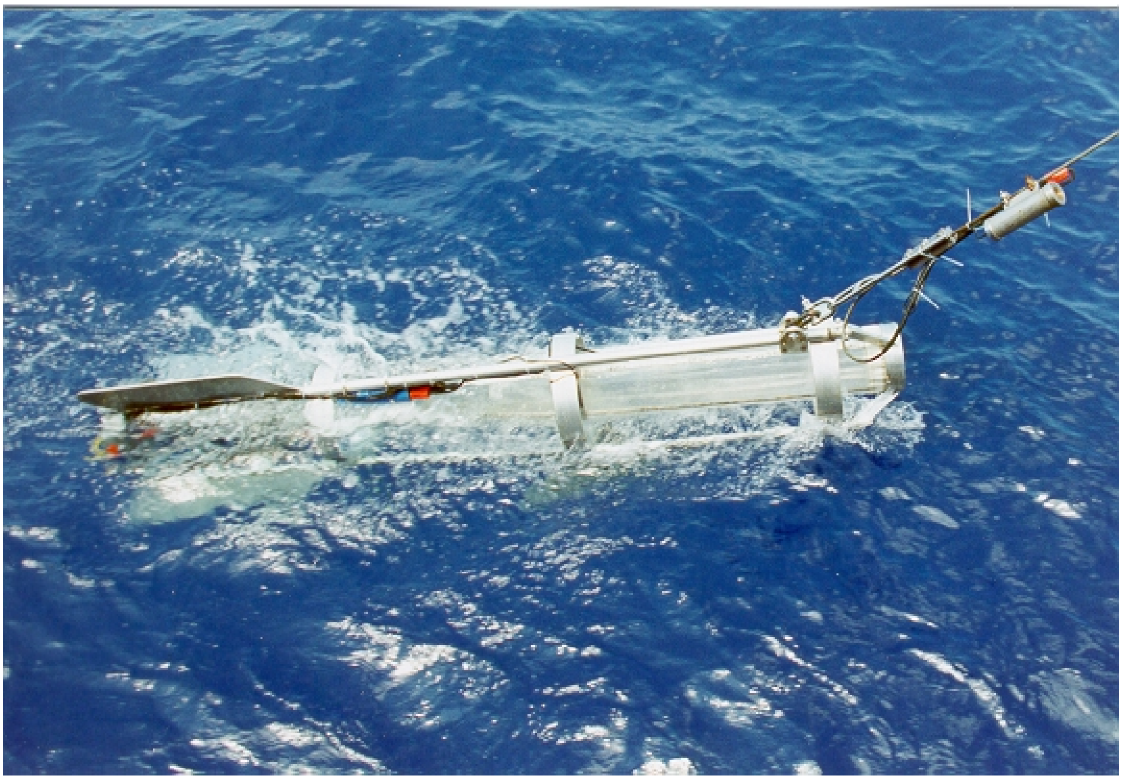

Figure 8. Ichthyoplankton recorder from the Institut fur Meereskkunde University of Kiel Germany, courtesy Norbert Rohlf.

Organisms entering the net opening (20 cm in diameter) are concentrated to an entrance area of the measuring channel of 15*15 mm, illuminated by strobed light emitting diodes (LED’s). The length of the field scanned by the CCD-camera is 20 mm.

The high amount of data provided by the Ichthyoplankton recorder (50 resp. 25 images per second) requires an automatic analysis. A first step, separating empty images from those with information included, has been achieved and is most important, as it allows to reduce the number of images substantially which have to be screened interactively. Further software development is required for an automatic qualitative analysis.

The Ichthyoplankton recorder has been used during several cruises within the framework of the ICES herring larvae surveys in the North Sea. In recent cruises, sampling has been carried out for comparison of sampling efficiency and larvae catchability between the IPR and standard gears. The analysis of the video images taped on these stations is in progress and will provide also information about the vertical and horizontal distribution of herring larvae and their prey in relation to environmental conditions.

and enables the discrimination between active ("living") and inactive ("dead") chlorophyll. It can be used in the early detection of algal blooms.

Autonomous analysers for nutrients and chlorophyll are available on the market and are presently used in ferrybox programmes (automatic or semi-automatic instruments and sensors attached to ships-of-opportunity). The high frequency ferrybox data have been successfully combined with satellite imagery, aerial surveys, buoy recordings, and traditional sampling onboard research vessels and at coastal stations since 1990 in the Baltic Sea. Ecosystem models using these data are at a pre-operational stage and can already produce early warnings for toxic algal blooms and long-term changes in plankton biomass and species composition. Participants recognised that the implementation of an integrated observing strategy that combines in-situ data with those acquired by remote sensing is highly valuable and deserves further attention.

Remote optical sensing as a phytoplankton observation technique received much attention during the workshop. Although primary productivity cannot be measured directly by remote sensing, most of the important parameters influencing PP can be (chlorophyll, suspended matter, SST, photosynthetic active radiation [PAR], wind, waves. The interpretation of satellite images is improving and achieves remarkable results, there are, however, restrictions to this method; e.g., it captures only surface pigments and cannot detect phytoplankton in deeper layers. Also, the current frequency of average satellite imaging (once per week) is still very low and does not reflect the rate of changes (variability) in marine ecosystems.

At present, the precise species composition of phytoplankton assemblages cannot be obtained by automated sampling methods (although pattern recognition techniques applied, for example, to optical images, may allow the automated detection of selected taxa). The workshop therefore recommended targeting functional groups, i.e. groups of organisms that respond in a similar way to recurrent patterns of selective factors and can be identified by common morphological and physiological traits. The effect of environmental forcing on phytoplankton composition and abundance is considerable, which means that physical data, e.g. circulation and turbulence, are of great importance when modelling primary productivity or dominance of particular functional groups.

Advances have been made in the acoustic assessment of zooplankton size and abundance but this method is still in a developmental phase and has yet to be made available for regular surveys. ICES accommodates the Zooplankton Ecology Working Group that compiles national zooplankton monitoring reports, which could be integrated into GOOS.

Assessment of benthos as well as of fish stocks is still largely done with traditional sampling methods, e.g. dredges, grabs, and coring devices for benthos, trawls and other ship-operated nets for fish stocks. These methods tend to be selective and invasive or even destructive. For large-scale mapping and classification of the seafloor, acoustic imaging represents a promising technology. It was stressed that quality control and comparability of benthic observations and data are still wanting and require future efforts. The suitability of benthic organisms as indicators for environmental quality assessment was briefly discussed. Megabenthos is not appropriate for this purpose as it generally displays a slow response to toxic substances (weeks to years) in contrast to microbenthos, which tends to respond much faster. It was suggested that tracing of fish routes using radio tags could be done on a much wider and more regular basis as it would help predicting fish distribution and give important insights into fish behavioural patterns under certain environmental circumstances.

Regular scientific fish and fisheries surveys are among the oldest operational oceanographic activities in European seas. Products derived from the gathering of data on distribution, abundance, age composition, maturity, and fishing mortality of the targeted species are used to predict abundance of year classes of the main commercial fish species for the coming year and derive recommendations for fisheries management. The large investment in long-term databases already existing and the need for continuity in order to maintain inter-annual comparability of the data, both make it very difficult to introduce any changes. There are efforts to introduce an ecosystem approach in fish stock assessment, as it has become very apparent that environmental variables, e.g. climate, food (especially primary productivity), and competition, greatly contribute towards fish population dynamics. Once the relevant variables for the different fish species have been identified, GOOS could provide the high quality and perhaps high-frequency environmental data necessary to run the new generation of fish stock models.

Recently, imaging techniques (acoustic and optic) have been introduced in both benthos and fish stock assessment. They, however, require combination with traditional methods for verification and ground-truthing. In the case of benthic sampling, the new imaging techniques provide a more precise and spatially correct idea of the state of the seafloor and its fauna. Acoustic methods are already regularly used in the monitoring of important fish stocks and of young-fish (larvae and eggs) in the North Atlantic. Precision and bias of acoustic surveys were discussed and the main problems of acoustic imaging identified, e.g. (a) no reliable species identification, i.e. limitation to biomass and distribution data; (b) avoidance of sonar beams by fish that are noise-sensitive.

In conclusion, workshop participants agreed that monitoring of relevant physical variables and fish stocks are already well covered. The measurement of primary productivity is on a promising track with integrated systems of semi-autonomous in-situ sampling and remote sensing. It was shown that the acoustic measurement of zooplankton biomass is feasible and could become an important method for zooplankton assessment in the future. The workshop did not cover the important role of microbes and their assessment. It was observed, though, that simple oxygen measurement of the sediment can give important insights into the nature of the bacterial community at specific locations and should thus be integrated into ocean measuring devices whenever possible (especially in coastal areas).

It was remarked that some new sensors now used in biological and chemical oceanography were originally developed for medical use because of the much bigger market and economic rewards for health products. Although the technological requirements and the market for operational oceanographic products will hopefully expand in the future, the rewards expected might not always convince commercial companies to invest the necessary time, personnel, and funds into the development of new technology. It might save development costs to regularly scrutinise new medical technology for its potential usefulness in operational oceanography.

Another concern of workshop participants was the wide diversity of sampling methods adopted by different nations and institutes or agencies that leads to non-comparable data. A standardisation of operational methods is desirable for data merging. In addition, further efforts in quality control was deemed necessary. It was also seen that one of the problems of sampling was to balance frequency and accuracy of the measurements, especially regarding certain biological and chemical variables that are difficult and expensive to monitor. Solutions to this problem may lie in (a) the creation of error models for the measurement of such variables measured or (b) responsive sampling, i.e. increasing the frequency and/or accuracy of measuring a specific variable when other data suggest a change in the ecosystem is occurring.

Workshop participants stressed that monitoring must be more closely related to user requirements and that the design of useful products must be given much more attention, i.e. user involvement in the strategy of bio-ecological operational oceanography is crucial. It was also suggested that fish stock assessment should not stop at commercial species but should cover non-commercial species at a greater degree than at present.

4 Long-term Monitoring and Ecosystem Health

4.1 Summaries of presentations

Ecosystem health within the framework of operational oceanography, Or: GOOS, the Health of the Ocean (HOTO) and Living Marine Resources (LMR) Modules

Franciscus Colijn
University of Kiel, Research and Technology Centre Westcoast
Büsum, Germany

In the description of the GOOS Design a discussion is held between balancing the user needs and the scientific and technical feasibility. Two modules have been defined with clear needs , which are relevant for this workshop: Health of the Ocean (HOTO) and Living Marine Resources (LMR). In this contribution the needs will be compared with what is actually possible and which kinds of information are already available or will become available in the near future. Because Ecosystem Health is not a well defined concept current literature on this item will be discussed and related to the needs compiled under both HOTO and LMR.

Discussions about ecosystem health are strongly linked to the human health concept on the one side and on reference norms on the other side. Both aspects will be reviewed briefly and the consequences for measuring parameters evaluated. Based on current knowledge the criteria and parameters so far used in descriptions of ecosystem health will be presented: forerunners in this field are groups around Costanza and Sherman.

Emphasis will be laid on the practical application of measured parameters for the purpose of the HOTO and LMR Modules.

The Continuous Plankton Recorder (CPR) survey and climate change issues

Philip C. Reid
Sir Alister Hardy Foundation for Ocean Science
Plymouth, United Kingdom

The CPR survey which is operated by the Sir Alister Hardy Foundation for Ocean Science (SAHFOS), in Plymouth, UK, is currently in its 68th year of existence. The survey and its products are unique as they comprise the only long-term and ocean basin wide operational survey of plankton in the world. The survey started in the North Sea in 1931 extending out into the Atlantic in 1939. Currently, the core area of the survey reaches from the east coast of the USA to the north west European shelf between approximately 37º and 64ºN. In recent years CPRs were also deployed in the Baltic, Mediterranean, Gulf of Guinea and monthly tows will start in the Pacific in 2000. Voluntary merchant ships on their normal passage are used to tow CPRs; typically 22 routes are towed in the core region each month of the year. On average more than 80000 nautical miles are sampled each year and more than 4000 samples analysed when the phyto- and zooplankton are counted and identified into ~400 taxonomic categories. Since the survey started close to 4 million nautical miles of the oceans have been sampled and approximately 200,000 samples analysed. The survey has achieved its unique position by making few changes to the CPR and by strict adherence to sampling and analytical protocols with the maintenance of a skilled team of plankton analysts. The survey is supported by an international consortium of funders comprising in 1999 eight countries, the European Union, UNIDO and the IOC. SAHFOS is also involved in the design and testing of new technology as eventual replacements for the CPR.

There has been an increasing recognition of the uniqueness of the CPR time series as a 'barometer' against which to assess climate change and the effects of pollution on the natural variability of marine populations and as environmental input to fisheries assessments. Evidence from CPR records suggests that the plankton integrates hydrometeorological signals and may be used as a possible index of climate change. Strong links have been demonstrated between the plankton and a major mode of atmospheric variability in the northern hemisphere, the North Atlantic Oscillation. There is evidence that some of the changes observed have also impacted fish stocks through changes in abundance, recruitment and distribution. Comparison between fishery statistics and CPR data for the North Sea suggests that the fishery may at times cause strong top down control on the plankton. Results from the survey are also being used to interpret eutrophication issues and assess planktonic biodiversity and it's spatial and temporal variability. The baseline data available from the survey are also being used to assess the spread of introduced species and occurrence of algal blooms, of relevance to studies on ballast water exchange. The scale of the changes seen over five decades emphasises the importance of maintaining existing and establishing new, long term and wide scale monitoring programmes of the world's oceans under the flag of the LMR module of GOOS.

The diversity of harmful algal blooms: a challenge for operational monitoring

Adriana Zingone
Stazione Zoologica 'Anton Dohrn'
Napoli, Italy

A broad spectrum of events comes under the category of harmful algal blooms (HABs), the common denominator being a negative impact on human activities. Harmful algal blooms involve a wide diversity of organisms, mechanisms of impact and bloom dynamics. Gaps in scientific knowledge and lack of adequate technology constitute a major hindrance to the improvement of observational capabilities and progress in predictive understanding of these phenomena. An effective HAB operational monitoring system should include a long-term, global, observing network for phytoplankton species composition and related physical, chemical and biological variables, coupled with an array of models and statistical tools and sustained by an effective data management system. Expected products encompass different temporal scales of prediction and levels of benefit. Early warning of HAB events allows us to put in action specific contingency plans aimed at minimising damage to human health and economic losses. The next step is to forecast HABs with a lead time in the order of 1-7 days, which would allow for more effective management and mitigation procedures. Finally, it would be necessary to assess the risk for HAB events in the context of long-term variations of climate and anthropogenic impact, to assist managers and decision-makers in planning the use of coastal areas.

Eutrophication assessment based on probabilistic methods; the development of a simulated normal distribution derived for a data base of nitrate values

Michael Karydis
University of the Aegean, Department of Marine Sciences
Mytilini, Greece

Eutrophication assessment is a complicated endeavour due to the number of interrelated parameters that have to be taken into account and the fact that there is overlapping between the frequency distributions of the concentrations values of the oligotrophic, mesotrophic and eutrophic water bodies. In addition, deviation from normality either results into data transformation, distorting the original information of the data, or eliminates considerably the number of statistical techniques used for data analysis. In the present work a probabilistic procedure is proposed for assessing eutrophication levels. Nitrate concentrations have been used from two data sets characterising oligotrophy and eutrophication respectively; a simulated normal distribution has been developed without data transformation or applying any drastic data manipulations. This procedure is described in a stepwise manner and as a method can be used to define eutrophication scales, assign critical values and test any nitrate concentration data for the evaluation of the trophic conditions of coastal areas.

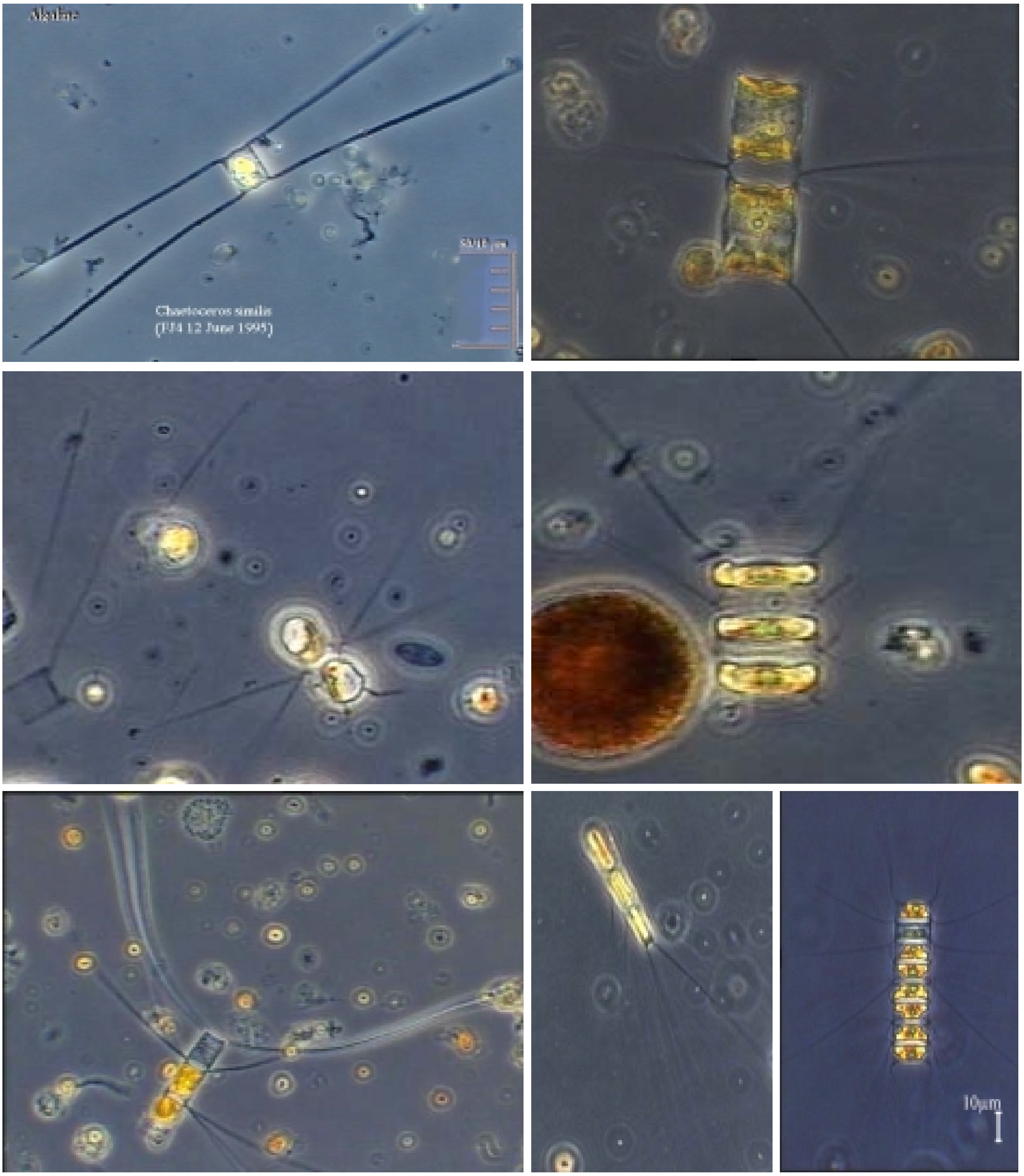

Figure 9. Algae of the genus Chaetocera *that can form harmful algal blooms. Photos from Alg@line, Finland (http://meri.fimr.fi/Algaline/eng/EnAlgaline.nsf?OpenDatabase)*

Pollution indicators

Remi W.P.M. Laane
National Institute of Coastal and Marine Management/RIKZ
The Hague, Netherlands

The marine environment is a sink for natural and man-made compounds. From the 1950's on concentrations gradually increased to levels where negative effects on organisms were detected. This sets off different political actions. No harmful effect of compounds on organisms and ecosystems is the international objective to protect the marine environment. A zero-emission of compounds in 2020 is one of the measures to reach this objective.

However, more than 150.000 compounds are produced by man whereas in national and international monitoring programs and on black and grey lists less than 100 compounds are included. The scientific challenge to develop pollution indicators which will be used in political actions will be discussed within a historical context:

- from concentrations to quality objectives
- from concentration to effects
- the role of bioassays and rapid screening assays
- toxicity identification evaluation methods

Anthropogenic and climatic influences on ecosystems in the Mediterranean Sea

Diana Ruiz-Pino and J.P. Bethoux
University Paris
Paris, France

Since the 50's functioning of the Mediterranean Sea has been disturbed by climate and environmental changes. At present, in Mediterranean deep waters there are several proofs of changes in hydrology (temperature and salinity increase in the western basin), circulation (a new and stronger deep water formation in the Aegean Sea) and nutrient budgets (nitrate and phosphate increase in the western basin). Some of these perturbations are linked to the global climatic change and some others are linked to the regional anthropogenic inputs.

These perturbations are creating several Mediterranean ecosystem changes. Examples of ecosystem changes were found in the Eastern Basin where more than 350 species have immigrated from the Red Sea. This event was linked to the increase of Red Sea inflow (after the deepening and widening of the Suez Canal and the vanishing of salinity effect along the Bitter Lakes) and the disappearance of Nile low salinity water along the Egyptian coast consecutive to the High Dam closing in 1964. In the Western Basin, barracudas, groupers and some other tropical thermophilic species are now encountered along the northern coasts.

The global Mediterranean ecosystem has been modified by the direct effect of human activities. Simultaneously, the effect of phosphate and nitrate inputs increase (by a factor of three since the early sixties) and dams on rivers for human freshwater use result in a concomitant increase of phosphate and nitrate concentration in the western deep water and a more or less constant silicon concentration. As a result of these two human effects we observed a peculiar nutrient P : Si : N ratios in both Western (1 : 21 : 22) and Eastern (1 : 32 : 24) basins compared to the world ocean (1 : 14 : 15). Examination of nutrient budget and ratios (P : Si : N) at a basin scale, allow us to consider the Mediterranean as a miniature ocean to explain ecosystem functioning and forecast evolution of industrial fishery across plankton species changes.

The relatively less anthropogenic disturbed Eastern ecosystem seems to be dominated by mat-forming diatoms having high Si/N molar ratio. These organisms, as during the well known sapropel past events, play a major role in the modern Mediterranean in both nitrogen fixation (by harbouring diazotrophic bacterial symbionts) and in the biological production. In the more disturbed Western Basin the anomalous nutrient molar ratio suggests that the disturbed ecosystem could be evolving toward a flagellates dominated system. The diatom ecosystem provides the basis for a classical food chain which produces fishery of anchovies and sardines (about 40% of the Mediterranean marine resources). In contrast, flagellate ecosystems provide the basis for a population of salps and medusas without an edible end member.

Water Management and Ecosystem health

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The EuroGOOS/ICES Workshop on bio-ecological observations is committed to the challenging task of examining future steps in bio-ecological operational oceanography. It will thus contribute to harmonise efforts in assessing and developing present and future international policies for the Marine Environment and it will define the specific role of EuroGOOS in this context.

The identification of possible actions cover a broad field of topics like eutrophication, hazardous substances, oil pollution, biodiversity, climate change, alien species and Integrated Coastal Zone Management. The North Sea Quality Status Report 2000 (in preparation) emphasises human impact on the marine environment, specifically fisheries, organic micropollutants, and nutrients.

This presentation views the definition of Ecosystem Health in the context of achieving certain goals regarding biodiversity, the European Water Framework Directive, ecological objectives and sustainable fisheries. The concept described is at present implemented by interdisciplinary committees (composed of policy advisors and scientific experts) that identify indicators and additional parameters needed for in-depth integrated analysis and modelling. In addition, related detailed bio-ecological observations will be described and the Dutch approach adopted in the GONZ project will be presented and discussed.

The further development of marine habitat classification will improve combination of advanced measurement techniques for seabed habitats, seabed dynamics and analysis of its functional role. Analysis of Pressure-State-Impact relations should consider trend and effect monitoring. A more integrated approach is needed for the development of indicators that bring together human pressure and state of the environment. This will be illustrated using examples from the fisheries sector where such an approach is being developed. EuroGOOS is encouraged to investigate similar approaches for the shipping/transport, fisheries, and other sectors.

Extraction of Information from Data Sets

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As we enter the true digital information era, one of the greatest challenges facing organisations and individuals is how to turn their rapidly expanding data stores into accessible, and actionable knowledge. Means for data collection and distribution have never been so advanced as they are today. While advances in data storage and retrieval continue at a breakneck pace, the same cannot be asserted about advances in information and knowledge extraction from large data sets. Without such developments, however, we risk missing most of what the data have to offer. Only a very small percentage of the captured data is ever converted to actionable knowledge. The traditional approach of a human analyst, intimately familiar with a data set, serving as a conduit between raw data and synthesised knowledge by producing useful analyses and reports, is breaking down. What is to be done with all these data? Ignoring whatever we cannot analyse would be wasteful and unwise. This is particularly pronounced in scientific endeavours, where data represent carefully collected observations about particular phenomena that are under study.

Knowledge Discovery in Databases (KDD) is concerned with extracting useful information from data stores. Data mining (DM) is then a step (automated or human-assisted) in this larger KDD process. The broad KDD process includes: retrieving the data from a large data warehouse (or some other source); selecting the appropriate subset with which to work; deciding on the appropriate sampling strategy; selection of target data; dimensionality reduction; leaning; data mining, model selection (or combination), evaluation and interpretation, and finally the consolidation and the putting to practical use of the extracted "knowledge". The data-mining step then fits models to, or extracts patterns from, the pre-processed data. However, mining the data alone is not the entire story. At least not in scientific domains. Scientific theories encourage the acquisition of new data and these data in turn lead to the generation of new theories.

Traditionally, the emphasis is on a theory, which demands that appropriate data be obtained through observation or experiment. In such an approach, the discovery process is what we may refer to as theory-driven. Especially when a theory is expressed in mathematical form, theory-driven discovery may make extensive use of strong methods associated with mathematics or with the subject matter of the theory itself. The converse view takes a body of data as its starting point and searches for a set of generalisations, or a theory, to describe the data parsimoniously or even to explain it. Usually such a theory takes the form of a precise mathematical statement of the relations existing among the data. This is the data-driven discovery process.

Most of the applications of data mining technology are currently in the financial sector. There is a very strong economic incentive to apply state-of-the-art technology for commercial benefits. Additionally, this domain is, relatively speaking, theory-poor, and the generation of new 'black-box' tools based solely on observations is accepted with little scepticism. In scientific applications, the situation is quite different. Clearly, there is an enormous amount of knowledge and understanding of physical processes that should not just be thrown away. We strongly believe that the most appropriate way forward is to combine the best of the two approaches: theory-driven, understanding-rich with data-driven discovery process. This presentation describes a number of data mining technologies as well as their applications in ecological modelling.

4.2 Session synthesis

This session dealt with approaches and problems in assessing changes in the ecosystem and distinguishing those that are climate-induced from anthropogenic ones. Presentations and discussions focused on definition and possible indicators of "ecosystem health" and on the use of long-term database for climate change assessment.

The term "ecosystem health" is often used in the context of human impact on natural systems, "unhealthy" systems being those that are not in a natural state due to anthropogenic perturbations. One problem with this definition is that in most cases we only have little understanding of the attributes indicating a natural, unperturbed system. Comparative approaches, based on the measurement of several state parameters of any ecosystem, have often served in the past to classify local systems as "natural" or "perturbed". However, indicator parameters for "ecosystem health", ranging from biochemical and cellular markers to reduced biodiversity and habitat loss, usually do not allow an easy conclusion as to whether a system is "healthy" or not - an expert opinion is still necessary and different experts might disagree. The GOOS module HOTO has defined marine ecosystem health for operational purposes as "*a reflection of the condition of the marine environment from the perspective of adverse effects caused by anthropogenic activities, in particular habitat destruction, changed sedimentation rates and the mobilisation of contaminants. Such condition refers to the contemporary state of the ocean, prevailing trends and the prognosis for improvement or deterioration in its quality*". A different definition developed by Costanza et al. (1992) was proposed to the workshop: "*An ecological system is healthy and free from 'distress syndrome' if it is stable and sustainable - that is, if it is active and maintains its organisation and autonomy over time and is resilient to stress*". The authors detail 3 main components of their concept: (a) **vigor** which is related to function, productivity, throughput and can be assessed through GPP, NPP, GEP, GNP, Metabolism; (b) **organisation** which relates to structure and biodiversity and can be assessed through diversity indices, average mutual information, predictability of the system; and (c) **resilience** which can be assessed through scope for growth, population recovery time, and disturbance absorption capacity. Both organisation and resilience are difficult to measure. It was remarked that maybe a definition of "illness" could be more useful.

It has long been recognised that high biodiversity and resilience are not necessary characteristics of natural ecosystems. The debate of whether we have a responsibility to preserve natural conditions even if they appear to be unstable is still ongoing, especially if we have the means of artificially altering such environments to achieve greater stability (and higher economic benefit). As an example in this context the technically possible artificial increase of Baltic water exchange with the North Sea was mentioned. This discussion cannot be solved by scientists but must be carried out on a socio-political level. However, it was acknowledged that a better communication between scientists and politicians would be very helpful in this context.

Toxic algal blooms were discussed at some length. A mostly naturally occurring coastal phenomenon, blooms can also be triggered by human activities (e.g. introduction of exotic species, eutrophication). Early detection of these

blooms could give coastal resource users more time to take protective measures. Among those benefiting from such a biological operational product are health agencies, aquaculture business, tourist industry, shipping, environment agencies etc. A prerequisite for the forecast of harmful algal blooms appears to be the long-term observation of phytoplankton species composition in conjunction with physical and chemical ocean variables. At this point, workshop participants voiced concern about the continuing disappearance of taxonomic expertise that is crucial in an ecosystem approach of resource management.

A major anthropogenic condition in many coastal areas is eutrophication that can be assessed by regular measurements of nitrate (it should be noted, however, that an agreement on the best way of assessing eutrophication has not been found yet in spite of intensive efforts, e.g. by OSPAR, to develop criteria to assess eutro-phication). Often, eutrophication of coastal areas has had devastating effects on local ecosystems (although schemes have been developed by some scientists to enhance biological production, e.g. in the North Sea, by a controlled release of nutrients). High social and political awareness of the detrimental consequence of eutrophication have long led to preventive measures, e.g. sewage treatment, in many European countries. However, operational monitoring of nutrients is necessary in estuaries and could represent an important GOOS product, especially in view of the earlier stated difficulties encountered by EEA trying to obtain reliable data from all areas.

Pollution was briefly discussed, with the background information that, in spite of many efforts to control the release of chemicals into natural waters, aquatic organisms appear to be increasingly affected in many coastal areas. The enormous number of more than 150,000 different chemicals produced by humans, the impact of which have mostly not yet been determined, represents a serious obstacle to measures against pollution. In some cases, concentrations of anthropogenic substances, e.g. copper, have recently declined in sediments off North Sea coasts. However, it was once more pointed out that the concentration of a chemical compound is meaningless without knowing what effect is has on the ecosystem - hence the importance of impact indicators.

In this context, the development and improvement of bioassays and rapid screening assays play an increasingly important role: they measure an observable toxic response to the interaction of toxicants and other constituents within a water sample, inherently including biological availability and interactions.

Changes in natural systems are not only due to anthropogenic impact but occur naturally as a result of climatic and other physical events. Thus, detection of change alone does not suffice to characterise a system as deteriorating or threatened due to human interference. Long-term observations can help establish naturally occurring temporal variability over decades. A good example of the great value of regular sampling over long periods of time is the Continuous Plankton Recorder (CPR) survey of the North Sea and Atlantic. It exists since 68 years and is now being used to assess the effects of climate change (especially with regard to the North Atlantic Oscillation) and of pollution (especially eutrophication) on plankton abundance, distribution and species composition.

Anthropogenic impact on phytoplankton was discussed for the western Mediterranean basin. Here, increasing levels of phosphate and nitrate are predicted to cause a shift from the now dominating diatoms to flagellates, which may ultimately result in a decline of local fisheries:

in contrast to diatoms, flagellates cannot serve as food basis for the economically important anchovies and sardines. Another important anthropogenic change in the Mediterranean was the sharp decline of the freshwater inflow from the Nile after building the High Dam in 1964. Together with the expansion of the Suez Channel, this led to an increase in salinity levels in the eastern basin and caused high immigrations of species from the Red Sea. Climate change, on the other hand, is judged responsible for a rise in temperature in the western basin with the resulting immigration of tropical species.

Workshop participants emphasised the importance of long-term data collections, as the CPR and the ones held by ICES, e.g. historical databases on fish stocks, and soon on benthos and on plankton. The lack of such collections for the Mediterranean and the Black Sea was noted and a speedy mending of this situation strongly recommended. As ICES does not cover these seas, MedGOOS could play a vital role in improving data collections here. Participants also recognised the necessity not only to continue those long-term databases already existing but also to bring together and make better use of the huge quantities of information hidden in numerous institutes and agencies. They suggested that biological data should be systematically collected by national and international agencies rather than by research institutes where they tend to remain scattered and difficult to access. EuroGOOS was encouraged to strengthen its efforts in this area. In this context GODAR (Global Oceanographic Data Archaeology and Rescue) programme should be mentioned in recognition of their excellent work to compile scattered oceanographic data, including biological and chemical.

A closely related topic of discussion was data storage. In spite of growing computer capabilities and electronic storage facilities, the storage of data on electronic media requires regular update due to the deterioration of the discs and tapes and software obsolescence and is thus costly. Data networks will become increasingly important to allow easy access to local data. Thus, projects and programmes set-up to initiate and facilitate this process must be greatly encouraged. Another topic of interest was how to make better use of increasing amounts of stored information. The concept of “Knowledge Discovery in Databases” (KDD) takes a body of data as a starting point and searches for a set of generalisations, or a theory, to describe the data or explain them in contrast to the traditional formulation of a hypothesis preceding the sampling of data.

An integrated monitoring approach was also recommended for the assessment of marine habitats (as for the assessment of primary production, see above). For the North Sea (North Sea Quality Status Report 2000, in preparation), authorities have recently emphasised anthropogenic problems besides climate change (especially fisheries, organic micro-pollutants, and nutrient increase), thus indicating that more funds for monitoring and prevention of anthropogenic disturbance have to be made available in the future. However, only close co-operation between politicians and scientists will assure that the necessary fast progress can be achieved.

Public opinion generally supports efforts to enhance marine protection, sustainable exploitation and safe use of the marine ecosystem. Nevertheless, specific measures, especially costly long-term monitoring of bio-ecological variables, certainly require improved education of the public which could be achieved through wider media coverage and through the Internet.

Furthermore, participants agreed that discussion of ecosystem “health” or “sickness” must be held separately for different ecosystems and that for each individual system a distinct definition of its desirable status should be derived. However, aquatic substances and organisms spread and can thus impact areas far away from their origin. It was therefore recognised that measurements and observation of many anthropogenic and natural substances should not be restricted to local “spots”, as is often done in practise. Larger scale co-ordinated observations are necessary to reveal processes and derive accurate interpretations and products (especially forecasts), e.g. a hemispheric or ocean scale for physical variables and a coastal scale for anthropogenic variables.

5 Ecosystem Modelling

5.1 Summaries of presentations

Critical analysis of the status quo in marine ecosystem modelling

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Direction and attitude of marine ecosystem modelling has changed during the last years. The change can be observed in three directions:

- tasks and aims,
- methods and techniques,
- financing policies.

There seems to be a trend away from modelling whole ecosystems with the aim of an integrated system understanding (e.g. large food-web models like ERSEM). Many ecosystem models are presently focused on particular scenario calculations, often related to coastal zone management. The reduction of modelling to limited aspects together with a stronger data orientation is a sign of increasing practical relevance of ecosystem models which reflects the current needs of research funding policies. Through other modern mathematical methods, e.g. neural networks, the two large aims, understanding and prediction, become even more decoupled.

In 1990 the most important task was to couple complex physical models with complex biological models. This task is more or less solved and has led to an increase in understanding the interaction between physical and biological processes.

In future, the trend to ecosystem models with practical use as support for decision makers will continue. New data bases and new measurement tools will increase this trend. Nevertheless, important open questions remain which can best be answered with a new generation of ecosystem models. These models will differ from the ERSEM type of models in an important aspect: they will explicitly contain general principles of ecosystem behaviour. Such principles aim at model reduction and can be derived from an analysis of the present models.

Physical and numerical aspects of integrated ecological 3-D modelling

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An overview is given of the different physical processes and numerical aspects which need to be considered when coupling physics with biology in three-dimensional models. The discussion is illustrated through a recent example of a yearly simulation for the North Sea carried out by the three-dimensional COHERENS model.

Vertical exchange processes are parameterised via a turbulence closure scheme. Accurate schemes are essential to represent mixing processes in stratified thermocline and halocline layers (where high chlorophyll concentrations are often observed) or to simulate the resuspension of inorganic and organic particulate matter in shallow areas with a strong tidal regime. Direct measurements of turbulence parameters (profiles of dissipation rates, bottom stress, etc.) have recently been collected in the North Sea.

Advective processes are of importance in areas of strong concentration gradients and at open sea and river boundaries. Most recent models use an explicit time-integration which imposes a numerical constraint on the maximum allowed time step and hence also on the number of biological state variables for the biology to limit the amount of CPU time in long term simulations. Implicit integration of the biological transport equations removes the stability constraint and is recommended in future modelling since the biological time scales are usually a few magnitudes larger than the physical ones.

Other aspects are the sensitivity of model results to the input of open boundary data, to the model's horizontal and vertical resolution and to the heat exchange at the air/sea interface.

Ecological modelling of the Adriatic Sea: Coupling physics with biology

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An ecosystem model has been developed by online coupling of the Princeton Ocean Model (POM) with the European Regional Seas Ecosystem Model (ERSEM).

POM is a finite difference, free surface, sigma co-ordinate, three-dimensional, ocean general circulation model, making use of an embedded turbulence closure sub-model. ERSEM is a generic, biomass based ecosystem model describing the biogeochemical processes occurring in the water column and in the sediment (as well as their interactions) in terms of the cycling of carbon, phosphorus, nitrogen and silicon within the marine ecosystem.

The POM/ERSEM system has been implemented in the Adriatic Sea in order to study its ecosystem dynamics. Simulations have been carried out by developing different and increasingly complex (from 1D to high resolution 3D) model set-ups. One dimensional simulations were performed for the northern Adriatic Basin; the model was implemented at the same locations of the PRISMA-I Project sampling stations S1 and S3, the former characterised by strong river-runoff (Po river) conditions while the latter has relatively open sea characteristics.

The model results highlighted the yearly phytoplankton cycle and its relations with the external nutrient inputs, the seasonal mixing processes and light distribution in the water column. Moreover, the comparison between the two stations allowed for a definition of the role of the bacteria in controlling the carbon fluxes in the trophic web under different trophic conditions.

As an intermediate step toward the 3D high resolution application, a coarse resolution 3D implementation with idealised basin geometry was developed. The model results relative to phytoplankton distribution are in good agreement with CZCS climatological satellite pictures of pigment distribution in the basin.

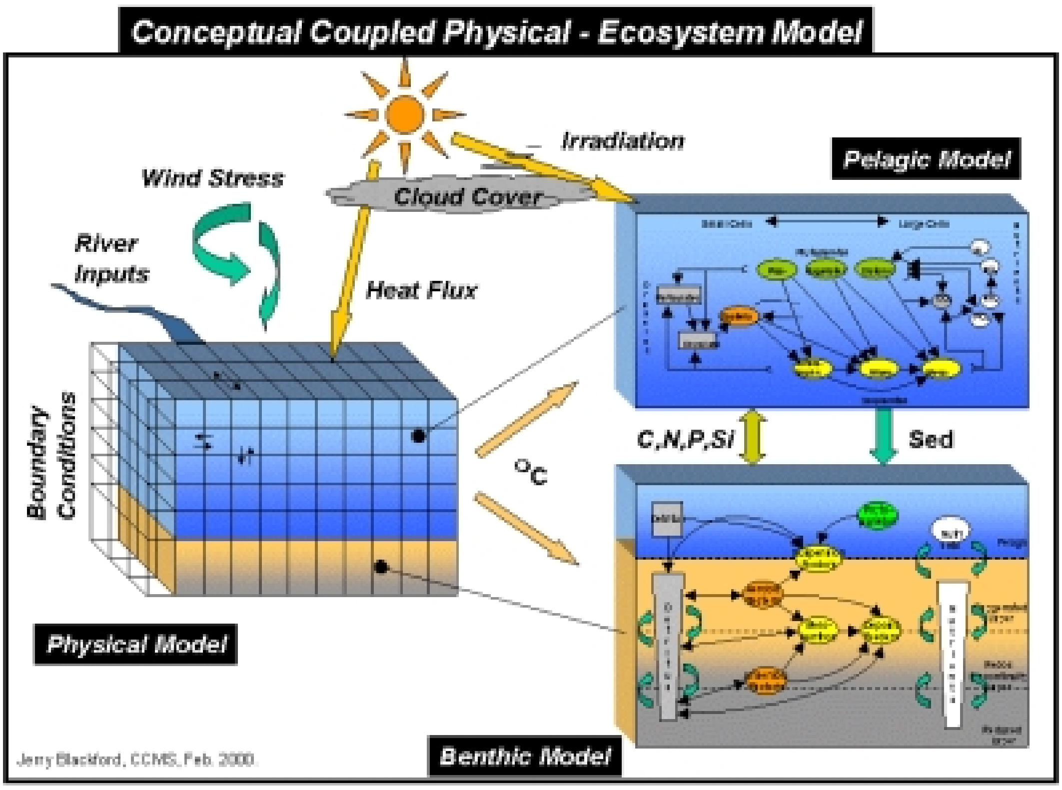

Figure 10. Schematic diagram of the European Regional Seas Ecosystem Model (ERSEM)

Despite the coarse resolution and the idealised geometry, the model is able to reproduce and maintain the north to south trophic gradient characteristic of the Adriatic basin.

The seasonal phytoplankton cycle in the northern, central and southern Adriatic sea appears to be strongly influenced by both the physical processes and the external, riverborne, nutrient input.

Finally, experiments with a high resolution implementation show a more detailed temporal and spatial variability of the biogeochemical properties distribution, further emphasising the importance of the circulation features in determining such variability. The dense water formation process in the northern Adriatic Sea is reproduced by the model and the resulting water mass shows distinct properties also from a biogeochemical point of view.

Benthic-Pelagic Coupling

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This contribution deals with the question to which detail benthic processes have to be modelled in large coupled hydrodynamic-ecological models. This question can only be solved for an area if the impact of the benthic system can be estimated on the functioning of the coupled system of transport processes and pelagic processes. The most important role of the benthic system is the mineralization of organic matter and regeneration of nutrients. This mineralization is mostly performed in the upper 30 cm of the sediment by the biota in the benthic system: macrobenthos (filter feeders and deposit feeders), meiobenthos and bacteria. The benthic system is fuelled by the sedimentation of particulate detritus from the pelagic system. The magnitude of the mineralization together with the bioirrigation and bioturbation, both caused by biological activity in the benthos, determines the vertical gradients and the oxygenation state of the sediment. This oxygenation state determines the thickness of the oxidized layer depth, the proportion of the detritus that is mineralized under anoxic circumstances and the denitrification in the system, a definitive loss process of the nutrient nitrogen.

For a benthic sub-model the most important aim is a proper estimation of the nutrient fluxes at the sediment-water interface. We tried to build a sub-model that is generic, fits into an ecosystem model and is thus efficient with respect to computer time. This led to a model structure in which only functional layers (oxic, anoxic) are distinguished but that includes all the important oxic and anoxic mineralisation and diagenetic processes. The first example will show that the benthic system in the North Sea is responsible for considerable mineralisation of the primary production and that the regenerated nutrients in the sediment are important for the pelagic system. The second example will show that even in a permanent stratified system the benthic system plays its role with respect to the oxygen concentration in the whole water column and, subsequently, that it controls the denitrification.

In the last part, validation of the benthic sub-model will be discussed. The large local variation of the benthic system, the limited number of field data due to work-intensive measurement methods and the lack of flux data in general, especially for the carbon cycle of the system, makes it difficult to perform a proper validation of the model. Particularly the short-term variations in the benthic system, mainly caused by changes in the sedimentation from the pelagic, can not be validated until now. However, simplifying the model in order to fit the limited number of available information would lead to a model that needs extensive recalibration for each specific area.

The influence of high frequency surface forcing on productivity in the euphotic layer

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This contribution deals with the question to which extent short-term variability in the abiotic environment determines seasonal as well as longer-term (interannual) variability of the ecosystem dynamics. We hypothesise that long-term variability of ecosystem behaviour directly evolves from small-scale/high-frequency variability. In order to make this distinction, we have to go as far as possible in resolving the smaller scale processes, and to demonstrate how the system-level behaviour is affected by the time-resolution of forcing functions/boundary conditions. Results from a model study of two different sub-basins of the Baltic proper will be shown, the Bornholm Basin and the Eastern Gotland Basin, and the simulation results will be compared with independent observations from the Baltic Environmental Database. A one-dimensional physical-ecological coupled model has been used to hindcast the behaviour of the major physical and hydro-chemical properties of the water column over the period 1979-90. This model shows sufficient potential skill to adapt to long-term changing ecosystem properties and to respond to local peculiarities of the ecosystem itself. Due to the implicit limitations of a one-dimensional model and to the lack of long time series of biologically relevant properties in the regions of interest, we concentrated our investigation on variables only indirectly related to biological processes, such as nutrient concentrations and oxygen saturation.

The hypothesis that long-term ecosystem behaviour in the Baltic is determined by small-scale variability induced by local forcing functions has been tested by applying different boundary conditions to the Bornholm Basin model. The frequency of meteorological forcing functions has been reduced and then applied as new boundary conditions to the standard model. Momentum and heat fluxes at sea surface have been calculated from three-hourly measurements and then averaged to daily and monthly values, which have been linearly interpolated to the model time step. Comparison between the obtained model results shows that reduced forcing frequency changes the time evolution of biological fluxes, generally reducing them to lower levels. This can be shown by comparing the annual carbon gross assimilation calculated by models with different set-ups. The annual gross carbon production predicted by the model using the 3-hourly boundary conditions is higher than the ones with the lower frequency, and also interannual variability is enhanced.

This indicates that variability in the physical environment at proper time scales increases the biological activities in the model and that estimate of the primary production is a direct consequence of description of the dynamical environment. We thus recommend that future operational model applications include the highest possible resolution of the surface forcing fields and, as a next step, we consider necessary the collection of biological observations at the same frequency to verify the model's capabilities and to establish whether in situ variability in the biogeochemical processes is indeed as high as our model results suggest.

Coupling automated data acquisition with modelling: An ongoing French case study: the Bay of Seine (Channel)

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Between 1997 and 1999, IFREMER deployed a set of four MAREL data buoys in a coastal eutrophicated area along the French Channel coast, the eastern Bay of Seine. First, a “wharf-station” was installed on the shore of the Seine estuary (in the turbidity maximum area) then three “open sea-stations” were moored in the coastal area receiving the dilution plume of the river Seine where high phytoplankton biomasses are known to occur during spring and summer. Hourly data series of temperature, salinity, turbidity, dissolved oxygen are available for surface level in the “estuary station” and at three depth levels in “open sea-stations”, where fluorimetric estimates of chlorophyll are also sampled every six hours.

This system, built for a continuous monitoring of water quality in a marine eutrophicated area, can also provide decisive calibration/validation data to a 3D ecological model of the whole estuary and bay of Seine and help to improve process formulation in the model. In return, the model delivers some spatial interpolation and extrapolation to the four automated data acquisition systems.

Some examples will be given of how the buoy data can be used to evaluate model adequacy showing either good validation for some variables (estuarine turbidity) or pointing out some deficiencies in process formulation for others (chlorophyll, oxygen).

5.2 Session synthesis

Ecosystem modelling has made great advances in the last decades during which it progressed from “naïve” mechanistic and process oriented modelling to data-driven approaches and individual-based models. Large projects that tried to model whole ecosystems have proven to be of limited use (also due to a lack of data) and the trend today appears to go towards more modest and perhaps more successful models of limited aspects of ecosystems (e.g. single ecosystems components like commercial fish production and processes, special events like toxic algal blooms, etc). During the last decade, coupling of complex physical and biological models has been largely accomplished, establishing, for example, the prominent role of turbulence for phytoplankton production and distribution. Future ecosystem models will tend to focus on specific applications, i.e. they will be designed to solve management problems and economic questions, they will be data oriented and have a user-friendly interface. In addition, the understanding of aggregate (“holistic”) properties of ecosystem could lead to a new generation of ecosystem models that are closer to reality than those available at present. Finally, the development of “integrative” models could combine natural processes with socio-economic ones and thus predict the consequences of technological innovations and other anthropogenic impacts on an all-encompassing level.

A number of ecosystem models are already operating in Europe, among them COHERENS (COupled Hydrodynamical Ecological model for REgioNal Shelf seas), and the POM (Princeton Ocean Model) / ERSEM (European Regional Seas Ecosystem Model) system. COHERENS is used for the prediction and monitoring of waste material in shelf and coastal seas and is freely available on the Internet (through the MUMM homepage). It is coupled to biological, re-suspension and contaminant models, and resolves meso-scale to seasonal scale processes. The combination of POM and ERSEM was successful in simulating ecosystem dynamics in the Mediterranean and could reproduce seasonal phytoplankton distribution in the whole basin. POM is a three-dimensional ocean circulation model whereas ERSEM is a generic biomass-based ecosystem model that describes the biogeochemical processes occurring in the water column and in the sediment (Cycles of C, P, N, and Si).

Benthic-pelagic coupling as part of ecosystem modelling was discussed at some depth. The sub-model presented to the workshop aimed at correctly estimating nutrient fluxes at the sediment-water interface. Among other things, the model shows the great extent to which the benthic system in the North Sea is involved in primary productivity by mineralisation of organic matter and subsequent reintroduction of nutrients into the aquatic system. Validation of the described model, however, has proven to be difficult due to a lack of field data, a typical problem when it comes to biochemical variables requiring difficult and costly measurements. Simplification of the model is not a viable solution as it would then need laborious re-calibration for each specific area. Therefore, a need for additional data, especially flux data for the aquatic carbon cycle, to help validate ecosystem models must be noted.

Spatio-temporal scales of observations can generate quite different results as was shown in a simulation exercise for the Baltic Sea. Low-frequency measurements of surface forcing fields generated a smaller estimate of gross carbon production than high-frequency measurements. This result has yet to be verified by field data of similar resolution (3 hourly measurements) but suggests that bio-ecological variables might have to be sampled at a much higher spatio-temporal resolution than generally done at present. In this context, the four experimental buoys in the Channel area of France are of interest as they are already delivering high-resolution temporal measurements (hourly) of bio-ecological variables at different depth levels (temperature, salinity, turbidity, oxygen, and chlorophyll). These data are not only used for the monitoring of water quality but also help calibrating and validating a 3-D ecological model of the whole estuary. This model can at present describe turbidity patterns with good results but is not yet apt to satisfactorily explain temporal chlorophyll and oxygen fluctuations (not doing too bad with regard to spatial distribution, though). The French data could (again) show that many bio-ecological processes are linked to the tides and that wind effects can reach down to the bottom of the water column influencing sediment processes.

The ability to address long-term ecosystem evolution as a response to climate change is presently being developed by global or basin-wide models (for example by GODAE, CLIVAR, MERCATOR and others). However, the short-term nature of many local bio-ecological processes complicates their projections into the far future. Workshop participants therefore recommended to carefully assess user requirements as to the type of bio-ecological products and to forecast periods in order to avoid unnecessary development costs. In addition, the demands of operational models should be used to determine monitoring strategy, i.e. type of variables and spatio-temporal resolution of measurements. High-resolution variables are urgently needed to validate and calibrate models but a lower-resolution monitoring might be found sufficient once this process is finished. Finally, better co-operation in sharing data and validation of models among modellers from different institutions and regions was viewed necessary in order to accelerate the development of bio-ecological operational models that could become shared components of a European Ocean Observing System.

6 Recommendations

These recommendations were formulated in sub-groups after the workshop sessions and discussed during a plenary session. They are supplemented by suggestions voiced during workshop sessions. Please note that the recommendations do not have the same titles as the workshop sessions, because some more detailed topics emerged.

1. User involvement

User involvement in the sampling strategy is of great value and must be given high priority. Users of bio-ecological operational oceanographic products identified by workshop participants are: the scientific community, environmental and public health agencies, coastal managers and decision makers, the public in general, fisheries and aquaculture business, shipping and tourist industry, and the navy. The following recommendations to improve the interaction with users were made:

a. EuroGOOS should initiate an additional user requirement survey directed at customers of biological operational products and assess their specific data needs and possible contributions to sampling and monitoring.

b. An improvement of interaction between marine scientists/operational agencies and politicians/public can be achieved through the following steps:
   - Elaboration of a summary report that includes all marine bio-ecological variables and indicators suggested for operational use by groups of scientists should be made available for discussion with end users by GOOS, EuroGOOS and ICES
   - Education of users of bio-ecological products as well as politicians and the public in general is important to help with strategic funding and the creation of useful and popular products. Scientists could play a crucial role in this process and help identify present and future needs of different applications in view of new technologies and products
   - Public awareness of bio-ecological marine topics could be enhanced by an improved presence in the Internet of agencies and programmes
   - EuroGOOS, ICES, and international conventions (OSPAR, HELCOM) should influence national governments and agencies towards greater acceptance of co-ordinated international monitoring. This includes preparation of material (possibly from projects such as Ferrybox and SeaFlux) showing the value of an approach that uses harmonised measurements throughout a region. This task is so important and labour intensive that an EU project initiated and/or supported by EuroGOOS, ICES, and EEA appears to be a good way to solve it
   - EU directives could help turn national agencies into users of EuroGOOS products to improve environmental protection, human health, and resource management.

c. Contribution of stakeholders to sampling and monitoring could reduce costs and improve acceptance of operational oceanography. Many industries are collecting their own data due to a lack of oceanographic products and could greatly benefit from a co-ordinated system. Possible candidates mentioned are the shipping industry (that is already contributing in ferrybox projects), fish and mussel farmers, port authorities, offshore industry, etc.

2. Biological Monitoring Technology

The main developments necessary to make biological monitoring technology fit for operational sampling, were viewed as follows:

a. Bio-sensors must be improved and new types developed:
   - New medical technology should be regularly scrutinised for its potential usefulness in operational oceanography
   - The development of acoustic assessment of zooplankton should be completed
   - Development of visual sensors for ichthyoplankton (see below)
   - Development of autonomous benthic sampling systems including optical imaging

b. Standardisation of the most common methods is desirable for data merging and quality control

c. P-I time series are needed for the calibration of remote sensing images in order to use them for primary productivity assessment

3. Fish Stock Assessment

Ecosystem considerations in fish stock assessment will be more important in the future and will require a new type of data in fish stock assessment. In this context, participants recommended:

a. Multiply scientific efforts to identify ecological variables and models that can be shown to have a significant effect on fish distribution and abundance. Re-evaluate the significance of primary productivity for different fish species in view of improved PP assessment methods. Also, consider the use of bottom variables instead of surface variables. Extreme physical or chemical conditions (e.g. high and low temperature, oxygen deficiency, etc) that can cause mass mortality or illness, should be taken into account.

b. Once these ecosystem variables have been established (including ichthyoplankton, see next recommendation), EuroGOOS and ICES should co-operate to determine a monitoring strategy, especially regarding spatio-temporal resolution and precision. As extreme events can have a distinct effect on biological organisms even at very short periods of duration, high temporal resolution of certain measurements might be necessary.

c. Spawning areas of commercial and non-commercial fish species should be regularly monitored by fisheries agencies. This, however, requires an improvement of our understanding of spawning patterns and environmental requirements in different fish species as well as the development of autonomous technology. It was therefore recommended to:
   - Initiate a comprehensive 3-year ichthyoplankton survey (EU project to be initiated and supported by EuroGOOS and ICES) in European Seas. Perform spot checks every decade (ICES)
   - Develop optical instrumentation that is already used in ichthyoplankton monitoring to reach an operational state

d. Non-commercial fish species should be given more attention by fisheries agencies than at present

e. Routine tracing of fish routes via radio tags should be given consideration

4. Sampling Strategy

a. It is highly recommended to adopt an integrated sampling strategy that co-ordinates different monitoring types and schemes (e.g. in-situ, remote sensing and cruises) whenever possible. Such an approach requires intercalibration of related data and relies on the standardisation of methods and minimum quality requirements.

b. Operational bio-ecological models should be used as a starting point to determine the type of variables monitored and the spatio-temporal resolution of measurements.

c. The monitoring of many biological and chemical variables is time consuming and costly. Frequency and accuracy of such measurements will have to be carefully balanced against user requirements. To overcome some of these problems, it was suggested that we should:
   - Create error models specifically for such variables
   - Adopt a responsive sampling strategy, i.e. increase the frequency and/or accuracy of measurements when other data suggest a change in the ecosystem that might effect the variable of interest

d. For many variables, the optimum ratio between accuracy and spatio-temporal sampling resolution can be gained by extracting the necessary information from existing databases. More use should be made of this approach

e. Better use should be made of the high-frequency monitoring potential of smart moorings or ferry box programmes in order to improve model (forecast) precision

5. Impact Indicators and Pollution

Impact indicators are crucial for coastal monitoring of pollution and eutrophication but are at present still lacking the required quality. An internationally co-ordinated, optimised, and standardised monitoring of inputs (from rivers, the atmosphere, and adjacent seas) and effects (on organisms and ecosystems) of chemical compounds (natural and xenobiotic) to the marine environment is therefore of great importance. Specifically, workshop participants recommended:

a. A common definition of important biological or ecological indicators is necessary in order to standardise and harmonise assessment in different areas

b. The development of new and improvement of existing indicators should be encouraged

c. For the time being, impact indicators should be supplemented by raw data

d. Progress should be made in revealing local transport patterns of contaminants in the water and the sediment for all European areas (OSPAR, EuroGOOS, ICES, EEA)

e. EuroGOOS and EEA should join forces and co-operate with other organisations (mainly OSPAR, Helsinki and Barcelona Conventions) to determine the types and spatio-temporal distribution of measurements (indicators) that could be integrated in a European Ocean Observing System

6. Long-term Databases

Workshop participants emphasised the necessity of supporting existing efforts of building long-term databases and of harmonising existing monitoring operations. In addition, data must be stored and preserved for future comparison. Finally, methods that can be used to extract the useful information from databases must advance. Specifically, participants recommended:

a. Start long-term bio-ecological databases in hitherto neglected areas, especially Mediterranean and Black Sea areas with the help of MedGOOS

b. Systematic collection of biological data should be performed by national and international agencies and not left to research institutes

c. Facilitate data access by
   - Using networks to improve and combine data sets from existing centres
   - Promoting the integration of modern user interfaces to important international databases that enable easy extraction and input of data.

d. Develop more and new methods of extracting data from large databases. Establish a “Data analysis and data mining” software repository (on the server of the Danish Hydraulic Institute under the responsibility of Vladan Babovic)

e. Ensure that existing archives of biological material held by institutes and museums are appropriately curated and maintained as potential sources for retrospective study in the future as new techniques are developed.

f. Ensure the continuation of the CPR, also in view of hindcasting changes in benthic communities through the variance patterns of meroplankton (Echinoderm larvae)

7. Data Analysis

Data analysis must be improved and extended. Workshop participants thus recommended

a. Establishment of (virtual) centres for data analyses which tasks it would be to assist with:
   - Education and training
   - Taxonomic identification
   - Modelling

b. Establishment of quality criteria for parameters, analytical and statistical methods, processes, and model results. This should be done in co-operation by international programmes and agencies, e.g. ICES, EuroGOOS, EEA etc.

8. Modelling requirements

a. Different transport and ecosystem models should be compared with each other and standardised before using them on an operational basis. They could be tested using data from projects such as Ferrybox and SeaFlux

b. The efforts of EuroGOOS in bringing together European modelling expertise are greatly appreciated and the importance of a continuation and broadening of the co-operation among modellers from different institutions and regions must be emphasised. Development of shared bio-ecological operational models that could become components of a European Ocean Observing System is only possible through the sharing of data and joint validation of models

c. High-frequency data are needed for the validation and calibration of ecosystem models, a few of which have been identified by workshop participants:
   - Flux data for the aquatic carbon cycle
   - Chlorophyll
   - Oxygen
   - Turbidity
   - Nutrients

d. The development of new ecosystem models should be based on identified user requirements, e.g. in consultation with EuroGOOS and using EuroGOOS and GOOS documentation

e. Nesting of models on different scales (mega - micro) is encouraged

f. Benthic processes and benthic-pelagic interaction deserves further efforts in understanding ecosystem dynamics and modelling

9. Products

Workshop participants identified a number of products from bio-ecological monitoring, some of which already result from existing models. Others will have to be developed. Initiation and support of research projects to develop such products is seen as a task of EuroGOOS. In addition, it was felt that **visualisation of data analyses and model results** should be given more importance to ensure wide use and easy access to operational oceanographic products. The following list should be analysed by the EuroGOOS Products Working Group and then transferred to the appropriate EuroGOOS Task Teams.

a. From the monitoring of primary productivity:
   - High quality data sets for scientific research (biodiversity, long-term trends in biological variability and community shifts)
   - Early warning systems for harmful algal blooms (based on transport patterns)
   - Detection of non-indigenous species among phytoplankton communities
   - Risk-assessment of environmental damage

b. From additional biological monitoring except fish:
   - Habitat mapping for different benthic organisms (EEA with EuroGOOS)
   - Zooplankton abundance and composition (EuroGOOS to establish formal links to the ICES Zooplankton WG)

c. From chemical monitoring:
   - Measurement of fluxes and transport tracking of hazardous substances (pollution) and nutrients (eutrophication)
   - Early warning (transport patterns) of oil spills, harmful algal blooms etc to enable rapid response

d. From physical monitoring:
   - High-frequency measurements of many physical variables, e.g. temperature, salinity, turbidity, turbulence, currents, tides, wave height, etc. (already available in many places)
   - Monitoring and forecasting of stratification patterns
   - Systematic quantification of oceanic inflow/outflow to European shelf seas, the Mediterranean and the Baltic Sea (product from existing models)
   - Transport patterns by eastern boundary/shelf edge current (product from existing models?)
   - Timing and intensity of spring stratification (spring bloom) (product from existing models)
   - Measurement of the area/volume of Norwegian deep water areas (research necessary)
   - Size of physically defined feeding areas for many fish species, e.g. salmon, herring, cod (temperature/salinity important in this context, research necessary)
   - Parameterisation of deep water formation in the North Atlantic and Mediterranean Sea (product from existing models)
   - Measurement of sediment re-suspension (long-term research)
   - Sediment budgets at regional sea scale (long-term research)

e. From long-term monitoring (climate change):
   - Evaluation of physical oceanographic and associated economic and social impacts for different periods into the future (research necessary)
   - Prediction of effects using models in ‘what if’ scenarios (ensemble modelling)
   - Evaluation of regional and global consequences of North Atlantic thermohaline shutdown
   - Feedback effects from ecosystems to physical climate models

Annexe 1

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FAO: http://www.fao.org/
GOOS: http://ioc.unesco.org/goos/
HELCOM: http://www.helcom.fi/
ICES: www_ices_dk.html
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OSPAR: http://www.ospar.org/

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List of Acronyms Annexe 4

AOP	Apparent Optical Properties
BOOS	Baltic Ocean Observing System
CLIVAR	Climate Variability Experiment
COHERENS	Coupled Hydrodynamical Ecological model for Regional Shelf Seas
CPR	Continuous Plankton Recorder
CPU	Central Processing Unit
CZCS	Coastal Zone Colour Scanner
DOC	Dissolved Organic Compounds
EEA	European Environmental Agency
EIONET	European Environment Information and Network
ERS	EuroGOOS Data Requirement Survey
ERSEM	European Regional Seas Ecosystem Model
ESA	European Space Agency
ETC/MCE	European Topic Centre on Marine and Coastal Environment
EuroGOOS	European Global Ocean Observing System
FAO	United Nations Food and Agriculture Organisation
FRRF	Fast Repetition Rate Fluorometer
GEP	Gross Ecosystem Product
GNP	Gross National Product
GPP	Gross Primary Productivity
GODAE	Global Ocean Data Assimilation Experiment
GODAR	Global Oceanographic Data Archaeology
GONZ	Graadmeter ONtwikkeling Noordzee (Dutch project on ecological indicators)
GOOS	Global Ocean Observing System
HAB	Harmful Algal Bloom
HELCOM	Helsinki Convention
HOTO	Health of the Ocean
ICES	International Council for the Exploration of the Seas
IFREMER	Institut Français de Recherche pur l'Exploitation de la Mer
IOC	Intergovernmental Oceanographic Commission
IOP	Inherent Optical Properties
KDD	Knowledge Discovery in Databases
LMR	Living Marine Resources
MAREL	Marine Water Quality Monitoring Buoy
MERCATOR	French Ocean Modelling Programme
MUMM	Unit for Marine Monitoring and Modelling (Belgium)
NASA	North American Space Agency
NPP	Net Primary Productivity
OSPAR	Oslo-Paris Convention
PAR	Photosynthetic Active Radiation
P-I	Photosynthetic versus Irradiance
POM	Princeton Ocean Model
PP	Primary Productivity
PRISMA-I	Project of the Consiglio Nazionale delle Ricerche (CNR), Italy
SAHFOS	Sir Alister Hardy Foundation for Ocean Science
TAC	Total allowable catch
UNIDO	United Nations Industrial Development Organisation

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