NOWESP

NORTH-WEST EUROPEAN SHELF PROGRAMME

Final Project Report

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PREFACE

About five years ago I discussed with Wim van Leussen our comments on the draft Quality Status Report for the North Sea Ministers Conference. In the report serious concern was expressed on several matters, such as the input of pollutants into the North Sea, the state of eutrophication, etc. However, the degree of seriousness of these concerns was not specified; it was noted that the impacts on the North Sea ecosystem are difficult to assess. One of the graphs in the report showed what probably is the main reason: the strong variability of the North Sea ecosystem, a variability which hardly correlates with anthropogenic influences. But other obvious natural factors, such as seasonal rhythm, neither do offer a satisfactory explanation. Besides seasonal cycles, inter-annual variability, and even inter-decennial variability are apparent in the data. This brought us to the question: What do we really know about the dynamics of the North Sea ecosystem ?

Of all coastal seas the North Sea is the most investigated; in the past decades some important field and modelling experiments have been carried out by British and German research groups. Therefore we were surprised to discover that even rather elementary questions about the functioning of the North Sea ecosystem could still not be answered. This stimulated Wim van Leussen to outline a first draft for a research programme to further unravel the ecosystem dynamics of the North West European Shelf. The leading idea behind this plan was to study patterns at larger spatial and temporal scales than was done before. Precisely for that reason the study area was broadened to the entire shelf. This first plan was quite ambitious, and included not only data collection and analysis, but also modelling and field investigations. Contacts were established with several groups in other countries with research experience in the North Sea. The contacts with the group of Jürgen Sündermann were particularly important to bring the programme into a good shape, and to submit the proposal for co-funding to the MAST Programme. The expert evaluation of the proposal was positive, but the programme was considered too ambitious. Martin Bohle-Carbonell of the European Commission strongly advocated to focus the programme on the collection and analysis of existing data. Although we first found this a too severe restriction, after all it was a wise decision. By focusing on this approach, an great wealth of data has been brought to the surface; a tremendous job has been accomplished by the participating institutes. The amount of collected data is even such that the analyses which have been carried out are by no means exhaustive. There is a plan to make the data base available on CD-ROM for further investigation by the international scientific community. Some of the questions on variability of the North Sea ecosystem have been elucidated. But it has also become apparent that several important gaps exist in the data coverage of the North Sea shelf. A European cooperative investment in the development of large scale monitoring systems, as foreseen in EuroGOOS, offers a challenging perspective.
The NOWESP project has come to an end. It provides a good starting point for future shelf research, which is necessary to assess the quality status of the North Sea. Then we will get a reliable basis for our ministers to take the right decisions for a sustainable management of the North Sea.

Job Dronkers (head research division, RIKZ)

EXECUTIVE SUMMARY

Shelf seas are highly productive ecosystems, but at the same time they are the sites of intensive and often conflicting human uses and interests. Shelf seas form an important transitional region between land and ocean and are subjected to many inputs. Besides the input of substances from the rivers, they also receive energy and materials from the ocean, sediments and solar and wind energy. These inputs are, however, not constant over time. The European Shelf is an open complex system, subject to considerable variation over time and space.

The North-West European Shelf, the focus of the NOWESP project, is a relatively large continental shelf in the Atlantic Ocean. It covers the area within the 20-metre depth contour (Figure A). The largest part is a semi-enclosed basin - the North Sea - surrounded by land masses accommodating highly industrialized societies.

The North-West European shelf is considered as an important marine area. It is important for its intrinsic natural values as ecosystem, as well as for its economic aspects, such as fisheries, recreation, oil- and gas, and sand/gravel extraction. To allow a better understanding of the physical, chemical and biological functioning of this ecosystem, (inter)-national monitoring programmes provide a host of data. From the interpretation of such data it has become clear that changes in many variables do occur, both in a geographic and a temporal framework. It is shown that although some changes can be related to anthropogenic influences, many changes originate from natural causes.

It is a recognized fact that changes in the North Sea environment, such as the size of fish stocks and mass mortalities of fish, cannot be explained solely by reference to human impacts. The general conclusion is that climatic variation influences the variations in physical, chemical and biological parameters in the marine environment, albeit to an largely unknown extent. Understanding the way shelf seas function and the factors and processes controlling their geographical and temporal variability is a prerequisite for improving our knowledge of these large marine ecosystems and their sustainable management.

The aim of the NOWESP project was to quantify both spatial and temporal variations in ecologically significant parameters in the shelf area on the basis of existing data and mathematical models.

In the following sections a brief overview of the results and the recommendation will be presented. More details are available, for example in the Final Report of the project, the Annex I, containing an overview of the NOWESP Network, Annex II, a series of scientific papers on the NOWESP achievements, and Annex III, a print-out of the NOWESP Research Data Base. The latter two Annexes are supplied as separate volumes.

1. DATA SETS

The basis of the NOWESP project (1993-1996) was the provision of a multi-parameter data set of existing marine data relevant to the estimation of trends, variations and fluxes on the North-west European shelf. Unlike existing databases (*e.g.* ICES), the NOWESP database was used not just for archiving, but also for merging data and for the flexible exchange of data between partners.

NOWESP

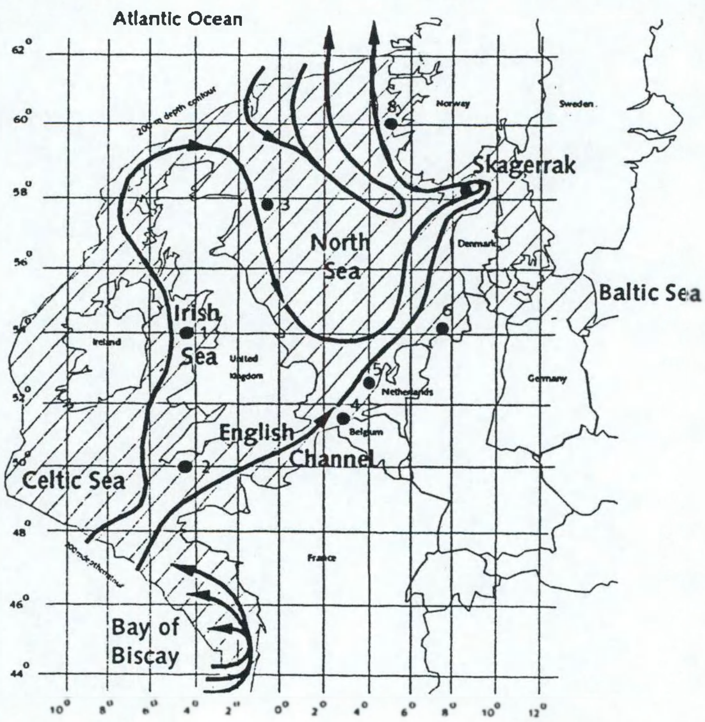
The North-West European Shelf Programme (NOWESP) is an EU-funded project under the Marine Science and Technology Programme (MAST II), involving participation by 18 institutes from 8 different countries over the 1993-1996 period.

The aim of the NOWESP project was to quantify both spatial and temporal variations in ecologically significant parameters in the shelf area on the basis of existing data and models. To achieve this aim, the following tasks were specified:

- create a research database on the North-West European Shelf;
- make this data available to all participating institutes;
- analyse the NOWESP data using uniform statistical methods;
- investigate the potential for a new generation of shelf transport models.

The last of these tasks involved intensive collaboration with the Modeling Marine Ecosystem (MMARIE) group, a concerted action within the EC-MAST programme.

Figure A. Map of the North-West European Shelf showing 200-metre depth contour and general residual current pattern. The map also shows the eight locations for which time series spanning more than 20 years are available in the NOWESP research database.

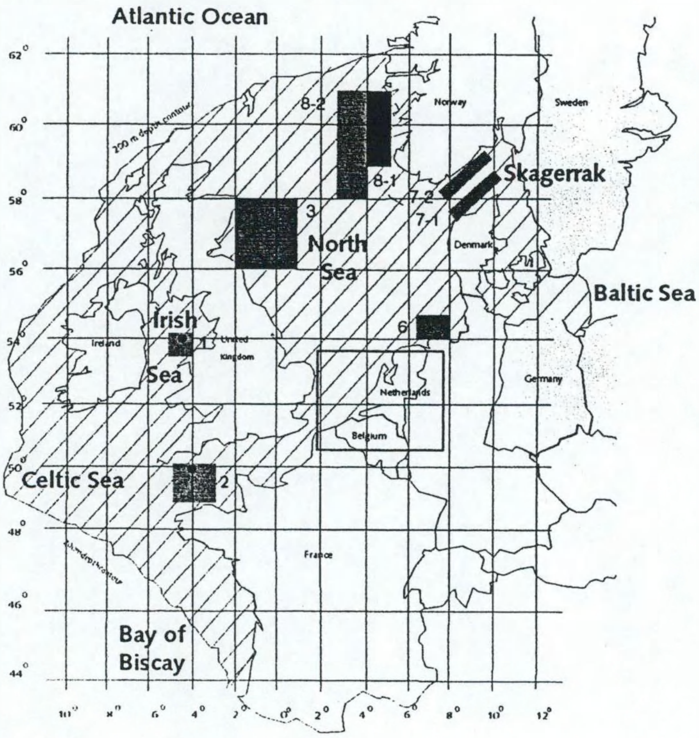


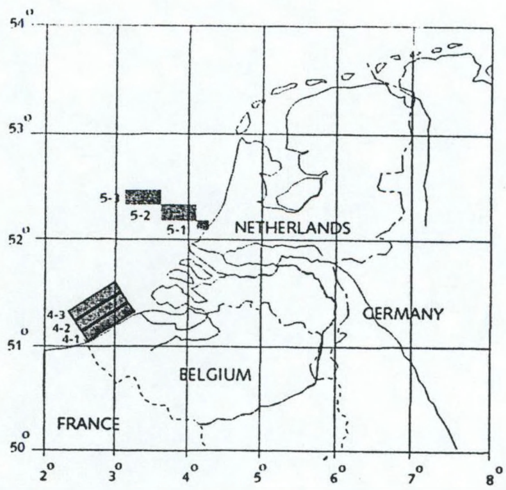
More than 3 million observations were stored from about 220 originators in almost 50 institutes throughout Europe. The acquisition of relevant data sets was not limited to data from the NOWESP partners. Data from outside the NOWESP group were also included whenever they were relevant to the aims of the project. The NOWESP data sets report contains a description of each data set included (*e.g.* number of data, maximum and minimum, geographical and temporal distribution), following a standard format.
Although the suppliers of the data were responsible for the quality of their data, the descriptions in the data reports were used to check the quality of the data before further use.
The NOWESP Research Database (see Annex III) was constructed as an integral part of the project, together with a related data management system (ORACLE). The coding and structure of the database allow data on the same parameters to be grouped in an easy and flexible way for different spatial and temporal windows.
Although there is a huge amount of data available from field measurements and monitoring networks in the NOWESP area, most of the data series are relatively short and cover only the North Sea. In general there is a lack of data for the Irish and Celtic Seas and for the area west of Ireland.
In the case of ten parameters (temperature, salinity, dissolved phosphate, nitrate, nitrite, ammonia, silicate, chlorophyll, suspended matter and zooplankton biomass), the data sets were sufficiently comprehensive to allow them to be merged to produce lengthy time series at eight locations (Figure B). To estimate fluxes and take account of gradients in coastal areas, as well as to have more data available for different areas, data sets were exponentially interpolated using fixed regular grids (about 20 km grid size) so that the spatial and temporal properties were preserved. Eventually, interpolated data sets were available for fourteen boxes (Figure B).
Experience with the creation and use of the NOWESP research database has shown that data acquisition and data quality control must be performed by all partners. To enable future projects to succeed in a similar compilation of relevant data, the data set should be shared between a research database group and a national or international data centre. This will allow use to be made of these data centres' software and experience in checking data quality.

2. STATISTICAL ANALYSIS

In order to study the variations and trends in the geographical and temporal distribution of the parameters over the shelf, the merged data sets of the NOWESP research database were exponentially interpolated into regular grids.
The data were then subjected to extensive statistical analysis using agreed techniques and computer packages. These techniques included time series analysis, auto and cross-correlation, kriging, principle component analysis and principal oscillation patterns, as well as more simple statistical techniques (*e.g.* means).

Figure B. The North-West European Shelf area, showing the 200-metre depth contour and the eight boxes where lengthy time series are available.





The following issues were examined within the project:

- Geographical distribution;
- Seasonal trends and variations;
- Decadal trends and variations;
- Trends and variations in fluxes.

The integrated evaluation of the long time series provided an opportunity to look for connections between the different boxes.

2.1 Geographical distribution

The geographical distribution of the parameters was examined only in the North Sea. The reason for this was that almost no data were available for Atlantic waters in the shelf area west of Ireland, or in the Irish or Celtic Seas. It emerged that the data were not evenly distributed over the North Sea and that they were derived often from measurements of single research cruises. Most data were from the coastal zones of the North Sea, where there are national monitoring programmes in operation. To overcome this problem, single data from ship measurements were merged with synoptic reflectance images obtained from satellites.

The monthly distribution of suspended particulate matter in the surface water of the North Sea was calculated on the basis of 1973-1993 data and composite reflection images constructed from data collected by the NOAA/AVHRR satellite in 1990-1991. The results of this premising method suggest that the two main fluxes of suspended particulate matter in the North Sea - off England and along the continental coasts of Belgium, the Netherlands and Germany - remain largely separate until they both arrive in the Skagerrak.

2.2 Seasonal trends and variations

In order to study the seasonal trends and variations in the different NOWESP parameters, the data from the NOWESP research data set were merged and exponentially interpolated to produce monthly means in the eight areas where sufficient data were available.

The seasonal cycle appeared to be dominant in the temperature, nutrients, chlorophyll and zooplankton data sets. The averaged seasonal characteristics of nutrients at the eight locations over the 1980-1984 period show differentiation between areas affected by rivers and remote areas on the shelf. Highest winter concentrations are found for nutrients in the Dutch and Belgian coastal zones: these are between approximately eight (nitrate) and four (phosphate) times higher than those observed offshore. The timing and magnitude of maximum chlorophyll values differed from place to place: there was a late spring bloom with low chlorophyll values in the Irish Sea, off the Scottish coast and in the Channel, an early spring bloom with high chlorophyll values in the Southern Bight and Skagerrak, and a late spring bloom with high chlorophyll values along the Dutch and Belgian coasts. The chlorophyll peak in the German Bight is dominated by a summer bloom. The peak in the yearly abundance of copepods varied from May-June in the south to July-August in the north of the shelf.

2.3 Decadal trends and variations

Time series analyses of monthly mean data on the physical, chemical and biological NOWESP parameters were constructed within eight boxes on the North-West European Shelf for the 1960-1995 period (Figure B).

All boxes show a remarkable increase in temperature between 1985 and 1990, related to the rise in atmospheric temperature over that period.

Nutrient concentrations are high in the river-dominated boxes, where the dissolved phosphate, nitrogen and silicate concentrations start to decrease in the eighties. The decrease in dissolved phosphate is much greater than that in the dissolved nitrogen compounds, giving rise to rather high N/P ratios (>20) in the coastal zones. No decrease in the concentration of dissolved phosphate was found in the Irish Sea: in fact, in this area there was actually an increase between the sixties and the nineties.

At Helgoland, the silicate concentration started to increase in 1985 and had approximately tripled by 1989; however, after that date there was a small decrease.

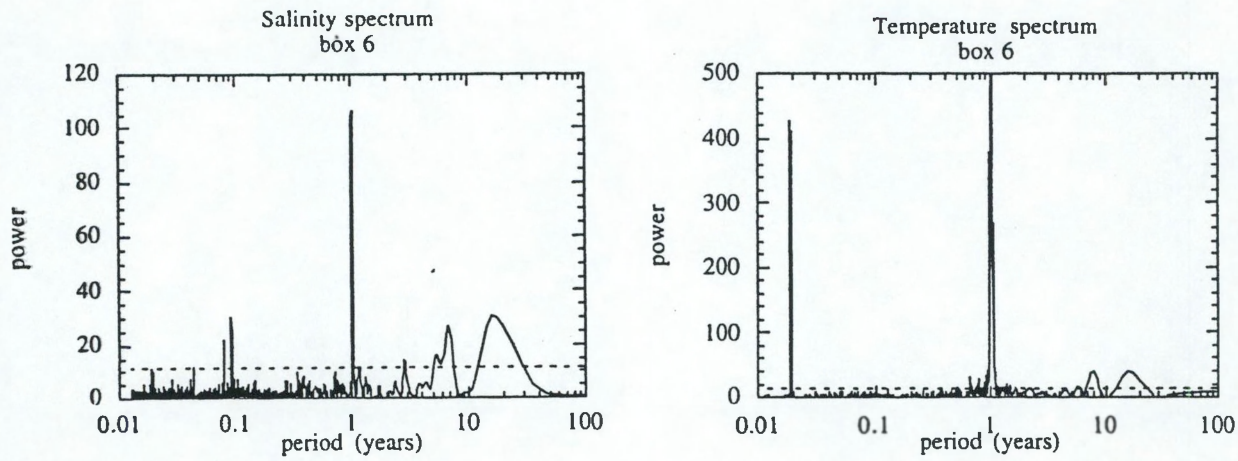
The integrated evaluation of the time series makes in possible to look for connections between the different boxes. Between some there appears to be a significant correlation, but it is usually difficult to relate this to any physical phenomena. The different water-masses are too strongly influenced by external factors (*e.g.* rivers, wind).

There is a tele-connection between the salinity and temperature at different parts of the shelf. Temperature and salinity on the shelf are heavily influenced by meteorological conditions (air temperature, precipitation and river discharge). The physical parameters of the North Sea are obviously controlled by external forces.

The nutrients and biological parameters are heavily locally influenced. The long-term changes in these variables do not show correlated behaviour. They are buried in the high variability connected with high-frequency changes on time scales of less than one month and on spatial scales less than the distance between the eight locations.

A clear annual cycle is visible in the records of all parameters. Longer periods were also significant in the salinity records (with frequencies of 2.7, 3.1, 4.7, 8.2 and 14.5 years) and in the temperature data (8 and 17 years). See *e.g.* surface salinity and temperature spectra in box 6, Helgoland (Fig. C).

Figure C. Sea surface salinity (a) and temperature spectrum in box 6 at Helgoland. The power on the vertical axis is a measure of the signal to noise ratio (from: Sündermann *et al*, 1997)



Spectral analysis of calculated mass fluxes in different sections reveals significant periods beyond the annual cycle: this suggests an advective influence from the Atlantic Ocean. Another external source of decadal variability is the atmosphere: no phase shift can be expected between corresponding signals in the time series at different locations in the North Sea.

2.4 Trends and variations in fluxes

Three hydrodynamic models, using the same long-term meteorological forcing data, show similar patterns of variation in the water volume transport through seventeen sections over a period of 39 years (1955-1993). The models varied from a simple depth-averaged storm surge model to a sophisticated three-dimensional baroclinic model with turbulence closure.
The generally accepted circulation pattern is confirmed, although difficulties arise in the Irish Sea. Mean water transport values through sections of the southern North Sea, where the water is well mixed, compared rather well. However, large differences occurred in the mean water transport in the northern part of the North Sea due to differences in model physics.
For instance, the annual mean flux of the water of the northern Atlantic entering the North Sea varies between 0.15 and 1.13 Sv, depending on which model is used (1 Sv = 10^6 $m^3.s^{-1}$).
Spectral analysis of the 39-year model runs shows a dominant annual cycle and a longer period signal of 7-10 years.
Combination of the water fluxes of two models and the climatological mean concentration of nutrients from the NOWESP research database produces estimates of the total amount and variation in the fluxes of nutrients through three boundary sections: the northern Atlantic, Skagerrak and Channel inflows. For example, the average inflow of nitrate to the North Sea is 4000, -136 and 162 ktonnes/year for these boundaries respectively. These values are considerable, especially when compared to riverine inputs to the area. The results give the impression that in the overall variations observed in the flux calculations, the uncertainties in the estimation of the flow are dominant over the nutrient variability.

3. NEW GENERATION OF SHELF MODELS

The existing shelf flux models used by the NOWESP partners have been reviewed. It appeared that very few models were really 'ecological shelf models' in the sense of mathematical. models which describe the (many) different and interrelated ecological processes. The existing models fall short because of:

- the large size of the study area and
- the various space and time scales involved: large space scales for transport processes, and small space scales (and thus small mesh sizes) in source or sink areas and in coastal zones of particular interest; large time scale for studying (seasonal or multi-annual) trends and global changes and small time scales when looking at 'catastrophic' events (*e.g.* oil spills).

- the complexity of the processes involved: many different substances interact with each other, so that many processes are interrelated and that consequently many differential equations have to be solved simultaneously;
- the 3 D character of flow, transport and interaction processes, in particular in shallow areas with very complex vertical and horizontal boundaries;
- the high level of accuracy which is often required.

Most participating institutes therefore resort to a new generation of numerical models to overcome the deficiencies of the present models. Such models require the use of High Performance Computing (HPC) techniques. The current generation of HPC systems use parallelism to increase both the calculation and storage capacities. For this reason most partners therefore have proceeded during NOWESP to the parallelization of the existing codes on different hardware platforms.

It has become clear however that this is not good enough. When modeling transport and interaction processes in great detail on a fine grid with a small time step, the processes must be described by the equations at the same level of spatial and temporal resolution. This means that better physics are necessary. Furthermore, in order to be able to perform simulations on a fine grid and with a small time steps more sophisticated and efficient numerical algorithms may be required. It has also become clear that, in order to obtain new generation models for marine ecosystems, an intensive and multi-disciplinary interaction between different specialists is needed (hydrodynamics, ecology, computer science,...).

This is the way forward as it has emerged in the minds of the partners during NOWESP and most of them are now moving in this direction. Thanks to the collaboration within NOWESP, an EU concerted action - MMARIE (Modeling MARIne Ecosystems using HPC. techniques) - has been set up to consolidate the interaction and cooperation.

It should be said that, although much progress has been achieved, there are as yet still no real ecological "shelf flux models" That goal is, however, expected to be achieved in the near future.

Exploitation and dissemination of NOWESP results

The NOWESP research database is being used by the project partners in many different ways and will continue to be used by them in the future. Of course, the data base will be available for other users as well. Data has already been used by an ASMO working group for the comparison of different eutrophication models and the data set could also be used, for instance, to optimize existing monitoring programmes. There are plans to put the NOWESP data set on a publicly available CD-ROM.

NOWESP results have been presented at many workshop s and conferences, and published in a multitude of reports and scientific publications in reviewed journals and in books. A special issue of the Deutsche Hydrographische Zeitschrift will be devoted to the scientific achievements in the NOWESP project.

The results of NOWESP have been compiled in a series of progress reports, and this Final Report. Separate volumes include:

Annex I	a description of the NOWESP European Network;
Annex II	the scientific contributions of NOWESP;
Annex III	the NOWESP Research Data Base;
Annex IV	the NOWESP Manual on Statistical Analysis Techniques.

4. RECOMMENDATIONS

NOWESP compiled a vast quantity of existing data from the North-West European shelf. Such focussed effort in this area is without precedent. Based on the results of the NOWESP project, the following recommendations for continuation of the present activities and for future research can be made:

- One or more national or international data centres or agencies should be chosen and given proper support by the EU to collect and store all available observational data, including the NOWESP data. The data can then be regularly updated by the providers and made available to researchers.
- The existing monitoring locations on the shelf where long time series are available are under political threat. For financial reasons, one time series has been stopped and others are likely to be abandoned in the near future. Support from the EU and national bodies is necessary to ensure the continuation of these unique time series.
- Atmospheric deposition is recognized to be an important source of pollution in sea water. The uncertainties regarding the amounts of atmospheric deposition on the shelf should be reduced by a coordinated international project on the subject.

- The national and international organisations (including the EU) should stimulate the development of 'smart sensors' to be used in permanent mooring arrays or in combination with *e.g.* the towed continuous recording devices. Results from on-line monitoring, and at selected locations continuous monitoring sites, will assist us to unravel the mechanisms that lay behind the variabilities so far not understood.
- International agreement should be reached on quality control procedures and quality standards for data to be stored in these databases. Proper arrangements should be made to preserve the economic value of the data for their 'owners' without compromising the use of the data by researchers, and to prevent unnecessary duplication of effort in the collection of data.
- The data needed are 'climatological' concentration fields for temperature, salinity, nutrients, suspended matter and chlorophyll. To collect these would require at least one monthly survey of the whole European shelf over a period of five years, with a proper spatial resolution (*e.g.* 1° by 1°) and covering at least those areas where climatological data are now totally lacking.
  From the modelling point of view, an alternative would be the availability of data from sufficiently representative fixed stations on the shelf, with weekly sampling over several years.
- It must be realized that virtually no data are available on the shelf boundaries. For this reason, consideration should be given to establishing a European effort aimed at creating a limited network of stations, especially at the shelf edge. These should measure a limited selection of parameters on a long-term basis (a long time series) for use in modelling, interpretation of long-term natural variations in the marine environment and changes due to human interference (eutrophication, pollutants, climatic changes and biodiversity changes). The EU could foster the coordination of nationally organized measuring campaigns across Europe.
- New monitoring strategies are required, by which operational oceanography is conducted through cooperation on a pan-European scale (in collaboration with, for example, GOOS and EUROGOOS).
- Methodologies should be promoted for the collection of geographically distributed data sets through remote sensing (satellite or airborne) techniques.
- The formulations of basic physics should be improved: turbulence must be simulated in a way that more closely represents nature.
- There is a need for a well-validated, detailed shelf circulation model which can represent the measured data properly during long-term simulations. Tides must always be included since they are important for mixing.
- A detailed North Atlantic ocean circulation model should be developed to provide proper boundary conditions at the shelf edge.
- Recent developments in High Performance Computing (HPC) appear to offer the prospect of operational models of this type for practical applications in the near future.

CONCLUSIONS

Monitoring of the marine environments is an ongoing activity. Through the NOWESP initiative the different disciplines in the fields of data collection, data treatment, data evaluation and modelling have been brought together. They formed the expert group in a truly EU wide approach.

After more than 3 years of close cooperation between the scientists involved in NOWESP, the project evolved sufficient momentum to continue its ongoing activities. It will be inevitable that national and international initiatives and support will be required to strengthen the monitoring activities, to develop new monitoring tools and to apply new modeling techniques.

For a better understanding of the shelf as a vital part of the marine environment and as a link between land and ocean, there is a general feeling that the NOWESP database should be extended to include data on the shelf boundaries (forcing functions), while detailed shelf flux models and modern data assimilation techniques will be helpful to fill in the gaps.

Data sets on the shelf should be analysed together with these new data from the boundaries in order to understand and distinguish between natural and anthropogenic sources and processes acting on and affecting the North-West European Shelf ecosystem.

The approaches developed within the NOWESP project are not necessarily specific for the North-West European shelf, and they may be applied to other areas of the EU (Mediterranean, Baltic), and beyond.

1. GENERAL INTRODUCTION

The North Sea is a very complex ecosystem, which is under stress due to human activities. As it is surrounded by a large number of countries with an active environmental management programme, it is one of the best studied marine systems in the world. Extended research cruises, combined with a number of numerical models have produced a high level of knowledge. The combined data sets of this area provide one of the most detailed sets of observations collected in any shelf sea. However due to the relatively large scale and the strong variability of the phenomena involved, present knowledge still has a rather fragmentary character. So far, hardly any insight exists in the long-term evolution of the (European) shelf system and no reliable estimates are available regarding the net retention or release of matter.

By studying processes and managing the North Sea it is important to recognise that the North Sea is not a closed ecosystem. The biological, physical and chemical processes that take place within this North Sea ecosystem, do not determine all processes. For example, the occurrence of sudden changes in salinity, in nutrient concentrations or in some fish stocks in the North Sea, can not be explained by internal processes only (Russell *et al.*, 1971; Otto, 1984; Mann & Lazier, 1991; Loewe, 1995; Becker & Pauly, 1996). It appears that other processes, such as the influence of the exchange with north Atlantic water masses and the meteorological conditions at larger scales, dictate to a considerable extent the processes in the North Sea ecosystem. Since about 6000 years, huge amounts of Atlantic Ocean water are entering in the south and the north, mixing with the North Sea water, with river water and water from the Baltic. The outflow mainly takes place as surface current in a northerly direction along the Norwegian coast. The general circulation pattern in the North Sea is anti-clockwise and the averaged transfer time of the Atlantic water in the North Sea is about 1 year (Otto *et al.*, 1990).

In addition, the North Sea surface waters receive sunlight, which is an essential energy source for the phytoplankton and results in the northern North Sea in temperature stratification during summer time. Wind energy is dissipated to the sea water. Depending on the strength and the direction of the wind and the time span of action, the residual current pattern may change dramatically. Under normal average wind direction (SW 4 Beaufort), Atlantic water is entering the North Sea in the south through the Strait of Dover. However, by northern or north-eastern winds North Sea water is leaving the North Sea through the Straits of Dover.

It is important to recognize that these fluxes of matter and energy in the North Sea are not constant in time and place and that anomalies of the fluxes can have a great impact on the organisms in the ecosystem. Similarly, much attention has been paid to the relation between the changes in fish stocks in the Pacific along the coast of Chili, temperature anomalies in South-America and Africa and the El-Niño-Southern Oscillation phenomenon (ENSO) (Diaz & Markgraf, 1992; Glantz, 1992). Recently, more and more attention is paid to the possible impact of the changes in the northern

Atlantic oscillation on *e.g.* fish stocks in the Atlantic and North Sea (Hoppema & de Baar, 1992; Lindeboom *et al.*, 1995) and anomalies in precipitation in Europe (Meincke, 1996; Hurrel & van Loon, 1997).

The general conclusion is, that climatic variability does influence (to an unknown extent) the variability in physical, chemical and biological parameters - and hence processes - in sea water (Mann & Lazier, 1991; Svendsen & Magnusson, 1992). Natural variability in these parameters may induce short term or long-term changes in different (other) parameters in the marine ecosystem (Mann & Lazier, 1991).

From scientific studies, including the present NOWESP project, it appears that it is of utmost importance to approach the North Sea at large, in which the continental shelf is considered an essential apart of the system. As a consequence, this approach should be part of the management of the North Sea as well. Insight into and understanding of the natural and anthropogenic variability and long-term trends of parameters and processes of this shelf ecosystem are necessary to manage the present human impact but also to manage the further problems as climate changes and sea level rise.

To tacle these questions at an appropriate scale and to exploit and co-ordinate European shelf sea research there was a strong need from the various research groups to start an integrated project in this area. In this integrated project more insight should be obtained into the variability of the ecosystem under the various conditions, large scale phenomena and the environmental response to perturbations (natural and man-induced). Herein the elements of the various regional and process-orientated projects will be integrated and synchronized to the large global scale programmes.

1.1 Monitoring of the marine environment

According to a definition formulated by UNEP, monitoring can be defined as:

> "Monitoring is the process of repetitive observing, for defined purposes on one or more elements of the environment according to prearranged schedules in space and time and using comparable methodologies for environmental sensing and data collection.
> Monitoring provides factual information concerning the present state and the past trends in environmental behaviour".

As a result of the multitude of monitoring activities in the past for the North Sea / shelf area, we have learned much about the sources, the (increased) concentrations in various compartments, and the fate of a number of compounds in the marine environment. Unfortunately, despite the plethora of information available, it is still not easy to say whether water quality is getting better or worse. It is often said that "We are data-rich and information poor" (Ward *et al.*, 1986).

All countries bordering the north-western European shelf have their national monitoring programmes for physical, chemical and biological variables. Often overlap exist, but sometimes monitoring methods or methodologies do not compare well, often data sets are not evaluated taking into account information from other sources, including data sets from bordering nations.

For a proper evaluation of monitoring data, and hence ultimately coming to an understanding of the functioning of the North sea at large, data from physical, chemical as well as biological origin should be involved, not to speak of *e.g.* meteorological data. By assimilation of a multitude of quality information over a large (shelf) area may result in the objective to understand the shelf/North Sea ecosystem processes. Quality data are a prerequisite where it comes to interpretation of processes at this large scale. It means that data obtained by various institutes or countries are truly comparable, so that they can be merged into one data set. It also means that the methods of evaluation - such as the use of statistical approaches - should be harmonized between these institutes (and countries), to allow agreement on the results obtained.

Several institutions are currently trying to harmonize these activities, for example the International Council for the Exploration of the Sea (ICES), the Assessment and Monitoring Committee (ASMO), the European Environmental Agency (EEA), the (Euro)GOOS initiative (Global Ocean Observing System), the Trilateral Monitoring and Assessment Programme (TMAP) focussing on the Wadden Sea area, and the Helsinki Commission (HELCOM). Many of their efforts have already resulted in several policy documents, *e.g.* various Quality Status Reports on the North Sea, Wadden Sea or Baltic.

Although several of these initiatives store (and sometimes evaluate) data on large geographic areas, they have, so far not tried to tackle the integrated processes on a scale of the North-Western European shelf.

1.2 Objectives of NOWESP

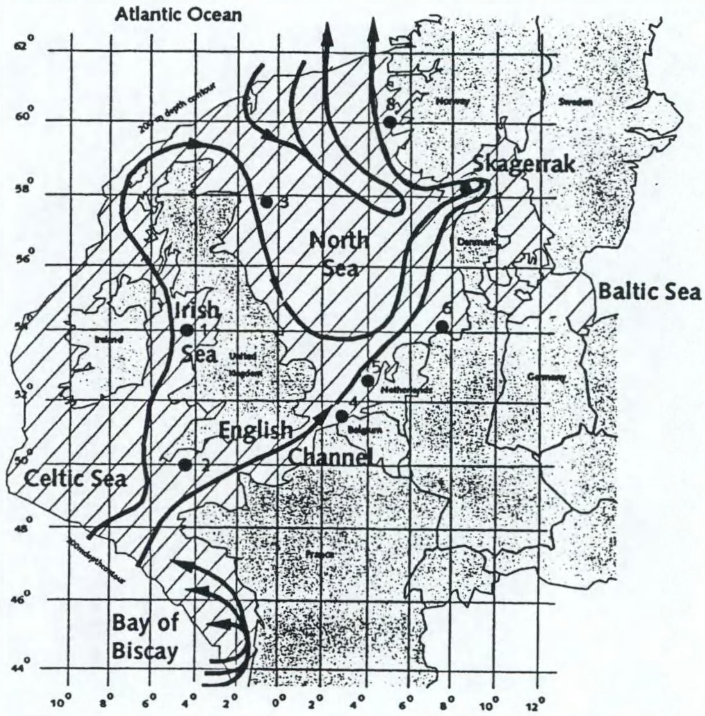
This is the challenge of what was called the NOrth-West European Shelf Programme (NOWESP). The North-west European shelf is considered to cover the area within the (about) 200 meter depth at the boundary with the Atlantic Ocean (cf. *Figure* 1). It includes the Channel, the Celtic Sea, the Irish Sea, the North Sea and part of the Norwegian Sea, as well as the smaller connecting and adjacent waters. The Baltic Sea in total is not considered a part of the shelf as such but the study of the exchange between the shelf and the Baltic is seen as a vital element of the project.

The objectives can be summarized in the following three points:

- *to quantify the biogeochemical fluxes*, such as the fluxes of nutrients, plankton, carbon, and the transport of organic and inorganic particulate matter, including their biological and chemical modifications;
- *to estimate their variabilities and trends*, and
- *to understand the nature of shelves as a link between land and ocean.*

Insight into the fluxes and the variability of the system is a prerequisite for understanding the shelf as a link between land and ocean. Therefore NOWESP concentrates on the first two points.

Figure 1. Map of the North-west European shelf. The eight locations for which time-series spanning more than 20 years are available in the NOWESP research data base are indicated. Arrows point at the average residual current field on the shelf. For the geographical positions and coordinates of the locations see *Table 4.*



Because the North-West European shelf, and especially the North Sea, is an intensively investigated area and possesses a large number of national monitoring networks, comprehensive hydrographic and chemical-biological data sets are available in the NOWESP partner countries. These data sets were made available for the purposes of NOWESP. It was not intended to establish a new databank of shelf data, but to prepare and provide a specific 'Research Data Base' of information relevant to NOWESP. Of interest were all data about the current field, temperature, salinity, nutrients, pollutants, suspended sediment, phyto- and zooplankton, organic carbon, and their inputs from the Atlantic Ocean, the Baltic sea, the rivers and the atmosphere.

The available data bases have certainly gaps (in space and time), are of different quality and scattered among many European institutions. But its compilation, its uniform central processing and objective analysis by means of by all partners accepted statistical methods and balance equations, promised new qualitative and quantitative findings on fluxes of matter and energy on the North-west European shelf. This was achieved by:

- compilation and standardization of different European data sets;
- statistical assessment of its reliability;
- statistical correlation of different physical, chemical and biological parameters;
- testing and validation of simple flux and balance models against the data sets.

This data analysis was also applied to the huge amount of numerical results from model calculations, which were already developed at several institutes among the NOWESP partners. These modelling results were obtained with an actual meteorological forcing. These data are especially necessary for the statistical correlation with measured patterns of dissolved/suspended substances and for estimating the advective transports in the balance equations.

After realization of these objectives, the analyses of NOWESP will provide a state-of-the-art of today's knowledge on shelf fluxes in the North-west European shelf. It will clarify the priorities of further field measurements and model developments from the viewpoint of fluxes. Additionally, NOWESP contributes to fulfil the need for data integration on a Community level, and the particular needs of the commitments of several member states concerning the fluxes of the various constituents over the shelf and especially in the North Sea.

Accurate modelling of the transport of particulate matter in general, and of organic carbon, in particular, on the continental shelf asks for models with a high resolution in specific regions (such as coastal zones, frontal areas, etc.). This is not possible with the present-day models. Therefore the possibilities of recent hardware developments were to be reviewed for a new generation shelf flux models, giving special attention to the required mathematical algorithms for local grid refinement and numerical approximation techniques that can be implemented efficiently on vector and parallel processors. In this way NOWESP contributes to the sharing of experience within Europe on the application of High Performance Computing (HPC) techniques in marine science.

1.3 Tasks of NOWESP

The North-West European Shelf Programme (NOWESP) is an interdisciplinary, integrated, international project aiming at more insight into the variability of the North-west European shelf seas system on the various time scales, into shelf-wide fluxes and into the environmental responses of the shelf seas to perturbations. For the period 1993-1996 the objectives of the NOWESP project can be summarized as the assessment of the fluxes of energy and matter, as well as their variability, on the basis of *existing* field and model data. This means that the main tasks of NOWESP are:

- the set-up of the NOWESP Research Data Base;
- the making available of these data sets to all NOWESP participants;
- the joint statistical analysis of the NOWESP data.

To arrive at these tasks the following specific objectives were defined:

- to acquire the comprehensive hydrographic and chemical-biological data sets from the various NOWESP partner countries;
- to make these data sets available for the purposes of NOWESP, *i.e.* to collect them centrally and to organize the data uniformly on a jointly defined grid;
- to define suitable statistical analysis techniques for joint applications;

- to analyse the data sets by modern statistical analysis programmes for:
  - reliability of the data
  - variability
  - trends
- to make an estimate of the fluxes and budgets, and to quantify the contribution of single processes (*e.g.* primary production);
- to review of existing Shelf Models;
- to assess the progress made on high performeance flux modelling;
- to determine the gaps in present data sets and in order to indicate the future needs on numerical modelling and field measurements.

This final report will, next to a section on the project management, give an overview of the methods used. It will illustrate the results that were obtained. Also, the report will describe the dissemination and exploitation of these methods and findings in order to contribute to the increase and spreading of the knowledge. It aims at the European scientific community on shelf sea research, as well as to the policy makers and environmentalists, responsible for the management of the North-west European shelf and similar Large Marine Ecosystems (LME's).

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2. PROJECT MANAGEMENT

2.1 NOWESP partners and participants

NOWESP involved 18 European institutes from 7 European countries (6 EC and Norway), which are listed in the *Table 1*.

***Table 1.* The NOWESP Partners**

no.	code	name and location	country
01	RWS/RIKZ	Rijkswaterstaat, Rijksinstituut voor Kust en Zee, The Hague	NL
02	IfM	Institut für Meereskunde, Hamburg	DE
03	KUL	Katholieke Universiteit Leuven, Leuven	BE
04	NIOZ	Nederlands Instituut voor Onderzoek der Zee, Texel	NL
05	POL	Proudman Oceanographic laboratory, Bidston	GB
06	IFR	IFREMER, Plouzane	FR
07	SAHFOS	Sir Alister Hardy Foundation for Ocean Science, Plymouth	GB
08	IMR	Havforsknings Institutet, Bergen	NO
09	IfO	Institut für Ostseeforschung, Rostock-Warnemünde	DE
10	MUMM	Management Unit of the North Sea Mathematical Models, Brussels	BE
11	BSH	Bundesanstalt für Seeschiffart und Hydrographie, Hamburg	DE
12	IfBM	Institut für Biogeochemie und Meereschemie, Hamburg	DE
13	ESU	Environmental Science Unit, Trinity College, Dublin	IE
14	CWI	Centrum voor Wiskunde en Informatica, Amsterdam	NL
15	TUD	Technische Universiteit Delft, Delft	NL
16	CRESO	Université de Bordeaux I, Bordeaux	FR
17	ERRC	University of Liverpool, Liverpool	GB
18	DH	Waterloopkundig Laboratorium, Delft	NL

At the various NOWESP institutes, the following persons were working on the project. The first-mentioned name is the first responsible scientist of the respective institute.

1. Rijkswaterstaat, Rijksinstituut voor Kust en Zee (RIKZ), The Hague, Netherlands
   Wim van Leussen
   Remi Laane
   Gerard Groeneveld
   Peter Bot
   Robert Wilson
   Marijke Visser (Utrecht University, Utrecht, Netherlands)
   Franciscus Colijn (present address: FTZ- Westküste, Büsum, Germany)
   Heino Fock (FTZ- Westküste, Büsum, Germany)
2. Institut für Meereskunde, Hamburg, Germany
   Jürgen Sündermann
   Peter Damm
   Günther Radach
   Jens Gekeler
   Thomas Pohlmann
   Klaus Herbig
3. Katholieke Universiteit Leuven, Leuven, Belgium
   Jean Berlamont
   Jason Yu
   Jean Monbaliu
   Zhi Wei Song
   Dirk Roose
4. Nederlands Instituut voor Onderzoek der Zee, Texel, Netherlands
   Wim van Raaphorst
   Katja Philippart
5. Proudman Oceanographic Laboratory, Merseyside, United Kingdom
   Roger Flather
   Jane Smith
   Julia McManus
   David Prandle
6. IFREMER, Plouzane, France
   Alain Ménesguen
   Thierry Hoch
7. Sir Alister Hardy Foundation for Ocean Science, Plymouth, United Kingdom
   John Gamble†
   Philip Christopher Reid
   Sonia Batten
   Harry Hunt

8. Havforsknings Institutet, Bergen, Norway

Lars Føyn

Einar Svendsen

Didrik Danielssen

Marek Ostrowski

9. Institut für Ostseeforschung, Rostock-Warnemünde, Germany

Bodo von Bodungen

Dietwart Nehring

Helga Schultz

Thomas Neumann

Norbert Wasmund

Günter Breuel

10. Management Unit of the North Sea Mathematical Models, Brussels, Belgium

Dries Van den Eynde

Jean Paul Mommarts

Joan Backers

11. Bundesanstalt für Seeschiffart und Hydrographie, Hamburg, Germany

Gerd Becker

Alexander Frohse

Peter König

12. Institut für Biogeochemie und Meereschemie, Hamburg, Germany

Venu Ittekkot

Kay Pegler†

13. Environmental Science Unit, Trinity College, Dublin, Ireland

Jim Wilson

Mary Brennan

14. Centrum voor Wiskunde en Informatica, Amsterdam, Netherlands

Piet van der Houwen

Ben Sommeyer

15. Technische Universiteit Delft, Delft, Netherlands

Len Dekker

Hai Xiang Lin

Mark Roest

Eric ten Cate

Edwin Vollebregt

16. Université de Bordeaux I, Bordeaux, France

Patrice Castaing

Osmar Möller

Jean-Marie Froidefond

17. University of Liverpool, Liverpool, United Kingdom

Peter Appleby

Simon Hutchinson (now at University of Salford)

18. Waterloopkundig Laboratorium, Delft, Netherlands

Guus Stelling

Erik de Goede

Kian Tan

We were deeply distressed to hear of the tragic and untimely death of Dr. John Gamble in August 1994. He was the Director of the Sir Alister Hardy Foundation for Ocean Science, and was hosting the 1st annual NOWESP meeting in Plymouth. His successor at SAHFOS is Dr. Chris Reid, who is also representing SAHFOS in the NOWESP project.

In the 3rd year of the project we were shocked by the tragic death of Dr. Kay Pegler of the IfBM (Hamburg). It was agreed that the participation of this institute in the NOWESP project should not be continued, because future research will be carried out outside the NOWESP area (deep ocean studies).

Dr. F. Colijn (RWS) took up his appointment as professor at the Forschungs- und Technologiezentrum Westküste an der Universität Kiel (Germany) per September 1995. Colijn continued his work within the NOWESP project as Task Group Leader of Task Group E. The FTZ became sub-contractor of RWS.

2.2 Project management structure

The management structure that was applied is schematically presented in *Table 2*.

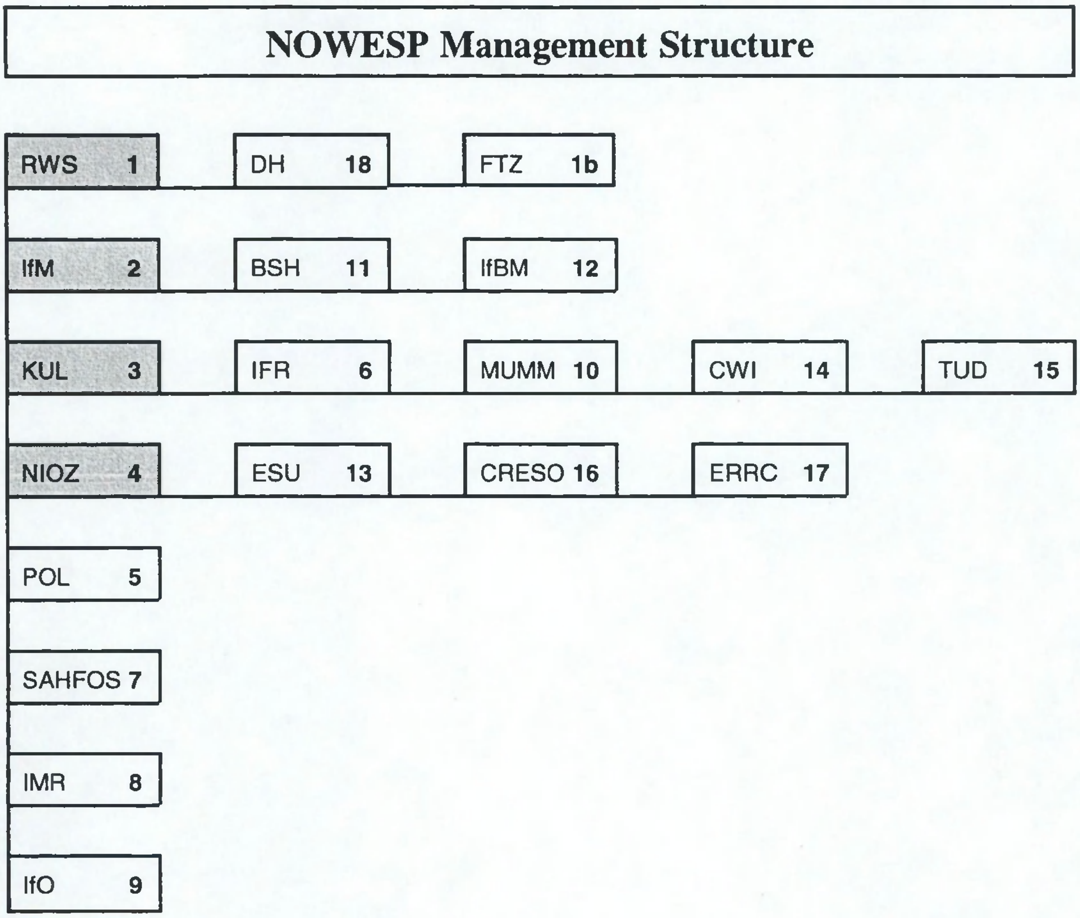


Table 2 Managent structure of the NOWESP project, with the acronyms of the institutes with the respective partner numbers. The left column gives contractors, the other columns depict the respective sub-contractors. The institutes with a shaded box formed the steering committee. Partner 1 was coordinator.

Each institute appointed a responsible scientist (see section 2.1). A Steering Committee was formed by members of the RWS, IfM KUL and NIOZ, being the coordinators for the various sub-tasks (see section 2.3).

RWS was overall project coordinator, with Dr. W. van Leussen as appointed coordinator. During his study-visit to America and at the end of the project, while Dr. W. Van Leussen moved to another job within the RWS organisation, Dr. R. Laane (RIKZ, the Hague) took over the projectleadership. At the end of the project he was assisted by Dr. K. Kramer (MERMAYDE, Bergen, NL).

2.3 Scientific management structure

In accordance with the management structure the NOWESP Steering Committee consists of the Overall Coordinator and the Coordinators of the Task Groups. Their main task was to keep the project on track, *i.e.* correctly in line with the contract and to guarantee the essential exchange and tuning between the work in various the Task Groups (see below).

Starting from the definitions of the main tasks of NOWESP, five Task Groups were formed, each lead by a task-group coordinator:

Task Group A: *Observational and model data.*
(coordinator: G.Radach, IfM, Hamburg, DE)
- *Subtask A1:* Acquisition of data sets
- *Subtask A2:* Organization of data sets
- *Subtask A3:* Interpolation of data using a fixed grid
- *Subtask A4:* Jointly applied statistical analysis technique

Task Group B: *Interface data/modelling.*
(coordinator: J. Berlamont, KUL, Leuven, BE)
- *Subtask B1:* Formulation of balance equations
- *Subtask B2:* Model runs for additional model data
- *Subtask B3:* Future observational and modelling needs on the base of existing data
- *Subtask B4:* Possibilities of new generation shelf flux models.

Task Group C: *Statistical analysis of Physical Parameters, Fluxes and budgets of water (mass), salt, heat, and conservative tracers.*
(coordinator: J. Sündermann, IfM, Hamburg, DE)
- *Subtask C1:* Statistical analysis of data sets
- *Subtask C2:* Variability and trends
- *Subtask C3:* Quantification of individual processes relevant for estimating fluxes and budgets (*e.g.* mixing)
- *Subtask C4:* Quantification of shelf fluxes and budgets (water, salt, heat, conservative tracers)

Task Group D: *Statistical analysis of SPM, Non-conservative tracers. Fluxes and budgets of bulk organic matter, organic carbon and SPM.*
(coordinator: W. van Raaphorst, NIOZ, Texel, NL)
- *Subtask D1:* Statistical analysis of data sets
- *Subtask D2:* Variability and trends
- *Subtask D3:* Quantification of individual processes relevant for estimating fluxes and budgets (*e.g.* resuspension)

Subtask D4: Quantification of shelf fluxes and budgets
(bulk organic matter, inorganic SPM)

Task Group E: *Statistical analysis of Biological Parameters.*
Fluxes and budgets of nutrients, carbon, phytoplankton, zooplankton, primary production
(coordinator: F. Colijn, RWS, The Hague, NL; later: FTZ, Büsum, DE)

Subtask E1: Statistical analysis of data sets

Subtask E2: Variability and trends

Subtask E3: Quantification of individual processes relevant for estimating fluxes and budgets (*e.g.* mixing)

Subtask E4: Quantification of shelf fluxes and budgets
(nutrients, phytoplankton, zooplankton)

2.4 Project time schedule

An overview of the project time schedule is presented in *Table 3.*

2.5 Project milestones and deliverables

The following project milestones and deliverables were defined (with the Task codes):

- Aggregation of a shelf data set interpolated on fixed regular grids (A1, 2, 3; B2)
- Description of the Research Data Base (A1, 2, 3; B2)
- Description of the applied regular grids (A2)
- Description of the joint applied statistical analysis techniques (A4)
- Formulation of the agreed balance equations (B1)
- Evaluation of the future needs on observational data and shelf flux modelling (B3)
- Evaluation of a new generation of shelf flux models (B4)
- Evaluation of observed variability and trends for selected variables (C1,2; D1,2; E1, 2)
- Quantitative contribution of single processes to the shelf fluxes for different regions (C3; D3;E3)
- Estimation of shelf fluxes (C3; D3; E3)
- Investigation of the feasibility of a digital atlas.

2.6 Management of data aquisition

Data aquisition was the main task of the different participants of NOWESP during the first year. Data have been gathered from all partners and from other non-participating institutes. In this year also a start was made to discuss and apply common statistical methods. Although a huge amount of data was available from field measurements and monitoring networks in the North-west European shelf area, most of the available data series have a relative short length. However, a number of long time series were found over periods of several decades.

Code	Description	year 1	year 2	year 3
-	Starting up phase			
A1	Delivery and acquisition of data sets			
A1	Delivery of other data sets			
A2	Organisation of data sets			
A2	Proposal of fixed grids			
A3	Interpolation of data			
A4	Proposal jointly applied statistical methods			
B1	Formulation of balance equations			
B2	Additional model runs			
B3	Review existing shelf flux models			
B3	Future needs on data and shelf flux modelling			
B4	Review new shelf flux modelling methods			
B4	Evaluation new generation flux models			
C1,2	Statistical analysis of physical data			
C3,4	Estimates of processes and budgets			
D1,2	Statistical analysis of OM and SPM			
D3,4	Estimates of processes and budgets			
E1,2	Statistical analysis of biological data			
E3,4	Estimates of processes and budgets			

Table 3. Work planning schedule and project time table. Dark shaded areas represent the planned core activities of the tasks, the light shaded areas demonstrate activities that link to other core tasks in the project illustrating the cooperation between different (sub)tasks.

Particularly the acquisition of additional data sets from other authorities proved to be an immense task. Nevertheless it was carried out quite successfully, and this effort has resulted in a unique shelf data set. For that purpose particularly the informal contacts between scientists were important, whereas EDMED files (European Directory on Marine Environmental Data), containing a fairly comprehensive catalogue on data holdings available in the European Community (BODC, 1994), as well as ROSCOP Cruise Summary Reports, in which measurements and samples collected at sea are reported to ICES, proved to be helpful in discovering additional relevant shelf data sets.

After discussion with the EC scientific officer, Dr. M. Bohle-Carbonell, high priority was given to enlarge the NOWESP data base with data from outside the NOWESP partners (see also section 4.6 for identification of sources). Search actions have been carried out by each of the Task Groups C, D, and E. The results were collected in data catalogues, in which each data set was provided with comments by the Task Group Leaders. It is the impression that in the light of the NOWESP objectives, most relevant European data sets are included in the NOWESP data inventory. This has been confirmed by the set of seven data reviews, executed on request of the EU by renowned European data experts. Unfortunately, the Danish data sets arrived after the deadline for inclusion in the total data base.

To complete the data acquisition process and to start up the next phase within the project concerning the analysis of the NOWESP data sets, including merging of appropriate data sets and agreements on joint activities, several meetings were organized during the period under review.

2.7 Management of the statistical analyses and data interpretation

The second year of the NOWESP project can be characterized by the transition from the first two tasks to the third one. This means much attention has been given to complete the NOWESP Research Data Base (NRDB) with relevant data, both from the NOWESP partners as well as from other authorities. Another action was to organize and structure the NRDB in such a way that the NOWESP partners could dispose of these data sets relatively easily. This holds both for their own data sets, additional data sets from other partners, as well as combined data sets, for which appropriate data sets were merged.
In addition, agreement was reached on common general statistical methods to be applied on the data sets.
The last part of the second year and the third year, NOWESP participants worked together on the statistical analysis of the data sets: variability, trends and correlations. Much attention has been given to the joint analysis of the NOWESP data sets. To be able to compare the results of the statistical analysis of data sets by each of the NOWESP partners, agreements were made on statistical analysis techniques and computer packages, to be used by the partners. These techniques have been described in a loose-leaf report (see progress Task A4). It should be stressed that it was not the intention to compose a new standard text, but only to select a limited number of techniques for joint applications.

As a challenge for close cooperation, four scientific papers were submitted to the ICES Symposium 'Changes in the North Sea Ecosystem and their Causes: Århus 1975 Revisited', to be held in Århus on 11-14 July 1995. Each of these papers, being joint productions by authors from different NOWESP institutes, was accepted for oral presentation.

2.8 Management of modelling exercises

The members of task Group B met at the occasion of the Modelling Marine Ecosystems (MMARIE) kick-off meeting on 3 January 1995, in Leuven. Modelling system dynamics of shelf seas is faced with gradients and processes on many space and time scales. Existing models are at present not capable to give the answers with sufficient detail. Therefore special attention has been given within the NOWESP project to investigate the possibilities for a new generation shelf models, where the computing power of modern High Performance Computing systems is exploited. In the period under review special attention has been given to the required mathematical algorithms for local grid refinement and numerical approximation techniques that can be implemented efficiently on vector and parallel processors. In this way NOWESP contributed also to the sharing of experience within Europe on the application of High Performance Computing Techniques in Marine Science.

2.9 List of workshops and meetings

During the NOWESP project, the following official meetings were organized:

03.09 -	04.09.1993	Kick-off meeting at IfM in Hamburg
	21.01.1994	Meeting Steering Committee, Schiphol Airport, Amsterdam
28.03 -	31.03.1994	Task Groups D and E at NIOZ, Den Burg, Texel
	13.04.1994	Task Group C at MUMM in Brussels
	22.06.1994	Task Group B at EUROSIM94 in Delft
	24.06.1994	Task Group B with MAST Modelling Committee in Brussels
	28.06.1994	Meeting Steering Committee, Plymouth
29.06 -	01.07.1994	2nd half-yearly NOWESP Meeting at SAHFOS in Plymouth
	09.11.1994	Meeting Steering Committee, Schiphol Airport, Amsterdam
28.11 -	01.12.1994	3rd half-yearly NOWESP meeting at IOW in Rostock-Warnemünde
	29.11.1994	Meeting Steering Committee, Rostock-Warnemünde
	03.01.1995	Task Group B at KUL, Leuven
	24.01.1995	Meeting Steering Committee, IfM, Hamburg
15.02 -	17.02.1995	Task Group C at IfM, Hamburg
13.03 -	14.03.1995	Task Groups D and E, at IfM, Hamburg
10.04 -	12.04.1995	Workshop at BSH, Hamburg
	19.06.1995	Meeting Steering Committee, Restaurant Las Lanzas, Leuven
19.06 -	21.06.1995	4th half-yearly NOWESP meeting at KUL in Leuven
	30.11.1995	Meeting Steering Committee, Schiphol Airport, Amsterdam
01.02 -	03.02.1996	5th half-yearly NOWESP meeting at University of Bordeaux
	02.02.1996	Meeting Steering Committee, Bordeaux
	11.04.1996	Meeting Steering Committee at IfM, Hamburg
11.04 -	12.04.1996	Workshop at IfM, Hamburg
	13.06.1996	Task Group B at EUROSIM96 in Delft
24.06 -	26.06.1996	6th half-yearly NOWESP meeting (Final Meeting) at Trinity College (ESU) in Dublin
	29.10.1996	Meeting Steering Committee, Schiphol Airport, Amsterdam

2.10 Overview of progress reports

The following annual management and scientific progress reports have been submitted:

- NOWESP, The North-West European Shelf Programme (1994) First Annual Progress Report, August 1993 - July 1994. MAST II MAS2-CT93-0067, 226 pp.
- NOWESP, The North-West European Shelf Programme (1995) Second Annual Progress Report, August 1994 - July 1995. MAST II MAS2-CT93-0067, 216 pp.
- NOWESP, The North-West European Shelf Programme (1996) Third Annual Progress Report, August 1995 - July 1996. MAST II MAS2-CT93-0067, 200 pp.

The scientific publications are given in the list of publications (section 5.3).

3. SYNTHESIS OF THE RESULTS

3.1 Executive summary

3.1.1 Introduction

The NOrth-West European Shelf Programme (NOWESP) is an interdisciplinary, integrated, international project aiming at obtaining more insight into the variability of the North-west European shelf seas system on the various time scales, into shelf-wide fluxes and into the environmental responses of the shelf seas to perturbations. To reach these objectives three main tasks can be distinguished:

a. acquisition of relevant data sets;
b. making these data sets available for all the NOWESP participants (and beyond);
c. analysis of these data sets by jointly agreed statistical analysis techniques.

This means that three main results can be defined:

- the NOWESP Research Data Base;
- experiences on working together with jointly agreed statistical analysis techniques;
- results of analyzed data series, contributing to more insight into the variability and trends of selected variables and processes in the North-west European shelf.

In this executive summary a brief explanation will be given of the methods used, of the results obtained, and of the dissemination of the results. Especially the scientific methods used and the results obtained will need more detailed descriptions for those seriously interested in the science of the project. A list of publications and presentations related NOWESP is enclosed. In addition, one is refered to the Annex II, where the papers that are submitted for publication in the Deutsche Hydrographische Zeitschrift are presented. In the relevant paragraphs appropriate references to this Annex are provided.

In the following section, a concise summary will be given of the scientific findings and conclusions in relation to these goals of the project.

3.1.2 Acquisition and management of (existing) shelf data sets

Because the North-West European shelf, and especially the North Sea, is an intensively investigated area and possesses a large number of national monitoring networks, comprehensive hydrographic and chemical-biological data sets are available in the NOWESP partner countries. In the first 2 years of the project (1993-1995) these data sets were made available for the purposes of NOWESP in a specific 'Research Data Base'. Of interest were all data on:

> current field, temperature, salinity, nutrients, pollutants (mainly trace metals and radio isotopes), suspended particulate matter (SPM), organic matter (DOC, POC), primary production and chlorophyll *a*, phytoplankton, and zooplankton (species distribution and abundance, including data from the Continuous Plankton Recorder surveys (CPR)).

The acquisition of shelf data sets was not limited to data of the NOWESP partners. Also relevant data from outside the NOWESP group were included in the data base. For example, EDMED files (European Directory on Marine Environmental Data), containing a fairly comprehensive catalogue on data holdings available in the European Community, as well as ROSCOP Cruise Summary Reports, in which measurements and samples collected at sea are reported to ICES, proved to be helpful in discovering additional relevant shelf data sets.

The water circulation over the shelf, under a variety of meteorological conditions, is an essential link in predicting the fluxes of the various constituents. Generally such data are scarcely available from field measurements. Therefore this information was obtained from long-term hydrodynamic computations with calibrated numerical models. The MAST project ERSEM provided a 39-year long simulation of the circulation on the shelf to NOWESP. For the assessment of the shelf fluxes the model data are as important as the observational data.

One of the major achievements of NOWESP is the NOWESP data set, the 'NOWESP Research Data Base (NRDB)'. This data base is housed at the Institut für Meereskunde (IfM) in Hamburg. Here the relevant data were processed, organized and documented, and made available to all NOWESP partners. The organization of the data sets was achieved by using an ORACLE data banking system. An overview of the loaded data sets can be found in the Data Inventory, added as Annex III to this report. Presently this data base contains more than 2.2×10^6 data records, taking up ~740 MB of storage capacity. The records include:

- ~ 90×10^4 physical data,
- ~ 41×10^4 nutrient data,
- ~ 14×10^4 data on suspended particulate matter,
- ~ 13×10^4 chlorophyll data,
- ~ 50×10^4 phyto- and zooplankton data, and
- ~ 65×10^5 data of miscellaneous variables.

In order to be able to use and interpret the data in a georaphic and temporal framework, they were gouped together according to preset schemes. The positions of stations and of coordinates are defined in the *Table 4*.

Within the NRDB long time series were available at 8 stations over the shelf (see *Figure 2*): in the Channel, the Irish Sea, along the east coast of Scotland, along the coast of Belgium, the Dutch coastal zone, the German Bight, the Skagerrak and Norwegian coastal zone. Long time plankton surveys were available for a number of CPR routes over the shelf. An overview of the characteristic properties of the time series are given in *Table 4.* The positions, measuring period, parameters and the originator of the data sets are presented in this Table.
Around these stations boxes were defined (see *Figure 3*). Data (*e.g.* on other variables) of other origin, but with positions within these boxes were considered to be repesentative for the entire box.

Figure 2. Locations of the unique set of eight long time series of shelf data (time series over several decades (see also *Table 4* for coordinates of the geographical position of the locations). The yearly averaged residual currents are indicated. Shaded area: the NOWESP area

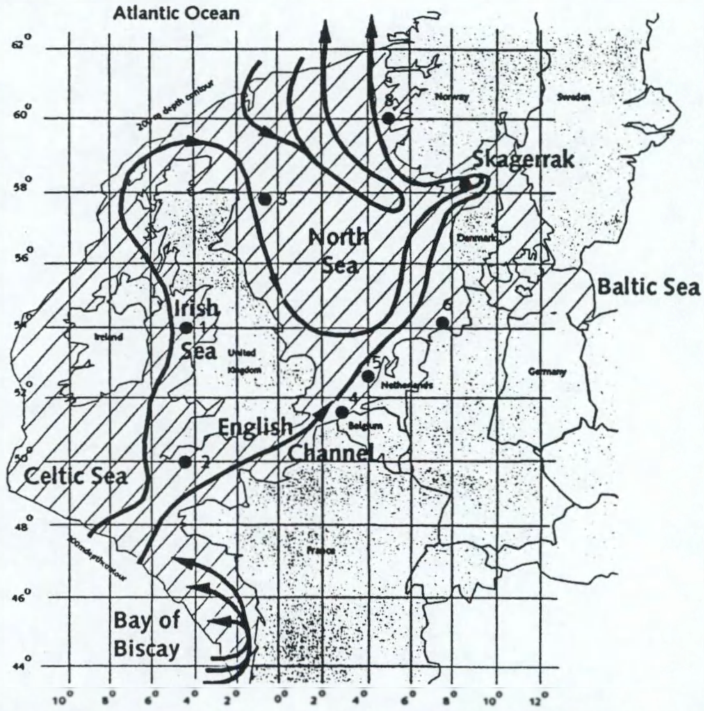
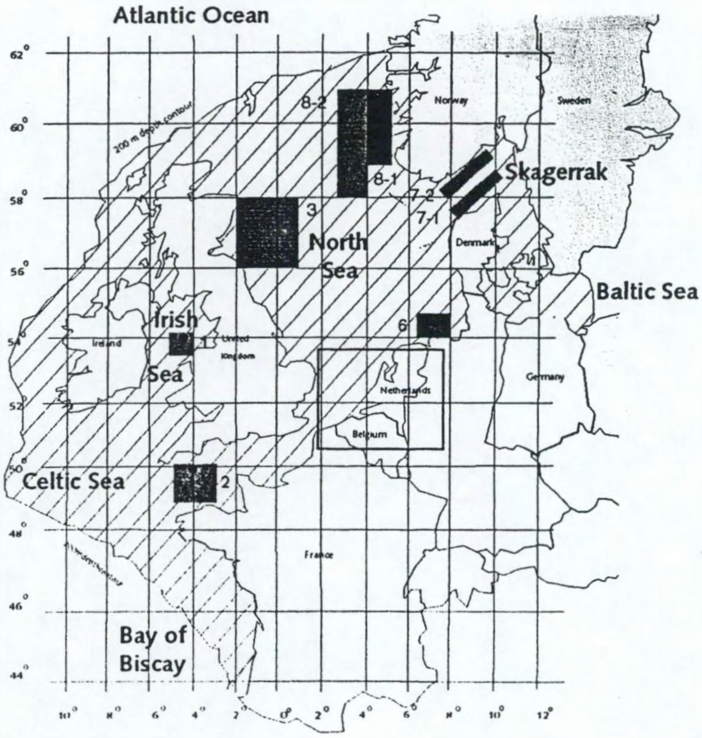


Table 4. Definition of position, period, variables and originator of long-term data sets					
station	name	position[1)]	period	parameters[2)]	originator
1	Port Erin	54°05'N, 4°50'W	1955-1994	S, T, Nutr., Chl *a*	Univ. Liverpool
2	Plymouth A1	50°02'N, 4°22'W	1903-1987	S, T, Nutr., Chl *a*	PML
3	Aberdeen	57°52'-59°85'N, 1°51'W-2°08'E	1960-1990	S, T, Nutr., Chl *a*	ML Aberdeen
4	Belgian coast	51°00'-51°52'N, 2°25'-3°27'E	1977-1992	S, T, Nutr., SPM, Chl *a*	MUMM
5	Dutch coast	52°12'-52°47'N, 3°15'-4°24'E	1973-1993	S, T, Nutr., SPM, Chl *a*	RWS/RIKZ
6	Helgoland	54°11'N, 7°54'E	1962-1993	S, T, Nutr., Chl *a*	BAH
7	Skagerrak	57°00'-58°00'N, 7°30'-10°30'E	1968-1994	S, T, Nutr., Chl *a*	DIFMR
8	Norwegian coast	58°40'-60°40'N, 3°00'-4°30'E	1940-1994	S, T	IMR

1) Only sites 1 and 6 are representing single points; for the other sites the positions area representing the position of a box of uniform hydrography, in which relevant data were merged

2) Only parameters relevant to NOWESP are indicated

Figure 3. Location of eight boxes and their subdivision in some areas. For the geographical position of the boxes and sub-boxes see Table 5.



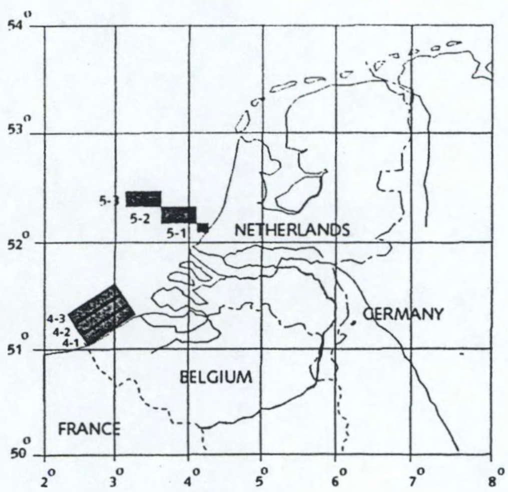


Table 5. Geographical positions of the NOWESP boxes.

Site		Longitude	Latitude
Box 1		5°00'W - 4°00'W	53°25'N - 54°10'N
Box 2		5°00'W - 3°00'W	49°00'N - 50°10'N
Box 3		2°00'W - 1°00'E	56°00'N - 58°00'N
Box 4-1	sub 1	2°25'E - 2°45'E	51°00'N - 51°17.5'N
	sub 2	2°45'E - 2°58.5'E	51°00'N - 51°25'N
	sub 3	2°58.5'E - 3°10'E	51°00'N - 51°28'N
	sub 4	3°10'E - 3°27'E	51°00'N - 51°34.5'N
Box 4-2	sub 1	2°25'E - 2°40'E	51°17.5'N - 51°27'N
	sub 2	2°40'E - 2°45'E	51°17.5'N - 51°30'N
	sub 3	2°45'E - 2°50'E	51°25'N - 51°32'N
	sub 4	2°50'E - 2°58.5'E	51°25'N - 51°34.5'N
	sub 5	2°58.5'E - 3°10'E	51°28'N - 51°38'N
	sub 6	3°10'E - 3°27'E	51°34.5'N - 51°42'N
Box 4-3	sub 1	2°25'E - 2°40'E	51°27'N - 51°42'N
	sub 2	2°40'E - 2°45'E	51°30'N - 51°47'N
	sub 3	2°45'E - 2°50'E	51°32'N - 51°52'N
	sub 4	2°50'E - 2°58.5'E	51°34.5'N - 51°52'N
	sub 5	2°58.5'E - 3°10'E	51°38'N - 51°52'N
	sub 6	3°10'E - 3°27'E	51°42'N - 51°52'N
Box 5-1		4°08'E - 4°28'E	52°02'N - 52°22'N
Box 5-2		3°48'E - 4°08'E	52°12'N - 52°32'N
Box 5-3		3°18'E - 3°48'E	52°22'N - 52°42'N
Box 6		6°40'E - 8°00'E	54°00'N - 54°45'N
	Helgoland	7°54'E	54°11.3'N
Box 7-1	sub 1	7°30'E - 7°50'E	57°00'N - 57°20'N
	sub 2	7°50'E - 8°10'E	57°00'N - 57°40'N
	sub 3	8°10'E - 9°10'E	57°15'N - 57°40'N
	sub 4	9°10'E - 9°30'E	57°20'N - 57°58'N
	sub 5	9°30'E - 9°50'E	57°40'N - 57°58'N
	sub 6	9°50'E - 10°30'E	57°45'N - 57°58'N
Box 7-2	sub 1	7°30'E - 8°00'E	57°40'N - 57°55'N
	sub 2	8°00'E - 8°45'E	57°50'N - 57°55'N
	sub 3	8°20'E - 8°45'E	57°55'N - 58°10'N
	sub 4	8°45'E - 9°10'E	58°05'N - 58°23'N
	sub 5	9°10'E - 9°50'E	58°15'N - 58°23'N
	sub 6	9°20'E - 10°30'E	58°23'N - 58°30'N
Box 8-1		4°00'E - 5°00'E	59°00'N - 61°00'N
Box 8-2		3°00'E - 4°00'E	58°00'N - 61°00'N

To deal with the strong gradients in the coastal zone and to separate water masses from different origing the coastal boxes of Belgium and the Netherlands were divided into 3 sub-boxes. The boxes in the Skagerrak and along the Norwegian coast were divided into 2 boxes.
For the calculation of fluxes transects were defined that mark distinct cross sections for import or export of water masses. Smith et al. (1997) defined for the NOWESP study a total of 15 (sub)transects, allowing detailed studies for the in- and effluxes of the Irish Sea and the North Sea: through the English Channel (3 transects), the Baltic (2 transects) and the open boundary with the North Atlantic (3 transects). In addition, these authors defined 7 transects that allowed a description of the fluxes within the North Sea itself (due to general circulation patterns).

The NOWESP Research Data Base group provided merged data sets for 10 state variables, the time series at the eight sites, and gridded data sets on the shelf for further use by the marine community (see annex III). Notwithstanding the large amount of data, gaps in data series are inevitable. In addition, the data are not distributed regularly in space and/or time. To enable the statistical ananalysis, interpolation procedures were applied by different methods, in order to obtain values at an agreed regular grid.

The data sets will be useful not only for further work on estimating fluxes across the shelf, but they will be basic for testing the validity of existing shelf sea ecosystem models, like ERSEM, NORWECOM, ECOHAM1, and others. Hence it is anticipated that the data sets will become available on CD-ROM.

3.1.3 Statistical treatment of the NRDB

The data, stored in the NRDB, was extensively statistically analyzed. Through combination of a large number of already existing data sets, where necessary the application of interpolation methods, and the application of modern statistical analysis techniques, information has been obtained from 'old data', which sometimes lead to new interpretations. These techniques have been described in a loose-leaf folder: *'NOWESP Manual Statistical Analysis Techniques'*.

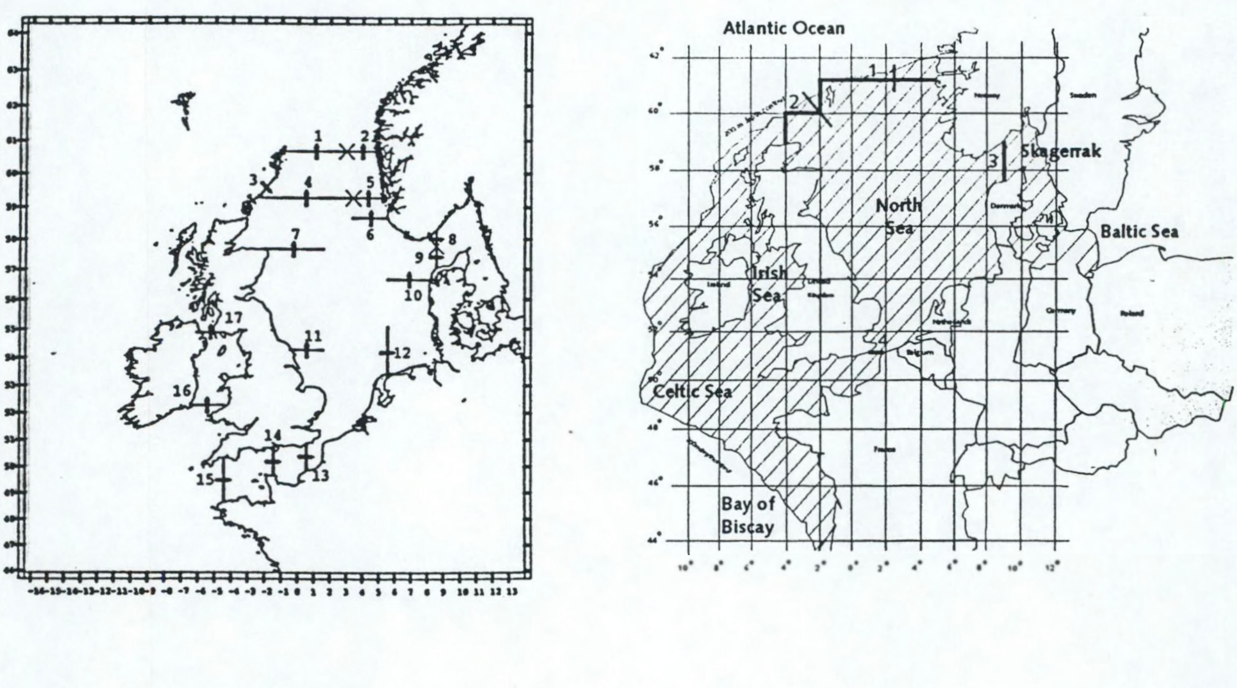
To be able to compare the results of the statistical analysis of data sets by each of the NOWESP partners, agreements were made on the statistical analysis techniques and computer packages to be used by the partners. These techniques included Simple Statistical Techniques, Time Series Analysis, Kriging, Principle Component Analysis (PCA) (see *Table 7*).

It should be stressed that it was not the intention to compose a new standard text, but only to take a limited number of techniques for joint applications. For each of these techniques examples are given in the afore-mentioned loose-leaf folder. The sequence and details of the procedures of data analysis were described for the NOWESP community in a communication by Radach, entitled 'A detailed concept for analysis of time series in NOWESP'. This paper served as a guideline for all working groups.

Table 6. Geographical positions of the cross sections with their length where fluxes of nutrients are calculated (see Figure 4b).			
section	from	to	length (km)
1	2°W, 61°N 2°W, 60°N	3°E, 61°N 2°W, 61°N	269 111
2	4°W, 61°N 4°W, 60°N	2°W, 60°N	111 169
3	9°E, 58°29'N	9°E, 57°5'N	156
4	0°55'E, 51°N	2°E, 51°N	76

Figure 4. Geographical position of the cross sections where fluxes of water (a) and nutrients (b) are calculated and compared (see also *Table 6*)

A B



Through merging of the appropriate data sets a more or less comprehensive data set resulted for a number of parameters. Due to the huge amount of data, it may be expected that, at least for several parameters and a number of regions of the shelf, a dense coverage would exist.

3.1.4 Analysis of shelf data sets

Spatial distributions of monthly mean data sets were obtained for temperature, salinity, the nutrients phosphate, nitrate, nitrite, ammonium, silicate, as well as for chlorophyll *a* and suspended particulate matter (*Figure 5*). Annual cycles were analyzed and compared with existing atlasses for the North-west European shelf. Although the distributions still have non-negligible gaps, in comparison with earlier attempts much larger areas can be mapped now with the NOWESP data set than before.

In specific areas with steep gradients, such as frontal and coastal regions, the resolution proved to be not sufficient. Furthermore, the shelf shows a dynamic behaviour and is varying continuously through changes in meteorological conditions and variations of the exchange with the Atlantic Ocean. Therefore special attention was given to problems such as under-sampling of fluctuations and insufficient resolution in some areas. For the particulate suspended sediment data these problems were solved through optimization of the statistical techniques and combining the NOWESP data with information from satellites (*Figure 5*).

For the *temporal distributions*, the above-mentioned long time series at eight locations (see boxes in *Figure 3*) were analyzed for the parameters temperature, salinity, suspended particulate matter, nitrate, phosphate, silicate, chlorophyll *a* and zooplankton (copepods). For the analysis of the box-data, the 35 year period 1960-1994 was chosen. This was because before 1960 not sufficient data is available for a proper analysis. Time series analysis was done on three different time scales: long-term (decade), annual and short-term (season). Also long time series for some variables from the Rockall Channel, just outside the NOWESP area in the Atlantic Ocean, were used in the analyses.

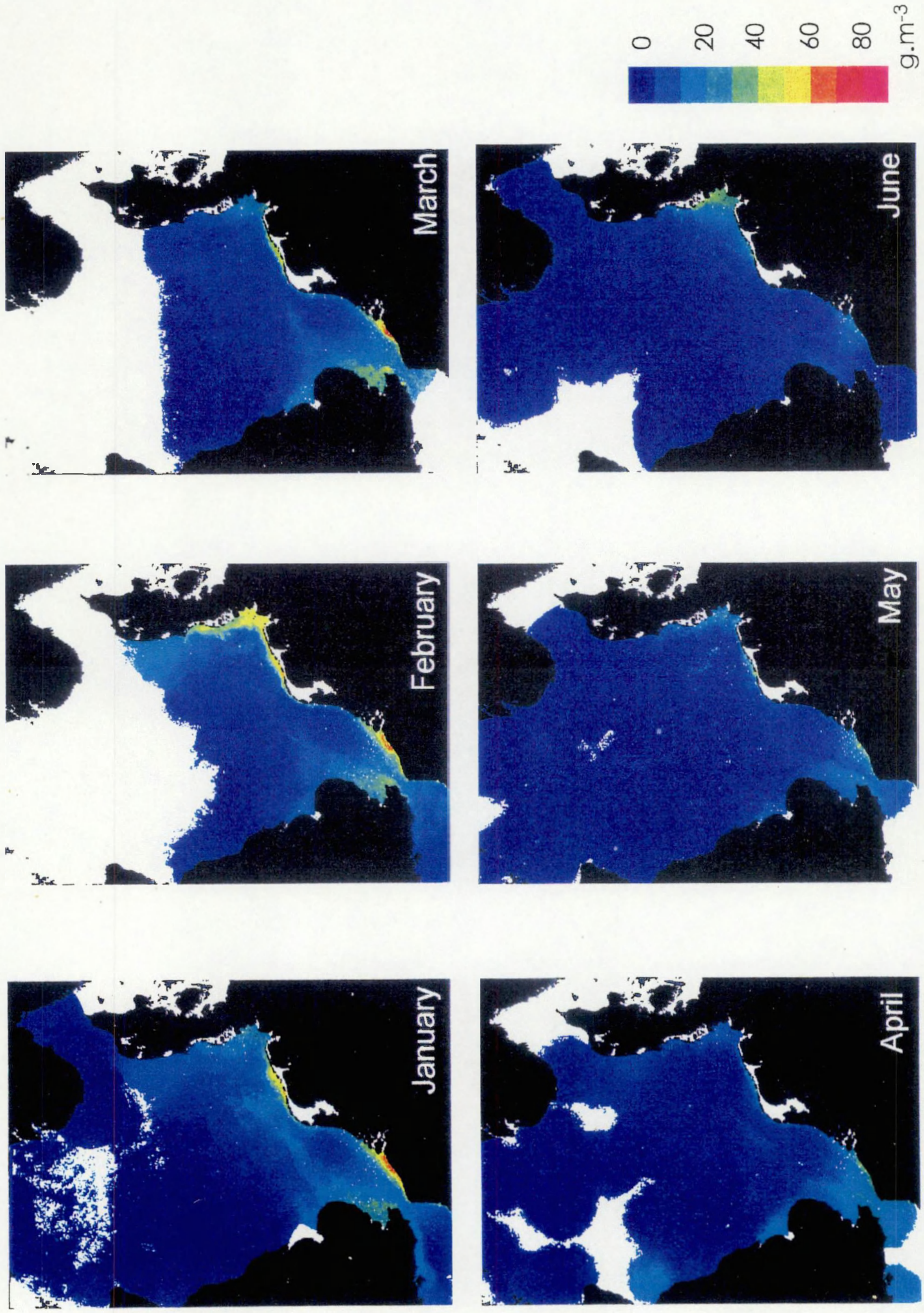
Seasonal cycles

From the analysis of data series of the eight longterm data series, the seasonal cycles appeared to be dominant. The simultaneous occurrence of temperature anomalies that were observed on the entire shelf proved that the sea surface temperature is mainly controlled by the heat flux from the atmosphere.The seasonal cycles of salinity are dominantly the result of fresh water inputs in the coastal regions, showing good correlations with seasonal variations of precipitation on land.

The seasonal cycles of biological parameters showed to be strongly influenced by the availability of light and, to a lesser extent, to water temperature.

Concentrations of nutrients demonstrated relatively high values in winter due to regeneration and input processes, and low values in summer as the major part of the nutrients is incorporated in biological compounds. This interplay between light and nutrient availability was investigated more in depth, giving special attention to the spatial variation of these processes over the shelf. Variations in nutrient and suspended matter concentrations, influencing the availability of light, together with differences in the hydrodynamic features over the shelf, were demonstrated to be responsible for the observed spatial variations in the seasonal cycles.

Figure 5. Monthly distribution of suspended particulate matter in the North Sea calculated with merged data sets from the NOWESP data base (1973-1993) and monthly composite reflection images (1990-1991). White areas in the distribution plots are caused by the lack of data in the particular area, black spots are due to cloud cover in th reflection composites.



Statistical Analysis Technique	Application	Methods and/or Statistical Parameters
Simple statistical techniques	Simple checks on data: o quick summary of the distribution, to detect suspect features of the data o comparison of data sets o to decide whether two data sets can be merged	median, hinges, extremes
Time series	o to detect the mean values and variability, to obtain information about the relevant temporal scales of processes o to demonstrate relationships between data sets at different locations o to use this information for prediction, interpolation, etc.	means, medians, standard deviations, trends (linear and nonlinear), variance spectra, auto-correlation and cross correlation functions, cross spectra and coherence spectra
Kriging	o to interpolate the data on the appropriate grids, o to determine averages over subregions (spatial averaging)	mapping, based on samples of data
Principle Component Analysis (PCA)	o to detect some structure within a data set o to determine correlations of patterns of different parameters with each other	spatial patterns
Principal Oscillation Patterns (POP)	o to detect some structure within a data set o to determine the development of such structures in time	empirical orthogonal functions (EOF's), spatial structures and their development in time

Table 7. Overview of agreed statistical techniques for application in the NOWESP project.

Seasonal variability

An example of the annual cycles is presented for dissolved phosphate as monthly means for the Irish Sea (box 1) in Figure 6.

A clear seasonal pattern is present during the period 1954-1994. As can be seen from the relatively high values in the winter period and the lower values during summer months. Starting in the 1970's the concentration of phosphate increased during the winter months. In the years 1975 and 1993 the concentrations were relatively high during the summer months. In general, phosphate concentration remains above 0.1 μM during summer in the Irish Sea, which indicates that phosphate is not limiting the phytoplankton growth and production. There may be an additional source by the runoff of phosphate from rivers.

Annual trend and annual variability

The results, as given for the various boxes (see *Figure 1* for the details) show, that the concentration of phosphate increases in the 1960's and 70's in the Irish Sea (box 1), the English Channel (box 2) and in the German Bight (box 6) (*Figure 7*). In contrast, the phosphate concentration decreases (*e.g.* Dutch coastal zone, box 5) or remains at about the same level (*e.g.* Skagerrak, box 7) in the 1980's and 90's, except for the box in the Irish Sea (1) where the concentration of dissolved phosphate continues to increase (*Figure 7*).

Decadal variability

Long-term variations and trends have a high scientific and socio-economic interest because they illustrate developments in the marine ecosystem. However, the determination of such trends and variations needs rather long time series, which are unfortunately extremely scarce. Investigations to analyse NOWESP time series for such variations were carried out primarily for the parameters temperature and salinity, of which a huge amount of data is available, but also for some biological parameters.

For water temperature and salinity prominent periods were found around 8 and 17 years. It appeared that for most other parameters (like nutrients) long-term trends were difficult to establish. This was mainly due to the fact that the sets of reliable data were too short for a proper analysis. Concerning the physical parameters, it seems that the decadal variability on the North-west European Shelf is mainly controlled by the synoptic climatological forcing. A distinct correlation exists between the atmospheric heat fluxes and the sea surface temperature and between precipitation (leading enlarged river runoff) and salinity in the coastal regions. Advection by the flow field (with global scales in the order of one year) seems to be of minor importance.

3.1.5 Fluxes and budgets

One basis of the flux calculations are the hydrodynamic models. Within the NOWESP group a number of such models are available. Simulations of the circulation over the North-west European Shelf covering periods up to 40 years were undertaken by three NOWESP institutes. Real-time forcing was obtained from 6-hourly sea surface pressure and wind data from a diagnostic model

Figure 6. Example of the annual cycles of dissolved phosphate (μM) presented as monthly means in box 1 (Irish Sea, A), box 2 (Channel, B) and box 5 (Dutch coastal zone, C) (From: Laane et al., 1996; see Bot et al., 1997).

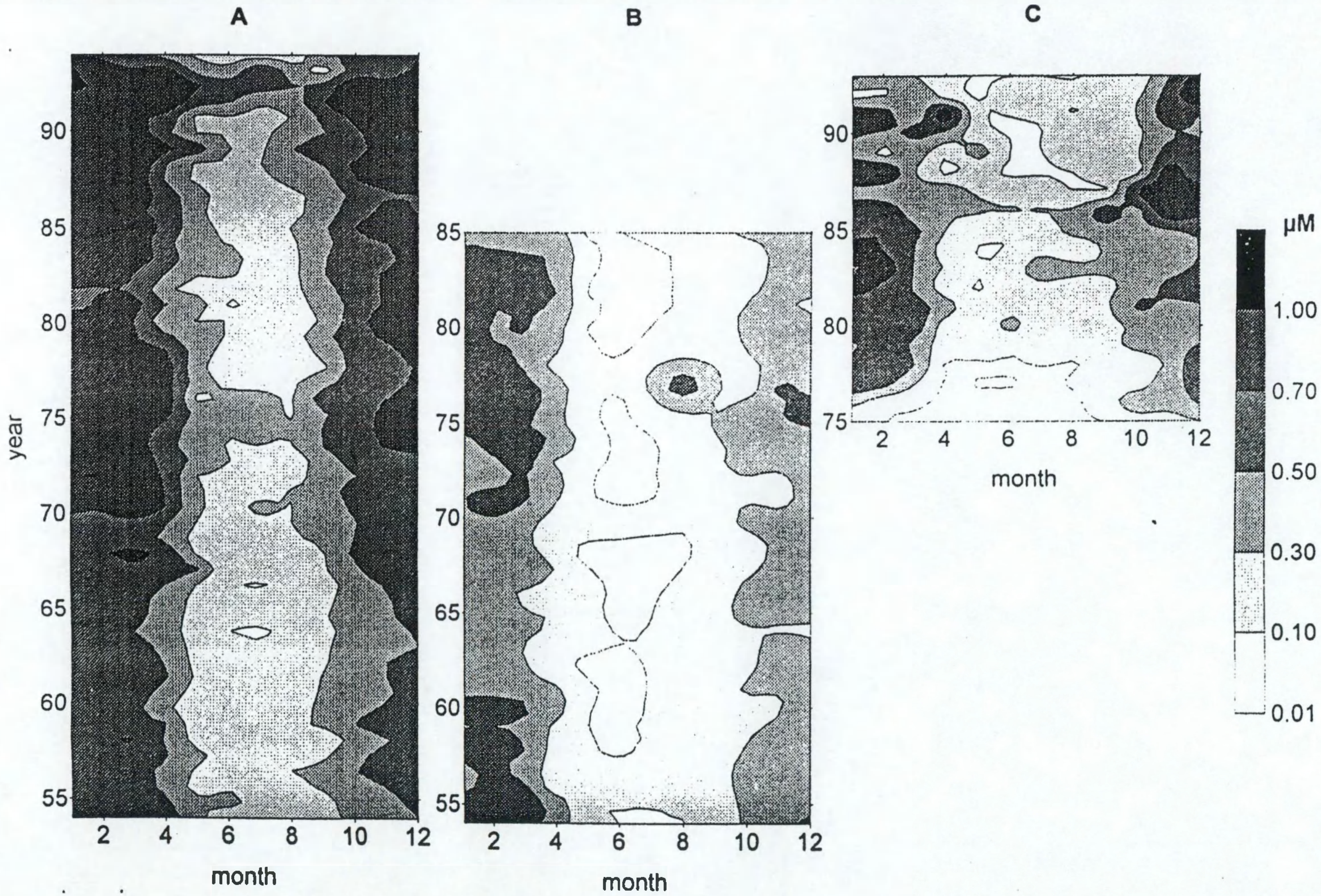
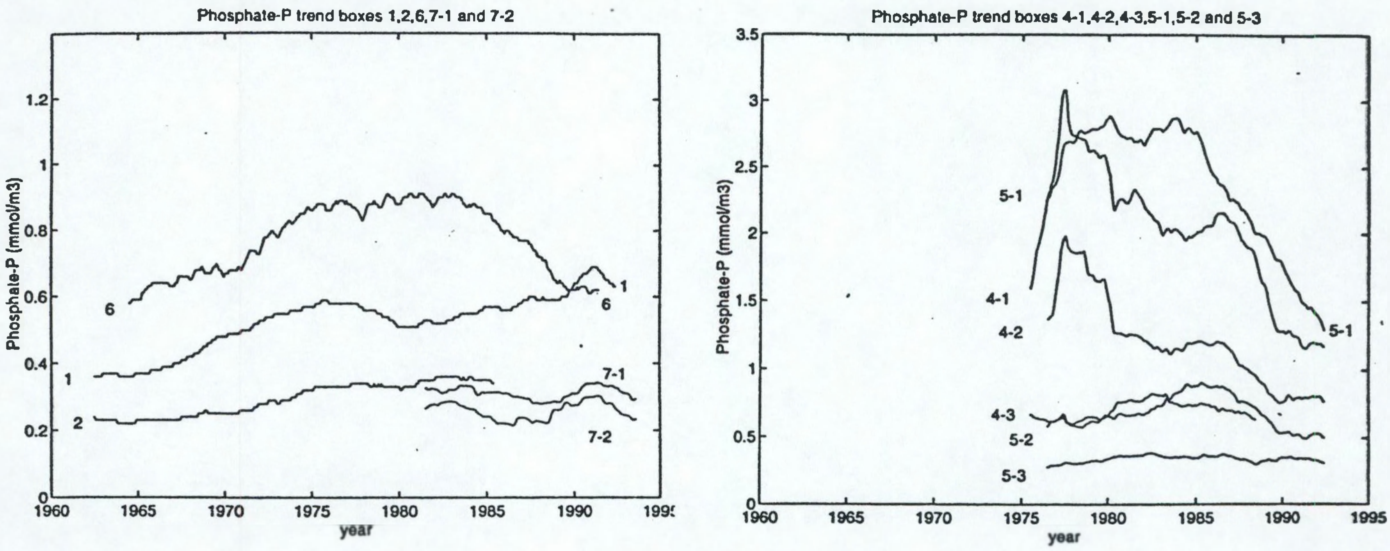


Figure 7 Trend in dissolved phosphate (in μM, running mean over 3 or 5 years) in the surface waters of all NOWESP boxes (From: Visser et al., 1997; Sündermann et al., 1997).



covering the eastern Atlantic and Europe on a 75 km grid over the period 1955 to 1994. The models varied from a 'simple depth-averaged storm surge model' to a sophisticated 'three-dimensional baroclinic model with turbulence closure'.

Volume transports (as function of inflow and outflow) across 11 key boundaries and through ERSEM boxes were calculated (see for the boundaries Figure 4A). An intercomparison between three models (IfM, IMR, POL) was made. Although flow directions confirmed generally accepted circulation pattern of the North Sea, and the variabilities in the water volume transport demonstrated a good similarity, the baroclinic and barothropic models showed significant differences in the mean values of the water transports. The baroclinic models (IfM, IMR) provide a more realistic representation of the water fluxes through the deep water sections.

Combination of these water circulations and the concentrations of nutrients give estimates of the constituent fluxes and budgets. Special attention was given to make an estimate for the nutrient fluxes from the Atlantic and Baltic inflow into the North Sea. Both the water flows and the nutrient concentrations showed distinct seasonal and interannual variations.

The annual mean fluxes of dissolved phosphate, nitrate and silicate through the boundary sections for the upper 30 meters and for the total water column for the years 1976-1995 are presented in Table 8. In general the mean annual fluxes of the three nutrients are in agreement with the data reported in the literature, the order of magnitude is similar. However, where in most literature studies the variation in the fluxes is caused by the variability in the nutrient data, in this study the variability is only caused by the variation in calculated water flows. It appears, when comparing both methodologies, that the variability in (calculated) transported water masses is considerably larger than for the nutrients.
The discrepancies between the different approaches as seen in some cases in the table, is only caused by the differences in the calculated water transport, as given by the respective models (the same nutrient data were used for both approaches).

Table 8 Annual mean fluxes F (in ktonnes/year) and their standard deviations of nitrate (N), phosphate (P) and silicate (Si) for two model calculations and four Sections (see Figure 4b), based on the sum of the products of monthly means of water transport (Q) and nutrient concentrations [C] (from: Laane et al., 1997)
(IfM: Institut für Meereskunde, HAMSOM model; IMR: Institute for Marine Research, NORWECOM model)

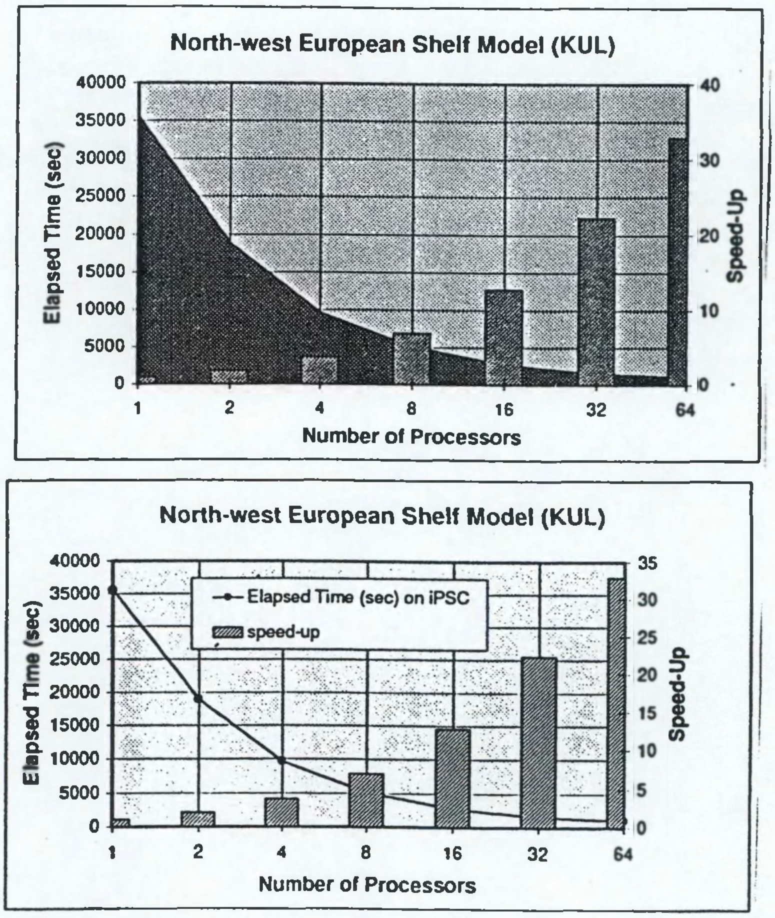
	IfM (30 m)			IMR (30 m)			IMR (total depth)		
	NO_3(N)	PO_4(P)	SiO_4(Si)	NO_3(N)	PO_4(P)	SiO_4(Si)	NO_3(N)	PO_4(P)	SiO_4(Si)
Section 1	842.4	140.5	696.2	735.1	122.5	610.0	3,635.3	651.9	3,519.2
s.d.	459.7	77.1	388.1	350.4	58.7	295.4	907.9	163.8	917.8
Section 2	811.6	160.4	853.0	207.2	39.6	210.4	336.5	61.5	327.8
s.d.	287.9	56.4	299.7	211.5	41.2	218.8	392.3	83.9	379.6
Section 3	484.0	103.5	775.9	-12.5	-6.1	-65.4	-136.1	-26.5	-179.9
s.d.	162.6	33.7	249.6	250.2	52.3	382.4	65.8	12.5	84.2
Section 4	146.8	39.9	195.7	116.7	33.1	164.7	161.8	26.8	161.3
s.d.	197.2	50.9	254.6	188.5	49.1	244.5	235.7	39.2	236.8

3.1.6 New generation shelf flux models

Modelling system dynamics of shelf seas is faced with gradients and processes on many space and time scales. Hydrodynamical, transport and biogeochemical processes are interrelated and have to be treated in a balanced and integrative way. Present developments either include advanced 3D hydrodynamic and transport models but use only a simplified ecological parametrisation, or they feature a sophisticated ecological model (including many different state variables), with a simple hydrodynamic parametrisation (the so-called 'box model', describing processes in an averaged environment over a large space). However, integrated ecosystem modelling, as well as large scale flux calculations with sufficient detail in specific areas, needs a new generation shelf models, where the computing power of modern High Performance Computing systems is exploited.

From experiences with High Performance Computing techniques it came clear that the availability of parallel computers with distributed memory offers interesting possibilities for large scale simulations. Because the numerical algorithms employed in existing models (e.g. ADI time integration) are often hard to parallelize, new generation flux models should make use of numerical algorithms which are not only chosen for mathematical properties such as robustness, stability, efficiency, and accuracy, but also for high performance computing properties like parallelization and vectorizability. Experiments with newly developed numerical algorithms, such as domain decomposition and time integration methods, demonstrated the possibilities of significantly faster simulations.

Figure 8 Example of the influence of number of processors on the elapsed time (sec) on the performance of the North-west European Shelf model (from Berlamont et al., 1997).



3.2 Shelf Sea data management: Lessons learned

After three years of project time the feasibility of setting up a research data base is discussed. Ways to optimize data access and evaluation are proposed. A project-oriented Research Data Base is a useful tool in research, because of its flexibility and proximity to the research going on in the project. However, several conditions have to be fulfilled to obtain the optimum benefit of such a service unit. Given the restricted staff which is usually devoted to such a task, an early start of the data management of the project is recommended.
For enabling future projects to succeed in an analogous compilation of relevant data for their use, as performed in NOWESP, the task of organizing the data sets for any short-termed project should be shared between a research data base group and a national or international data centre, to utilize the experience and software of the data centres. The delivery of the quality controlled data sets obtained within any data-producing project to the national data centres has to be ensured. It is recommended that in the future the quality control of the data should be ensured by the originators and/or by the data centres before delivering the data sets to the research data base. The delivery of the (full) data sets should be checked and the quality should be approved by authorized data centres.

3.3 Future needs on numerical modelling and field measurements

Through concerted actions of experts in the fields of data management, data analysis and shelf flux modelling, the 'future observational and modelling needs' were indicated. It became clear that particularly accurate data sets from the shelf boundaries are needed. These include the inputs from the rivers, ocean and the air, as well as exchanges with the bottom. Also more insight into the climatological variability and its impact on the sea is required. The long time series are of eminent importance, so that the European Community should be in support of initiatives that aim at ongoing long-term measurements, at least in view of enhanced harmonization of methods and measurements. New monitoring strategies are required, in which operational oceanography is executed by collaboration at a full European scale.

There is a strong need for a (or some) detailed and high resolution Continental Shelf Model(s) which is (are) verified over a long period of time (e.g. 20 years). It seems that the recent developments on High Performance Computing (HPC) are able to make such models operational for practical applications in the near future.

It was concluded that for a better understanding of the shelf as a link between land and ocean, the existing NOWESP data base should be extended with data of the shelf boundaries (forcing functions), whereas detailed shelf flux models and modern data assimilation techniques will be helpful to fill the gaps. Data sets of the shelf should be analyzed together with these new data from the boundaries.

4. EXPLOITATION OF RESULTS

4.1 •ontribution to the management of the North-west European Shelf

The North-west European Shelf, situated between land and ocean, is a highly valuable resource for fisheries, minerals, oil and natural gas. It is located adjacent to large human populations and therefore subject to atmospheric and coastal inputs of pollutants. Physical transport of these pollutants, their modification by the coastal food web, and their transfer to humans, have become problems of increasing complexity in the continental shelves.

The urgent need for quality data, for harmonized approaches of collection and interpretation is in support of new initiatives for international monitoring programmes. Incorporation of additional sources of information, such as from remote sensing or from integrated mathematical modelling, seems a way to increase our understanding of the functioning of shelf areas. It has become evident from the NOWESP project that larger scale monitoring programmes are a prerequisite if we want to understand shelf related processes. For these scales the common national monitoring programmes, mainly focusing on the areas in the viscinity of the country of concern, seem not sufficient. New initiatives are under way, however, such as e.g. (Euro)GOOS and OPTIMON.

Overfishing is an additional human-induced stress on the food web of the continental shelf. Furthermore the shelves are very important areas for shipping and recreational use. It is clear, therefore, that from an economic and social point of view the importance of the continental shelf cannot be overstressed and they seem certain to become of even greater significance in the future. A proper management of such Large Marine Ecosystems (LME's) represents a major challenge to international cooperation the coming decades.

For the North-west European Shelf, together with the East Atlantic, such a cooperation is established by the Environmental Assessment and Monitoring Committee (ASMO), where assessments are being made for all OSPAR convention regions. Thus an overview of the present status of the health of the environment is given, including all aspects of man's influences. From monitoring and research prorammes, the required information is obtained to judge the quality of the marine environment.

NOWESP contributes to more insight into the variability and long-term trends in the behaviour of the shelf ecosystem. Particularly the data, gathered from so many sources, may be helpful in supporting the above-mentioned management activities. We have the intention to organize a NOWESP presentation in the ASMO Committee.

4.2 Use of data sets: the NOWESP Research Data Base

A key element within the NOWESP project is the NOWESP Research Data Base (NRDB), in which a tremendous amount of shelf data is stored. These data sets were obtained not only from the NOWESP partners, but also from institutes, data centres, and individuals outside the NOWESP group. The NRDB is located at the Institut für Meereskunde in Hamburg.

The data compiled during the execution of the NOWESP project represent a unique data set for the North-west European shelf. The data set is sufficiently comprehensive to allow for definition of long time series at about eight sites, which have been analysed by means of time series analysis. It further enables the derivation of climatological annual cycles of horizontal distributions of nine main state variables. NOWESP thus provides very valuable data sets for estimating budgets and fluxes across the shelf and in addition important data sets for the forcing and validation of ecological shelf models.

During the project the data sets could be obtained by all the NOWESP partners through a FTP server in Hamburg. In June 1996 the NOWESP data sets were written on EXABYTE tapes.

It is our feeling that additional to European MAST projects, the NOWESP data set is also valuable to serve the needs of a number of large international projects, such as the current international global core projects within the International Geosphere-Biosphere programme (IGBP), like Land-Ocean Interaction in the Coastal Zone (LOICZ, the UK-LOIS), Joint Global Ocean Flux Study (JGOFS), and Global Ocean Ecosystem Study (GLOBEC), which need large data sets to reach their goals. These activities contribute to the presence of the EU concerning shelf sea research in the world-wide community.

4.3 Use of models: Initiation of new activities within the MAST Programme of the EU

Although the modelling part of NOWESP is only a minor part of the NOWESP project, it showed to be very stimulating in bringing European scientists together, investigating the possibilities of new hardware developments for aplications in Marine Science. To arrive at a broader platform for exchange of experiences and information concerning High Performance Computing (HPC) and Marine Science ('Application of High Performance Computing Techniques for the Modelling of marine Ecosystems', MMARIE) started as a Concerted Action of the MAST in the field of numerical modelling of marine ecosystems.

During the first annual meeting of NOWESP in Plymouth (June 1994), the initiative has been taken for the North Sea Model Advection-Dispersion Study (NOMADS). It is a concerted action, commisioned by the EU, for the comparison of the various European advection-dispersion models for the North-West European shelf. Such models are availabale at a number of institutes in the various countries within and around the North-West European Shelf. The aim of NOMADS was and is to compare the spatial and temporal coherence of the simulation results of the advection-dispersion models for a well defined realistic simulation of the North sea, and, to compare the charateristics of the used advection-dispersion models for a schematic idealized case of relevance to the North Sea.

From the NOWESP results it is concluded that for a better understanding of the shelf as a link between land and ocean, the NOWESP data base should be extended with data of the shelf boundaries. These 'forcing functions' include the inputs from rivers, ocean and the air, as well as exchanges with the bottom. Also more insight into the climatological variability is required. Detailed shelf flux models and modern data assimilation techniques are expected to be helpful to fill the gaps. Such a next step is being translated into a proposal for a future NOWESP II project, in which data of the shelf will be analyzed together with the new data from the boundaries.

4.4 Use of methods

4.4.1 Data assimilation

The approaches of data collection and of data assimilation as has been used in the NOWESP project proved to be very helpful for cooperative and integrated actions on the analysis of merged data sets, of which the data had several origins. This experience could be made available to other institutes and individuals in the European Community. Therefore the organization of a special course 'statistical analysis of marine data' is under consideration, financed as a Supporting Initiative by the EU.

4.4.2 Common approaches in application of statistical methods

In order to harmonize the statistical analysis of the various data sets a set of common statistical approaches was agreed upon (see Table 7). It was explicitly not the intention of the project to develop new statistical methods or to compile a new Handbook on statistical methods. The Manual on Statistical Analysis Techniques that was produced, was submitted to all partners during the second year of the project. It served only to have a written down agreement on the statistical techniques used, and hence to allow comparability between the different partners of the project.

4.4.3 Application of High Performance Computing (HPC)

High Performance Computing (HPC) systems are coming available at a rapid rate, and are increasingly being applied for several scientific disciplines, where huge amounts of computer processing is needed. It was the challenge of the modelling part of NOWESP to investigate the possibilities of such new hardware developments for applications in marine science, and particularly for realistic simulations of the transports of biogeochemical substances over the continental shelf.

The current generation of HPC systems is based on parallellism to increase both the calculation and storage capacities. Nowadays, a whole range of parallel systems is available in the computing centres of research institutes and universities. These systems may consist of a relatively small number (8 to 16) very powerful (vector)processors, or they may contain many (even thousands) of standard (low cost) processors (= massively parallel computing). The processors can be connected to a global shared memory or each processor can have its own memory (distributed memory systems).

Despite all these differences in hardware, the algorithmic and software issues to exploit the various parallel systems are essentially the same (data locality, work load balance, minimisation of communication and synchronisation, etc.). Recently some standards and software environments have been developed, which make parallel programming easier and allow to write portable software, which can run on various parallel systems.

As a kind of 'spinoff' of NOWESP, the EU has funded the already mentioned project MMARIE. Its objective is not to fund research on numerical modelling, but to create an interdisciplinary forum for the exchange of ideas and experience about the development and validation of (new generation) marine models, which use High Performance Computing techniques (HPC), and incorporate the full complexity of marine ecosystems ('ecological models'). Apart from establishing an internet network between partners, exchange of software, exchange of researchers and the organization of short courses on HPC and a workshop on parallellization of existing sequential codes, the concerted action pays special attention to the devlopment of new algorithms, particularly suitable for parallelization. MMARIE will also organize an intercomparison ('benchmarking') of parallel softwares and their implementation on different hardware platforms. In 1997 a joint meeting will be organized between the three actually existing MAST II concerted actions i.e. NOMADS, MEDMECS and MMARIE in Barcelona to exchange ideas and experience on benchmarking. In 1997 MMARIE will organize one of the parallel sessions of the conference of the European Geophysical Society in Vienna on the particular problem of cooperation between researchers of different disciplines (biology, chemistry, environmental sciences, numerical modelling, hydrodynamics, mathematics, computer science, etc.) in achieving full ecological models.

4.5 PhD work within the project

Although several students were involved in the activities of the NOWESP project, the work of Z.W. Song led in 1995 to a PhD thesis at the Katholieke Universiteit Leuven, under the title: 'Parallization of hydrodynamic models for distributed memory computers'.

4.6 Transfer of data and models from/to institutes

During the NOWESP project many contacts arose, through which the first valuable steps were made to convince people of the importance of the need for data integration within Europe. Outside the partners of the NOWESP group, the following contacts resulted in valuable contributions by transfering data and/or models to the NOWESP and the NRDB:

AWI	Alfred-Wegener-Institut, Bremerhaven, DE
BAH	Biologische Anstalt Helgoland, Hamburg, DE
BFAFi	Bundesforschungsanstalt für Fischerei, DE
BODC	British Oceanographic Data Centre, Bidston, GB
BSH	Bundesamt für Seeschiffahrt und Hydrographie, Hamburg, DE
DOD	Deutsches Ozeanographisces Datenzentrum, Hamburg, DE

HELCOM	Helsinki Commission, Helsinki, SF
IAB	Institut für Allgemeine Botanik, Univ. Hamburg, DE
IBL	Institut für Biochemie und Lebensmittelchemie, Univ. Hamburg, DE
ICES	International Council for the Exploration of the Sea, Copenhagen, DK
IFMKI	Institut für Meereskunde, Univ. Kiel, DE
IHF	Institut für Hydrobiologie und Fischereiwissenschaft, Univ. Hamburg, DE
IOC	Institut für Organische Chemie, Univ. Hamburg, DE
IOCB	Institut für Organische Chemie und Biochemie, Univ. Hamburg, DE
MAFF	Ministery for Agriculture Fisheries and Food, Lowestoft, GB
MBA	Marine Biological Association, Plymouth, GB
MLA	Marine Laboratory, Aberdeen, GB
NOD	Norwegian Ocean Data Center, NO
PEML	Port Erin Marine Laboratory, Isle of Man, GB
PML	Plymouth Marine Laboratory, Plymouth, GB
RUG	University of Groningen, NL
RWS-RIZA	Rijkwaterstaat, Lelystad, NL
RWTH	Rheinisch-Westfälische Technische Hochschule, Aachen, DE
SMHI	Swedish Meteorological and Oceanographic Institute, Göteborg, SE
TUHH	Technische Universität Hamburg-Harburg, DE
UL	Université de Liège, Liège, BE
VUBB	Free University of Brussels, Brussels, BE

Unfortunately, data sets from Denmark arrived after the deadline for submission, when data processing had already started. All together all these contacts contributed essentially to the dissemination of the conviction of the relevance of data integration on an European scale.

4.7 Exploitation of NOWESP results by each of the NOWESP participants

4.7.1a Rijkswaterstaat, Nat. Inst. for Coastal and Marine Management (RIKZ)

Rijkswaterstaat (RWS) is a department of the Netherlands Ministry of Transport, Public Works and Water Management. One of the responsibilities is the management of the Dutch part of the North-west European shelf. The management of the North Sea was predominantly directed to the Dutch part of the North Sea.

To that end the unique NOWESP data set is extremely helpful in the analysis and understanding of the variability and trends of the shelf as a so-called Large Marine Ecosystem (LME). Particularly the discrimination between man-made and natural variability has its attention. The data set will also be applied for the calibration and verification of shelf flux and water quality models.

The statistical analysis of shelf data by jointly agreed techniques increased the experience with shelf data, particularly the analysis of data series with gaps and data sets at points on unequal distances. This experience is expected to be helpful for analysis of shelf data in the future.

The NOWESP project stimulated thinking on a wider scale. So it may be expected that the experience and knowledge of the NOWESP project will have an important impact on te scale of thinking

concerning the health of the marine ecosystem. A first example is already the so-called 'North-West European Shelf Pilot Model', a transport model for the shelf area that runs on a PC (section 5.4.3). The Model was a co-production of Rijkswaterstaat, National Institute for Coastal and Marine Management /RIKZ and Delft Hydraulics.
The RIKZ organised the ASMO Modelling Workshop on Eutrophication Issues (5-8 November 1996, the Hague) in which the NOWESP data set played an essential role.

4.7.1b Forschungs- und Technologiezentrum Westküste, Büsum (FTZ)

The data set of NOWESP will be used also by the FTZ-Westcoast in follow-up projects on the eutrophication state of the german Wadden Sea. They form a background and long-term data set against which the present situation will be compared. Moreover it is intended to use some of the data sets in the FTZ GIS system for the Wadden Sea of Schleswig-Holstein. The comparisons will facilitate the ideas on natural and man-made effects on the coastal zone, which is also a major topic in a nationally funded project TRANSWATT.

4.7.2 Institute für Meereskunde, Hamburg (IfM)

The Institut für Meereskunde der Universität Hamburg is one of the leading german institutes in North Sea research. Since 1984 it is the coordinator of major national projects on nutrient and contaminant fluxes such as ZISCH, PRISMA and KUSTOS.
The forthcoming national synthesis of the last decade of North Sea research (on demand of the German Bundesminister für Bildung und Wissenschaft, Forschung und Technologie) will be highly influenced by the NOWESP findings and philosophy.
The institute organised the recent International Symposium 'New Grand Challenges in North Sea research' with up to 200 participants from all countries surrounding the North Sea. The NOWESP results have been one major issue, and the EC DG XII was one of the sponsors of the Symposium.
The Institute für Meereskunde has contributed, by its partnerships in several MAST projects, to the exchange of knowledge between these projects. From ERSEM large data sets became available for NOWESP, and from NOWESP merged data sets were used as validational tools in ERSEM. Also, ERSEM made available a 39-year long hydrodynamic simulation of the circulation on the North-west European shelf, which was used for estimating the fluxes of nutrients across the shelf.
The NOWESP data set was provided to the ASMO Modelling Workshop on Eutrophication Issues (5-8 November 1996, the Hague) to enable a comparison between different eutrophication models. The NOWESP data set was also utilized for the comparison of three-dimensional ecological modelling in the German project KUSTOS.

4.7.3 Katholieke Universiteit Leuven (KUL)

Important aspects for the exploitation of the work and of the results of NOWESP was for the KUL the successful PhD study of Dr. Z.W. Song at our University.
Through the NOWESP project, a concerted action MMARIE (numerical modelling of marine systems) within the EU MAST II framework has been set up, a joint action between several NOWESP partners and a number of other institutes (CETIIS, Ivry-sur-Seine, France), CRS4 (Cagliari, Italy), SOTON (Southampton, United Kingdom), Univ. Bradford (United Kingdom), and LIM (Barcelona, Spain).

4.7.4 Netherlands Institute for Sea Research, Texel (NIOZ)

In the most recent science plan of the Netherlands Institute for Sea Research presented in 1996 two major research areas were prioritized:

- cycling and transport of matter and energy in and across coastal seas, shelf seas and oceans, and
- long-term variability in the functioning of marine systems.

The research performed within the NOWESP project fits extremely well within both items and the results will be, and have been, used in several ongoing and future research projects. To give an example, the NOWESP data set of suspended matter concentrations in the North Sea has been used together with satellite-borne reflection images to assess the spatial distribution of particles in this area. This project was funded by NIOZ and the Space Research Organization Netherlands (SRON), and is continued in an extended form, including modelling of sediment transport, together with several Dutch institutes in 1997 (funded by the Netherlands remote sensing board, BCRS).
The time series collected during the project in the NOWESP Research Data Base will be used in several studies on long-term variability and on marine ecosystem changes, presently carried out at NIOZ. Part of these studies is funded by the EC and hence carried out in cooperation with other European institutes.

4.7.5 Proudman Oceanographic Laboratory, Bidston (POL)

Proudman Oceanographic Laboratory (POL) is part of the National Environment Research Council of the United Kingdom. A large proportion of the research undertaken at the laboratory is modelling the hydrodynamics and processes of shelf seas including sediment, nutrients and salinity modelling. data collected for the NOWESP data base will be valuable for use in the calibration and validation of these models in projects such as LOIS/NORMS, PROMISE and a new NERC special topic 'Amodelling study to the nutrient dynamics, spatial and interannual variability of the marine ecosystem in UK continental shelf seas between 1988 and 1995'. Other data produced for NOWESP such as the 40 year model runs provide a unique hydrodynamic data set for use in other applications such as the analysis of extreme events.

4.7.6 IFREMER, Plouzane

The results of the Channel ecological model dealing with:

- the evaluation of nitrogen, phosphorous and silicon fluxes going from the Channel into the North Sea;
- the evaluation of the effect of a reduction by 50% of the Seine nutrient inputs on the phytoplankton biomass (annual mean, peak values) and primary production along the French coast of the Eastern Channel, and
- the importance of interannual fluctuations of phytoplankton abundance and diatom vs.dinoflagellate balance, as caused by either natural meteorological fluctuations or man-made trends in terrestrial loadings,

have been used as the French contribution to the ASMO modelling workshop on eutrophication in the frame of OSPARCOM (The Hague, 5-8 November 1996) and where mainly based on NOWESP results.

4.7.7 Sir Alister Hardy Foundation for Ocean Science, Plymouth (SAHFOS)

The Continuous Plankton Recorder Survey has operated across the North-west European Shelf for several decades and the NOWESP project enabled similar time series of physical and chemical data to be compared with the plankton dynamics, revealing interesting correlations which will be further investigated.The application of joint statistical techniques provided valuable analytical training in time series analysis which will be applied to future investigations.

4.7.8 Instititute of Marine Research, Bergen (IMR)

The institute of marine research (IMR) is an institute under the Norwegian Ministry of Fisheries. IMR has the main responsibility for advising Norwegian authorities in matters concerning the marine environment and the living resources therein.

The work within NOWESP has shown how valuable long time series of environmental data are, when looking into changes considered to be due to the impact of man. The research data base, NOWESP RDB, gathered both from official and non official sources (governmental institutes and universities) is a solid basis for understanding and thereby advising on the variability, both natural and anthropogenic, that occur within the NOWESP area.

IMR is continuously working on the refinements of its model of transport of nutrients and predicting primary production, the NORWECOM, in a 4 by 4 km grid. The results of NOWESP so far are a valuable asset in the monitoring of nutrients entering Norwegian waters and in predicting possible changes due to 'extra' inflow.

4.7.9 Institut für Ostseeforschung, Rostock-Warnemünde (IOW)

Within the IOW the NOWESP-results and experience gained in NOWESP have been widely exploited with regard to data handling, evaluation of long-time data series and preparation of data for the purpose of data assimilation in the near future by modellers. The most important result was to discover the existence of serious gaps in spatial and temporal resolutions of the data collected in the western Baltic Sea. This had led to the installation of equipment on our ships which enable a more continuous sampling, e.g. fluorescence probes for underway mapping of sub-surface chlorophyll, as a measure for phytoplankton development. Preparations to increase the use of automatic sampling systems are underway.

4.7.10 Management Unit of the North Sea Mathematical Models, Brussels (MUMM)

The Management Unit of the North Sea Mathematical Models (MUMM) is a research department of the Belgian Ministry of Public Health and Environment and is charged amongst others, to provide scientific advice to support the decision processes of the Belgian policy on international conventions and to manage mathematical models for studying the impact of decisions or of events.

To fulfill these tasks, MUMM is responsible for the management and the monitoring of the water quality of the Belgian Continental Shelf. Of course, the management of this area is carried out in conformity to the management of the other parts of the shelf.

The NOWESP data base therefore is extremely useful for the analysis and the understanding of the variability and the trends on the shelf. First of all, much more data became available on the Belgian Continental Shelf, which can be used in the analysis. However, the Belgian Continental Shelf is only a small part in the North-West European Shelf and is largely influenced by and related to the latter. Therefore, the availability of the data on the entire North-West European Shelf and the results of the analysis of these data, already performed in the NOWESP project, is a large step forward in understanding the variability and the trends on the North-West European Shelf and on the Belgian Continental Shelf in particular. Especially the discrimination between man-made and natural variability and between local and large-scale influences is of great interest.

The data set is of course also of a great importance of the calibration and the validation of shelf transport models.

At last, the statistical analysis of the shelf data, using jointly agreed techniques, increased the experience with shelf data, particularly the analysis of data series with gaps and data sets at points with unequal distances. The gained experience will be very useful for analysis of shelf data in the future.

4.7.11 Bundesanstallt für Seeschiffahrt und Hydrographie, Hamburg (BSH)

The working group 'Physical Seawater Properties' is one of the departments of the BSH very much interested in the analysis of time series from the North-West European Shelf. Special focus is on sea surface temperature and sea surface salinity (SST and SSS) data, mainly in context with questions of climate variability.

From our point of view, the NOWESP data set is indeed unique and helpful in filling data gaps at locations in which we are particularly interested. It further provides the possibility of linking signals from the Atlantic Ocean with those we see in the NOWESP boxes. The analysis of decadal variability and trends should give hints whether or not we can identify a climate change.

It is pointed out, that there is a need for more and much longer time series in order to obtain reliable answers to the questions mentioned. This means that, based on our international contacts within the NOWESP project, we have to complete the data set with respect to our investigations. It would make sense for our group to incorporate in our research data sets from the adjacent Atlantic in order to highlight evident relations with the North Sea System.

4.7.12 Environmental Science Unit, Trinity College, Dublin (ESU)

The activities of ESU-TCD in the NOWESP project can be grouped under the following headings:

- Identification of suitable Irish data bases for NOWESP;
- Tailoring and quality control of data bases to fit NOWESP requirements;
- Correction and checking of data bases (NORSAP, Dublin Bay) supplied to NOWESP data base,
- Interrogation of Irish Data Centre extended EDMED for Ireland for other possible data bases;
- Supply of data bases from FRC and UCG to data base and preliminary analysis of data.

The ESU participated in the NOWESP Workshops in Plymouth (Wilson, Brennan), Rostock-Warnemünde (Wilson) and Hamburg (Brennan). In addition, the Unit organised and hosted the June 1996 Workshop in Dublin.

4.7.13 Centre for Mathematics and Computer Science, Amsterdam (CWI)

A main research topic at CWI concerns the numerical treatment of environmental pollution problems, in the air as well in the water. The expertise obtained during the NOWESP project has been exploited in these environmental studies.

4.7.14 Delft University of Technology, Delft (TUD)

The results from the NOWESP project with respect to massively parallel simulation of continental shelf flow and transport models have been applied to the software package TRIWAQ, which is developed and used by RIKZ of Rijkswaterstaat in assisisting coastal and marine management. The parallel version of the TRIWAQ implementation is currently being in test use by RIKZ. The parallel TRIWAQ software enables more efficient usage of computing facilities (e.g. using a cluster of workstations which are idle at night) and enables the simulation of more accurate and complex models within an acceptable computing time through the use of high performance parallel computers.

4.7.15 University of Bordeaux, Bordeaux (CRESO)

Remote sensing techniques are of unique importance for coastal marine research to know parameters below the water surface, such as the concentration of suspended matter, phytoplankton pigments and yellow substance. During the next five years, a new generation of ocean colour sensors will be launched by different agencies (SeaWifs (NASA), Meris (ESA), OCTS (NASDA) and MODIS (NASA). In order to provide calibrations between sea colours and suspended matter (SPM) concentrations, sea truth measurements were realized from the data obtained in September 1994 in the Celtic Sea.

Radiance data of the sea-surface (upwelling radiance) and of the sky (down welling radiance) were recorded with a Spectron SE-590 in 256 channels. These spectra were processed to obtain reflectance curves between 380 nm and 1100 nm. Then from these data, the reflectances corresponding to AVHRR/NOAA channels were extracted and compared with the SPM data. This calibration as used to analyse an AVHRR C1 satellite immage.

Moreover, in 1996, from these spectral curves the refectances for CZCS, SeaWifs an Meris were simulated. A similar study has been realized off the Gironde estuary (France) in the years 1994/1995.

4.7.16 University of Liverpool, Liverpool (ERRC)

Participation in NOWESP has stimulated our interest in the long-range transport of radionuclides. Though our work on the radiometric dating of estuarine sediments we have a growing data base on the distribution of ^{210}Pb, ^{137}Cs and ^{241}Am around the North-west shelf. Work in progress is concerned with using inventory ratios to distinguish fall-out ^{137}Cs from that deriving from NPP discharges (principally Sellafield).

4.7.17 Delft Hydraulics, Delft (DH)

The NOWESP contribution of Delft Hydraulics has been committed entirely to the development of domain decomposition methods. Domain decomposition is applied with two purposes: (1) The increase of modelling flexibility and (2) High performance computing on parallel platforms. Within

the framework of NOWESP the emphasis has been on explicit coupling techniques for different domains with implicit flow and transport solvers. A number of publications on this subject had been written. Within Delft Hydraulics the development of
Domain decomposition as part of the DELFT3D simulation system is still in progress. This is due to the successful preliminary studies that were enabled by the NOWESP project.

5. DISSEMINATION OF RESULTS

Due to the number of NOWESP partners (18 institutes from 7 European countries), the large number of meetings and intensively working together on the various subjects, particularly the analysis of data series, contributed already in itself to the dissemination of shelf sea knowledge and experience between the various renowned European institutes on shelf sea research (see section 2.7).

5.1 List of presentations related to NOWESP

During the NOWESP programme a large number of oral and/or poster presentations have been given by representattives of the NOWESP institutes:

1993, September 20-23	MAST Workshop Assessing Data Quality Methods, Experiences and Application, Dublin, IE
G. Radach	The North-west European Shelf Programme - Aims and Data Needs
1994, March 8-11	Oceanology International 94
W. van Leussen	North-West European Shelf Programme - NOWESP
1994, June 21-23	EUROSIM 1994 Conference: Massively Parallel Processing: Applications and Development, Delft, The Netherlands
W. van Leussen	Shelf flux modelling: a challenge for the future
H.X. Lin	Parallel simulation of 3-D flow and transport models within the NOWESP project
E.A.H. Vollebregt	Massively parallel simulation of fluid flows: first results
E.D. de Goede	A multi block methods for the 3-D shallow water equations
J. Kok	Efficient solution of linear systems for the time inegration of 3-D transport models
Z.W. Song	A comparison of parellel solvers for the 2-D shallow water equations on distributed memory parellel computers
B.P. Sommeijer	Time integration of three-dimensional numerical transport models
P. Damm	Monthly climatological distribution of fresh water in the North Sea and its turn-over time
1994, July	EUROMARGE ^{210}Pb intercomparison exercise
	The ^{210}Pb dating methodology, with emphasis on problems and solutions

1995, February 1-3	Symposium on Long-term changes in marine ecosystems, Arcachon, France
R. Laane	Internal variation of dissolved inorganic nitrogen and phosphate in the Dutch coastal zone of the North Sea during 1961-1992 and the possible ecological conseuences
1995, May 12	Sir Alister Hardy Foundation for Ocean Science Colloquium, The Hague, The Netherlands
S. Batten	A review of CPR contributions to EU Programmes
1995, June 19-21,	NOWESP Workshop, Leuven, Belgium
A. Ménesguen	The three-dimensional global model of the Channel
1995, July 11-14	ICES Symposium 'Changes in the North Sea Ecosystem and their Causes: Århus 1975 Revisited', Århus, Denmark
F. Colijn et al.	NOWESP: Investigations on the variability and trends in the North-West European Shelf
R. Laane et al.	Interannual and seasonal variation in dissolved irorganic phosphate in the Rhine, the Dutch coastal zone, the Channel and the Irish Sea
P. Bot et al.	Phytoplankton in the North-West European Shelf programme (NOWESP)
D. Danielssen et al.	Long-term hydrographic variation in the Skagerrak based on the section Torungen-Hirthals
P. Damm et al.	Climatological means and inter-annual variability of currents, temperature and salinity on the North-west European shelf
1995, November 7-10	Second MAST Days and EUROMAR Market, Sorrento, Italy
W. van Leussen	Acquisition and analysis of shelf data sets, and initiatives for a new generation shelf transport models
G. Radach	Setting up the NOWESP Research Data Base: experiences in an interdisciplinary research project
J. Sündermann	Decadal variability on the North-west European shelf
1996, May 6-10	28th International Liège Colloquium On Ocean Hydrodynamics, Liège, Belgium
T. Hoch et al.	Ecological model of the English Channel
1996, May 24	Netherlands Oceanographers Club (NOC), the Hague, Netherlands
R. Laane	NOWESP: Collection and interpretation of data on an international scale

1996, June 24-26	*Journées PNOC, Nantes, France*
T. Hoch *et al.*	Modèle 2D-H bicouche de la production primaire pélagique et du cycle annuel des éléments associés en Manche
1996, October 9	*EUROGOOS - Operational Oceanoraphy, the Challege for European Co-operation, The Hague, The Netherlands*
R. Laane	North-west European Shelf Programme (NOWESP)
1996, October, 21-23	*New challenges for North Sea Research - 20 years after FLEX '76, Hamburg, Germany*
F. Colijn	Mutual interference between land and sea
W. van Raaphorst	Benthic processes in the North Sea: Resuspension and deposition of particulate matter

5.2 Conferences and symposia

Already during the NOWESP project (1993-1996), some international symposia organized special sessions around results of the North-west European Shelf Programme. Examples are the 1994 EUROSIM Conference on 'Massively Parallel Processing Applications and Development' and the 1996 EUROSIM Conference 'HPCN Challenges in Telecomp and Telecom: Parallel Simulation of Complex Systems and Large-scale Applications', where special NOWESP sessions were organized, as well as the 1995 ICES Symposium 'Changes in the North Sea Ecosystem and their Causes: Århus 1975 Revisited', where a set of coherent papers were presented.

The NOWESP project was also a stimulance for organizing the International Symposium 'New Challenges for North Sea Research - 20 years after FLEX'76' on 21-23 October 1996 in Hamburg. It was stated that the understanding of shelf sea systems and their role as a link in global cycles within a changing environment forms one of the 'grand challenges' of actual marine research.

From 19 to 21 March 1997, the ICES Symposium on 'The temporal variability of plankton and their physico-chemical environment' was held in Kiel, Germany. During this Symposium the variability and interpretation of long-term series on phytoplankton and zooplankton were discussed, as well as relevant abiotic conditions such as temperature, salinity, and nutrient levels.

5.3 List of publications related to NOWESP

The primary contribution of dissemination of results of the North-west European Shelf Programme to the scientific community is the publication of these results in qualified scientific journals and the presentation of these results during symposia on the concerned topics.

The list of publications, produced within the NOWESP-project or related to the investigations within the NOWESP project, is as follows:

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5.4 Publication plans

5.4.1 Special issue of a scientific journal (DHZ)

The main findings of the NOWESP project will be published in a series of 12 manuscripts. It is the intention to publish them, after normal refereing procedures, together as a Special Issue of a specialised journal on shelf sea research, the Deutsche Hydrographische Zeitschrift

It is our conviction that such a Special Issue will largely contribute to the dissemination of recent shelf sea results. The manuscripts are enclosed as Annex II to this report in the form as they are submitted to the DHZ.

5.4.2 Publication on CD-ROM

In September 1993 a proposal 'The North-West European Shelf Programme Data Base on CD-ROM' has been submitted as a MAST suportive initiative for Ocean Data and Information Management. However, because at that time NOWESP was too much in a preliminary state, no budget was obtained to carry out this task. Nevertheless the set up was taken over for a much smaller data set, and resulted in a CD-ROM 'North Sea Tidal Data 1984-1993'.

5.4.3 Other initiatives: WWW Home page, Poster, North-West European Shelf Pilot Model

WWW-home page

As agreed during the final meeting of NOWESP in Dublin (June 1996), a NOWESP home page will be installed on the WWW. This home page will be linked to the MAST-II project home pages of the EU.

Poster

During the second year of the project a large size poster 'NOWESP' representing the project activities was prepared for the second MAST Days & EUROMAR Market in Sorento (IT). This poster was also presented at the EuroGOOS meeting in The Hague and distributed to all participants.

North-West European Shelf Pilot Model
The 'North-West European Shelf Pilot Model' has been developed to illustrate the capabilities of such large scale models in analyzing long-term substance transport through the Celtic and North Seas, and to explore the needs for a new (3D based) generation of environmental and ecological models for the North-west European shelf. The model has been developed to run on a PC and was distributed to a wide audience within NOWESP and beyond.
The first version became available on diskette in April 1995; more recently (June 1996) it was published on Internet (http://www.wldelft.nl/shelf/). The Model was produced as a co-production of Rijkswaterstaat, National Institute for Coastal and Marine Management / RIKZ and Delft Hydraulics.

5.5 External relations

In the period under review several contacts existed with institutes and persons outside the NOWESP project, from which data was obtained for inclusion in the NOWESP Research Data Base.

The cooperation with ICES during NOWESP was reached a formal basis during negotiations between NOWESP and ICES on 6 march 1995. As a result the NOWESP partners were asked to give permissions both to ICES and the NRDB, to enable an exchange of their institute's data between ICES and the NRDB. In October 1995 about 644000 data were delivered to ICES, whereas ICES provided a data set of nutrients and chlorophyll to the NRDB in October 1995.
To arrive at a better cooperation between ICES and the NOWESP project Van Leussen and Radach visited ICES (Dr. H. Dooley) in Copenhagen. A number of questions were clarified, and it was agreed that ICES would become an advisor of the NOWESP group, particularly providing the project with their large experience on quality control of marine data sets.

Contacts with the MAST project ERSEM resulted in extra data to complete the time series at NOWESP box 3.

NOWESP participated in some of the meetings of the FLUXMANCHE I & II projects, and vice versa. Appropriate data from the FLUXMANCHE project has been made available for the NOWESP project. However, these data sets came available in a very late stage of the project (July 1996), and can no more be loaded in the NRDB.

Through the NOWESP project, a concerted action MMARIE (numerical modelling of marine systems) within the EU MAST II framework has been set up. In this concerted action, not only a number of partners within the NOWESP prject participate, but also a number of other institutes join MMARIE: CETIIS (Ivry-sur-Seine, France), CRS4 (Cagliari, Italy), SOTON (Southampton, United Kingdom), Univ. Bradford (United Kingdom), and LIM (Barcelona, Spain).

Contacts of IFREMER with Rijkswaterstaat(The Hague) and Institut für Meereskunde (Hamburg) initiated thanks to the NOWESP project, have been maintained in the frame of the ASMO working group on eutrophication modelling.

External contacts of the ERRC involve close cooperations with the Italian CNR Istituto de Geologia Marina (Bologna), the Universitat Autonoma de Barcelona and the cooperation through the MAST project EUROMARGE, e.g. through the ^{210}Pb intercomparison exercise.

The data base from NOWESP will be used in the project PROMISE, of the MAST III Programme.

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GLOSSARY

ADI	Alternating Direction Implicity
ASMO	Environmental Assessment and Monitoring Committee
BAH	Biologische Anstalt Helgoland, Hamburg, DE
BODC	British Oceanographic Data Centre, Bidston, GB
BSH	Bundesanstalt für Seeschiffart und Hydrographie, Hamburg, DE
CRESO	University of Bordeaux, Bordeaux, FR
CWI	Centre for Mathematics and Computer Science, Amsterdam, NL
DH	Delft Hydraulics, Delft, NL
DHZ	Deutsche Hydrographisches Zeitschrift
DODC	Deutsches Ozeanographisches Datenzentrum, Hamburg, DE
EC	European Commission
EDMED	European Directory on marine Environmental Data
ERRC	University of Liverpool, Liverpool, GB
ERSEM	European Regional Seas Ecosystem Model
ESU	Environmental Science Unit, Trinity College, Dublin, IE
EU	European Union
Euro-GOOS	European Global Ocean Observation System
FTZ	Forschungs- und Technologiezentrum Westküste, Büsum, DE
GLOBEC	Global Ocean Ecosystem Study
GOOS	Global Ocean Observation System
HPC	High Performance Computing
IAB	Institut für Allgemeine Botanik, DE
ICES	International Council for the Exploration of the Sea
IfBM	Institut für Biogeochemie und Meereschemie, Hamburg, DE
IfM	Institut für Meereskunde, Hamburg, DE
IfO	Institut für Ostseeforschung, Rostock-Warnemünde, DE
IFR	IFREMER, Plouzane, FR
IFREMER	Institut Français de Recherche pour l'Exploration de la Mer
IGBP	International Geosphere-Biosphere programme
IMR	Institute of Marine Research, Bergen, NO
IOW	Institut für Ostseeforschung, Rostock-Warnemünde, DE
JGOFS	Joint Global Ocean Flux Study
KUL	Katholieke Universiteit Leuven, Leuven, BE
LME	Large Marine Ecosystem
LOICZ	Land-Ocean Interaction in the Coastal Zone
MAFF	Ministry of Agriculture, Fisheries and Food, GB
MAST	Marine Science and technology
MMARIE	Modeling Marine Ecosystems
MUMM	Management Unit of the North Sea Mathematical Models, Brussels, BE
NIOZ	Netherlands Institute for Sea Research, Texel, NL

NODC	Norwegian Oceanographic Data Centre, Bergen, NO
NOMADS	North Sea Model Advection-Dispersion Study
NOWESP	North-West European Shelf Programme
NRDB	NOWESP Research Data Base
ORACLE	Data banking system
OSPAR	Oslo and Paris commissions
OSPARCOM	Oslo and Paris Commission
PCA	Principle Component Analysis
PML	Plymouth Marine Laboratory, Plymouth, GB
POL	Proudman Oceanographic laboratory, Bidston, GB
POP	Principal Oscillation Patterns
RIKZ	RWS National Inst. for Coastal and Marine Management The Hague, NL
ROSCOP	Cruise Summary Reports
RWS	Rijkswaterstaat, The Hague, NL
SAHFOS	Sir Alister Hardy Foundation for Ocean Science, Plymouth, GB
SSS	Sea surface salinity
SST	Sea surface temperature
TUD	Delft University of Technology, Delft, NL
UU	Utrecht University, Utrecht, NL
WWW	World Wide Web

Annex I

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