

THE BIOGEOCHEMISTRY OF NUTRIENTS, METALS AND ORGANIC MICROPOLLUTANTS IN THE NORTH SEA

There can be no doubt that men and their activities have weighed heavily on coastal areas in the last fifty years. In some respects, the situation may even continue to deteriorate which will further reduce their attraction. The discharge of waste, their carriage by the Scheldt and the deposit of atmospheric pollutants all constitute threats. There is, on the one hand, increasing eutrophication and a proliferation of algae resulting from the increased carriage by

water of nitrogen and phosphorus and, on the other, the threat that the life of animals and plants will be reduced by contamination by heavy metals and micropollutants. The so-called "red tides", the dramatic proliferation of certain colonies of algae and mercury and cadmium pollution are already universally recognised. The purpose of this research project is to examine the principle means by which pollutants are carried to the North Sea and to track them once they reach it.

THE PROJECT

The atmosphere

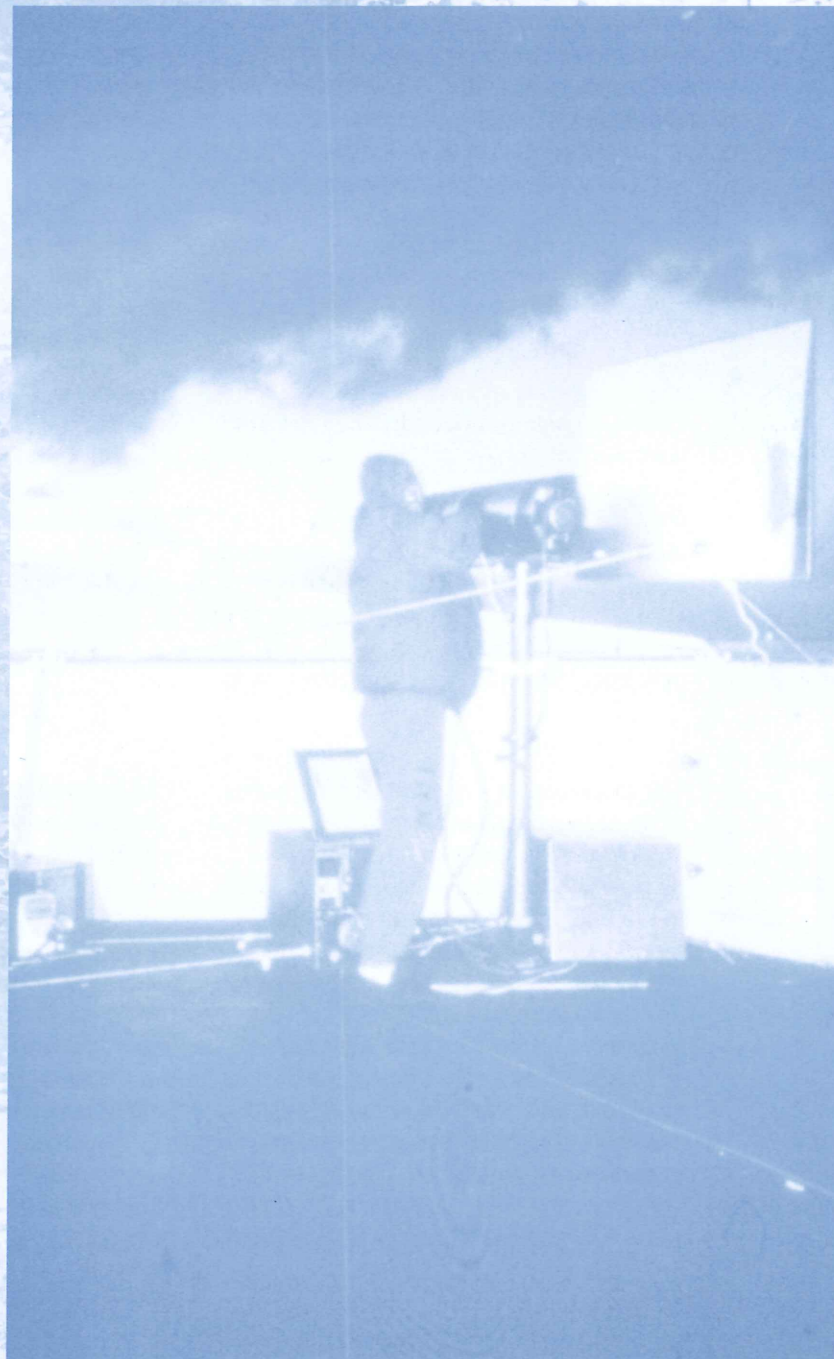
Atmospheric flows of certain toxic metals, polychlorobiphenyls, polycyclic aromatic hydrocarbons and pesticides have already been studied for some time. However, with other significant groups of inorganic and organic pollutants and data on the interaction between the air and the sea currently either do not exist or else are unreliable. Everybody realises that atmospheric transport to the oceans is one of the principal sources of nutrients on a world-wide scale (such as nitrogen and bioavailable trace elements of which silicium is one) which play a vital part in primary production. Extremely high levels of deposit can have a profound effect on the ecosystem of the North Sea and, locally, in certain atmospheric conditions, produce excesses of algae. So far, no one has given it any thought in mathematical models. Consequently detailed and reliable data on the quantities of the main nutrients deposited by the atmosphere have to be gathered. This will involve monitoring based on location, season and the origins of the atmospheric mass above the North Sea.

A very significant part of organic contaminants is Volatile Organic Compounds (VOC), a large group of chemically different substances which have multiple and diverse effects. VOC affect atmospheric processes, some types are carcinogenic, others are persistent and have the effect of causing bioaccumulation. Nine types of VOC, all of them chlorinated, have been included in the list of the 36 priority toxic pollutants presented at the Third Conference on the North Sea. Consequently there will have to be research into their sources, concentrations

and flows in the marine environment. A first monitoring campaign has shown that the Scheldt is a significant source of VOC in the marine environment. As regards these composites, it seems that there is a flow from the water into the air with the various places located in the centre of the continental plateau. On the occasion of outbreaks of algae, high concentrations of certain hydrocarbons were measured. Whatever causal relationship may exist between the proliferation of algae, increased concentrations and air/sea flows will have to be studied.

Where heavy metals are concerned, the level of atmospheric pollution above the North Sea seemed to rise when the wind was from the Southeast, for example, from Belgium. Airborne deposits of cadmium and lead equal those from rivers or direct outflows of industrial waste and wastewater. Quantities of zinc and lead, unlike other elements, seem to be decreasing. The great variations in concentrations and deposits have required taking a large series of measurements in order to establish reliable and accurate averages.

Another significant observation is that the main differences in the flow of deposits modelled and those measured are caused by particles which are relatively among the largest (>4µm) which are responsible for from 85 to 99% of dry deposits. Such particles settle rapidly and do not fly far. Since virtually all of the North Sea is close to their continental sources, special attention is paid to such particles in the project.



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As regards the aquatic phase in the North Sea, the research is intended, within the general context of the problems involved in eutrophication, to give a qualitative and quantitative description of how nitrogen is absorbed. This is determined by (1) the availability of nutrients, (2) the relationships between the various nutrients (covering, among others, those between nitrogen and phosphorus and nitrogen and silicates) and the various forms of nitrogen and (3) species of phytoplankton.

The description will have to be drawn from the study of two aspects: (1) the sequestration of carbon through primary productivity, and, (2) the quality aspect underlying the food chain in the form of the relationships between the different types of plankton (diatom and non-diatom).

The study of trace elements in the water, both those which are essential and those which are toxic, will focus on their

bioavailability and the biogeochemical cycles. This will include rates of adsorption, assimilation and chemical speciation. Such studies of speciation in the waters of the North Sea are of crucial importance in gaining a better understanding of transport mechanisms and conversion and the contrast between bioavailability and toxicity. The study will concentrate chiefly on parasite elements such as mercury and cadmium and on those which are essential such as iron and manganese.

Additionally, a number of volatile organic compounds will be measured in water and sediment of the North Sea and the Scheldt estuary. Also, possible natural production of certain VOC in sediment will be studied.

isotopes. Special attention will also be paid to mercury in the air and in water. The main objective of the contribution of the Chemical Oceanography Laboratory (Prof. R. Wollast) of the U.L.B. (French-speaking Free University of Brussels) is to gain a better understanding of the biogeochemical behaviour of trace metals such as manganese, copper, zinc, nickel, cadmium and lead.

To achieve this aim, attempts have to be made to better define the speciation of the particulate trace metals and the physico-chemical properties of the suspended matter.

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Coordinator

The UIA group is a unit of MiTAC (Micro- and Trace Analysis Center), which is a consortium of three research groups, involving some 80 scientists. The aim is to develop micro- and trace analysis methodologies and to apply these to relevant environmental problems. In MiTAC the research group of Prof. Dr. R. Van Grieken has a long experience in developing and applying various micro- and trace analytical techniques suitable for environmental research. The group of the coordinator is involved in many scientific programs.

Relevant recent projects, concerning the North Sea, were the EU Environment Project ACE (Aerosol Characterisation Experiment) (1996-1998), EU Environment Project on the Effect of Marine Aerosols on Historical Buildings (1996-1999), Impulse Programme on Marine Sciences, Belgian OSTC (1992-1996) and EUROTRAC Programme ASE (Air Sea Exchange) through OSTC (1990-1993). In the framework of the above projects, collaboration exists or has recently existed with a number of research teams.

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Partner 1

The major research activities of the Laboratory of Analytical Chemistry and Geochemistry are related to studies of the biogeochemical cycling of nutrients, major elements and trace metals in the sea including the interfaces air/sea and sea/bottom and the development of analytical tools required for the study of those cycles. During the past 20 years this Laboratory participated in a number of national and international programs and field experiments. The participation to international field experiments such as

FLEX-JONSDAP in the North Sea (1976); MEDETNA, PHYCEMED and ALBORAN in the Mediterranean Sea (1980 & 1981); ANTARES, EPOS in Antarctic waters (1988-1996); Lake Baikal (1990-1992); JGOFS (1989-1991); OMEX (1993-1996); the North Sea and the Scheldt estuary were frequently studied in collaboration with national and foreign colleagues

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Partner 2

The research of the Environmental Chemistry and Technology group of the Faculty of Agricultural and Applied Biological Sciences of the University of Ghent is focused on volatile organic compounds. The Laboratory is working on the environmental fate and behaviour of VOC, next to the study on chemical and biological abatement techniques for these compounds. A necessary prerequisite is that high performant analytical methods to measure these compounds at the environmental concentration levels are developed, with paying special attention to

include quality assurance protocols. Specifically to the marine science research, a first research programme, i.e. in the Impulse Programme Marine Sciences 1992-1996 of the Federal Belgian Government was carried out, investigating the presence of VOC in the North Sea environment. The research has been continued with a new project : "Biogeochemistry of nutrients, metals, and organic micropollutants at the North Sea."

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Partner 3

The Laboratory of Chemical Oceanography of the Université Libre de Bruxelles (ULB) has an international and pluridisciplinary dimension and is specialized, among others, in the study of chemical and biological processes influencing the transfer of trace elements from the dissolved to the particulate phase. In addition to its collaboration to the "Sustainable management of the North Sea", the laboratory takes part in several international programs. The laboratory acts as coordinator of the project OMEX (Ocean Margin

Exchanges), for which the studies are focussed on the ocean margins and the typical processes occurring in these regions. It is also involved in BIOGEST, where the biogases (CO₂, CH₄,...) and their air-water exchanges are studied in 9 European estuaries. All these programs imply the determination of many parameters: contents in nutrients, dissolved and particulate carbon-nitrogen-phosphorus, metals; uptake rates of radioisotopes: ⁶⁰Co, ⁵⁴Mn, ¹⁰⁹Cd, ⁶⁵Zn, ⁵⁹Fe, ³²P, ¹⁴C.

THE PARTNERS

Thanks to the experience acquired in the course of the Impulse Programme Marine Sciences of the OSTC, the Centre for Analysis of Micro- and Trace Elements at UIA (Universitaire Instelling Antwerpen, Professor R. Van Grieken) and the Laboratory for Organic Chemistry of the University of Ghent (Professor H. Van Langenhove), the focus in the project will be on research into air/sea flows of certain new organic composites (UG) and nutrients (UIA) and refining our quantitative understanding of the behaviour of heavy metals (UIA) by reducing uncertainties and studying speciation in atmospheric transport.

The contribution of the Laboratory for Analytical Chemistry of VUB (the Flemish Free University of Brussels, VUB, Prof. W. BAEYENS), consists of analyzing the distribution of nutrients, the relocation of nitrogen and the dissemination of trace elements such as aluminium, iron, manganese, copper, zinc, nickel, cadmium and lead, with particular attention to the dissolved phase, the mechanisms and the kinetics of trace elements using stable

AMORE – ADVANCED MODELLING AND RESEARCH ON EUTROPHICATION

The coastal waters of the Southern Bight of the North Sea receive large quantities of nutrients of anthropogenic origin via rivers and the atmosphere. Eutrophication is apparent in the coastal zone in the form of undesirable qualitative changes in the structure and functioning of the planktonic ecosystem, and can be observed in the form of occasional accumulation of foul-smelling foam on beaches. Guaranteeing sustainable North Sea resources for future generations and protecting the quality of coastal waters is now both a national and an international

concern. National and international regulations on sewage treatment facilities and farming practices aiming at the reduction of nutrient supply to the coastal sea have already been implemented in the various countries which border the North Sea. However, the scientific knowledge needed for a rational estimate of the reduction required and of the nutrient(s) which have highest priority for reduction (ammonium, nitrates and/or phosphates) is currently lacking.

THE PROJECT

The goal

This research project contributes to the implementation of an integrated land-coastal zone research methodology to assess and predict the eutrophication level of the coastal North Sea and the associated undesirable

effects. The ultimate aim is to reduce the current context of uncertainty in which decisions to counteract the eutrophication of the North Sea and protect its natural resources are made.

The environmental

Questions involved

What is the natural capacity of the coastal North Sea planktonic system to absorb surplus nutrients resulting from human activities in the surrounding river basins ?

What are the relative contributions made by natural processes and human activities to the phenomenon of eutrophication and is there a synergy?

What is the level of nutrient reduction required to protect biological resources from the harmful effect of nutrient enrichment?

The methods

- To establish an observational data base of key biogeochemical parameters from which changes in the quality of North Sea coastal waters can be monitored, signs of future deterioration can be rapidly detected and the positive and negative results of new purification regulations can be evaluated.

(meteorological conditions) and/or by anthropogenic factors. The current set of nutrient and phytoplankton monitoring parameters has been extended to secondary trophic levels.

Sampling site selected: station 330, 20 miles offshore of Ostend and subject to the influence of water from the Scheldt. The reference station has been sampled by ULB-GMMA since 1988 under the joint framework of the National Programmes for joint Oceanographic Research Activities and the Impulse in Marine Science and the European Commission's Environment and MAST Programmes (Phaeocystis projects and COMWEB). Results so far indicate that station 330 is sensitive to disturbances induced both by natural changes

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- To improve understanding of the mechanisms which structure coastal trophic networks in response to changes in the input of nutrients.

Two principal questions will be dealt with and studied by conducting process-level studies in natural and laboratory-controlled conditions :

- How does the structure of the phytoplankton community change when the input of nutrients alters?
- And what are the related changes in the higher trophic levels, particularly zooplankton?
- The knowledge gained will be integrated in a mathematical model resulting from the 'on-line' coupling of a 1km-resolution 2D-hydrodynamic model simulating the dispersal of the waters of the Scheldt in the coastal zone with an upgraded version of the existing mechanistic biogeochemical model MIRO, revised on the basis of knowledge gained in the process-level studies.

A list of key physico-chemical and biological indicators allowing the rapid diagnosis and prediction of significant trophic changes and their harmful effects. A "Green Book" will be published listing the parameters, how they are measured and the sampling strategy.

A validated mathematical model to be used as a scientific tool for predicting eutrophication phenomena in the Belgian coastal zone and their effects on adjacent zones and to guide decision-making regarding the reduction of the input of nutrients into the sea.

MIRO is an ecological model developed by ULB-GMMA which describes the dynamics of Phaeocystis colonies blooms in the North Sea coastal zone in response to riverine nutrients loads. Although already operational, the model suffers from weak points as regards the low resolution of hydrodynamic and related resuspension processes and the lack of knowledge of some physiological parameters for which adequate measurement methods are presently lacking. Resolving these uncertainties is MUMM's main task in co-operation with ULB-GMMA and VUB-ECOL.

A data bank gathering physico-chemical and biological data recorded at station 330 of the Belgian monitoring network since 1988. This will be used for (i) the long term assessment of trophic changes in the ecosystem, (ii) the validation of the mathematical model and (iii) the evaluation of the effects of present and future water treatment policies.

THE PARTNERS

The co-ordinator, the Microbiology of Aquatic Environments Group (Groupe de Microbiologie des Milieux Aquatiques, ULB-GMMA) of the Free University of Brussels (Dr. C. Lancelot), an internationally recognised expert in coastal eutrophication, the initiator of the monitoring programme at station 330 and originator of the MIRO ecological model.

The laboratory for Ecology and Taxonomy (VUB-ECOL) of the free University of Brussels

(Dr. M-H. Daro), specialist in zooplankton dynamics and the evaluation of its trophic influence with 20 years experience.

The Management Unit of the Mathematical Model of the North Sea (MUMM) (Dr. Ir. G. Pichot), specialised in mathematical modelling of marine systems and active in exploiting scientific research to provide support for decision-making.

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Coordinator

GMMA, head by Dr C. Lancelot, is an interdisciplinary research unit of the Université Libre de Bruxelles, active since more than 10 years in the study of general aspect of aquatic microbial ecology. It is developing an integrated conceptual methodological approach based on field observations, process-level studies and numerical work, that aims to develop a generic mechanistic biogeochemical model of the planktonic ecosystem based on physiological and geochemical principles. When coupled with hydrodynamical models of appropriate spatio-temporal resolution, such a model can address local, regional

and more global environmental questions. International collaboration of relevance to the AMORE project includes EC research projects on biogeochemical interactions between the Danube river and the north-western Black Sea (EROS-21 funded by the Environment and Climate Programme) and on comparative analysis of food webs (COMWEB funded by the MAST Programme)

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Partner 1

The plankton group of the Ecology and Systematics Laboratory of the Vrije Universiteit Brussel focusses on interactions between suspended particulate matter and mesozooplankton. Spatio-temporal distributions and trophic processes are studied in estuarine and coastal zones situated in both temperate and tropical regions. International collaboration of relevance to the AMORE project includes research projects on the environmental effects of the Sigma Plan (OMES project in

cooperation with The Netherlands), on comparative analysis of food webs (COMWEB funded by the MAST Programme), on the construction of an interdisciplinary geographic information system (G.I.S.) of the Guayaquil area aiming at the monitoring and modelling of the Guayas estuary and the Estero Salado (INOCAR, Guayaquil, Ecuador) and on causal factors of biodiversity: community structure, phylogeny and biogeography in the scope of a 15-year collaboration with Kenya (KMFRI, Mombasa).

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Partner 2

MUMM is a federal government scientific institution with activities in marine research, monitoring and management. Research at MUMM focusses on providing the necessary knowledge and tools for scientific management of the North Sea ecosystem based on mathematical modelling (with particular experience in physical oceanography), remote sensing and in situ measurements. International cooperation of relevance to the AMORE project include

research projects on river plume dynamics ("PROFILE"), 3D ecosystem model coupling and dissemination ("COHERENS") and optical remote sensing ("MULTICOLOR") as well as environmental management activities such as participation in the Oslo and Paris conventions for the prevention of marine pollution. Oregon State University (contact Y. Spitz), sub-contactor to MUMM, has particular expertise in adjoint model techniques for ecosystem models.



ICAS: THE IMPACT ON NORTH SEA ORGANISMS OF POLLUTANTS ASSOCIATED WITH SEDIMENT

Although releases of persistent pollutants such as heavy metals and polychlorinated biphenyls (PCBs) into European seas are strictly controlled or forbidden, such pollutants continue to represent a threat to numerous marine ecosystems. What has happened is that their low solubility has caused them to associate with sediment which is now a major source of secondary pollution and contributes to the persistence of the initial pollution. In the North Sea, the main areas affected by polluted sediment are the estuaries (the Western Scheldt for example) and the "hot spots" resulting from the direct discharge of residues into the sea.

The information available on the impact of heavy metals and PCBs associated with sediment on marine organisms, particularly benthos, mainly comes from bioassays for toxicity studying the impact of complex non controlled pollution. That makes it impossible to distinguish between the relative toxicity of the various pollutants involved. Further, the species studied are rarely key or dominant species which are representative of the benthic ecosystems of the North Sea. The result is that the principal ecological impact of pollutants associated with sediment is, as yet, mostly unknown.

THE PROJECT

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The objectives of the research

To determine the impact of heavy metals and PCBs associated with sediment on representative species of macrobenthos in the North sea. These include the common starfish, *Asterias rubens* and the sea urchins *Echinocardium cordatum* and *Psammechinus miliaris*.

To use the common starfish to study heavy metal pollution in the North Sea.

ACTIVITIES

The impact of heavy metals and PCBs associated with sediment will be investigated at several levels of biological organization ranging from biochemistry to ecology (population biology) to cover the broadest possible spectrum of effects. We will, therefore, study the effects on:

- the induction and activity of molecules implied in detoxication of these pollutants;
- the activity of the immune system;
- skeletal growth (an element characteristic of the organisms studied);
- the development and metamorphosis of larvae.

Heavy metal pollutants will be biomonitoried by using the common starfish (the digestive system provides a short term indicator (days or weeks) and the skeleton functions as a long term integrator (months and years)).

The work projected will make it possible to evaluate the risks from heavy metals and PCBs associated with sediment and contribute to compliance with the commitments Belgium has made to various international organizations (international conferences on the protection of the North Sea, the Oslo and Paris Commissions). The data obtained, combined with that from other networks which measure flows of pollutants, can provide a basis for deciding whether clean-up is necessary (in tourist or fishing areas, for example), or whether special attention should be paid to certain regions (as regards, for example, the disposal of sludge from dredging).

THE PARTNERS

The research as a whole will be based on the knowledge acquired by the laboratories participating in the network.

- **The Marine Biology Laboratory** of the (French-speaking) Free University of Brussels (Dr. Ph. Dubois): the biology and ecotoxicology (heavy metals) of adult starfish and sea urchins. More particularly the research proposed is a direct application of the most recent laboratory results acquired under the Programme of Encouragement of Marine Science funded by the Federal Office for Scientific, Technical and Cultural Affairs (OSTC) from 1992 to 1996.
- **The Marine Biology Laboratory** of the University of Mons-Hainaut (Professor M. Jangoux): biology of larvae, and particularly metamorphic events.
- **The Organic Chemistry Laboratory** of the University of Mons-Hainaut (Professor R. Flammang), analysis by mass spectrography of complex organic mixtures. It will be used on its own or coupled with gas chromatography (apart from its reputation in general, the laboratory is well known for having developed a new type of tandem mass spectrometer of which only a few specimens exist).

Pooling these skills will make it possible to deal with the impact on the entire life cycle of the organisms studied (adult and larval life, including metamorphosis) of the principal pollutants associated with sediment and which have a long remanence (which means that they constitute a long term threat to the marine environment and human activities associated with it).

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Coordinator

The research activities of the Marine Biology Laboratory deal with the biology, ecology and ecotoxicology of marine invertebrates. Investigations mostly concern the Echinodermata used as paradigm of the macrobenthos. The overall aims of the research are: (1) the fine understanding of the original biological model developed by the Echinodermata, (2) the precise determination of their role in both healthy and altered (i. e. polluted) marine benthic ecosystems, (3) the farming of echinoderms of commercial interest (aquaculture). Main themes of research encompass morpho-physiology of digestive, reproductive, immune, and skeletal systems, larval biology and ecology of metamorphosis, ecology of populations and symbioses, aquaculture of sea-urchins, and metal ecotoxicology. The

latter theme focuses on the study of the distribution, fluxes, and biological effects of metal contaminants in the Posidonia oceanica (sea-grasses) meadows and in littoral communities of the North Sea. In these ecosystems, echinoderms are key species and used as bioindicators of metal contamination. The experimental approaches include in situ, aquarium, and cell culture procedures. International collaborations concerning ecotoxicology include the International Atomic Energy Agency (Monaco; Prof. S.W. Fowler), the Istituto Nazionale Tumori (Napoli, Italy; Prof. G. Pagano), and the Universidad de Barcelona (Spain; Prof. J. Romero).

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Partner 1

The research activities of the Laboratory of Marine Biology of the University of Mons-Hainaut mainly focus on (1) structures and functions of defensive organs, (2) study of symbioses with echinoderm host, (3) adhesion mechanisms of larvae and adults to benthic substrata, and (4) biology of individuals (larvae and postlarvae) prior and just after metamorphosis. In the frame of the latter research theme, the Laboratoire of Mons performs in routine -as well for echinoids as for asteroids- (1) fertilizations

and follow up of embryonic development, (2) rearing of larvae, (3) induction of metamorphosis and follow up of postlarval stage, and (4) rearing of small juveniles during the first weeks of their benthic life. International collaborations are developed with the University of Lille (France; Dr D. Davoult), the Bødo Colege (Norway; Dr N. Hagen), the Marine Laboratory of Banyuls-Sur-Mer (France; Prof. A. Guille), and the University of Bangor (Wales, U.K.; Prof. G. Walker)

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Partner 2

The major research themes developed by the Laboratory of Organic Chemistry of the University of Mons-Hainaut are (1) the determination of new molecules (particularly heterocycles with 5 or 6 atoms derived from azols and azines, respectively) that are pharmacologically-active and the subsequent optimization of their production at the industrial level, (2) the study of fundamental aspects related to production and characterization of new families of reactive molecules, and (3) the analysis of complex environmental mixtures. Tandem Mass Spectrometry or MS/MS is the main analytical tool used. (From 1991, the laboratory has been developing a new prototype of tandem mass spectrometer in close collaboration with Micromass Inc., UK.) For the analysis of complex environmental mixtures, the Laboratory uses

chromatographic techniques coupled with mass spectrometry (GC-MS/MS). The GC-MS/MS approach is currently used in the laboratory for the characterization of atmospheric organic pollutants and PCBs in the marine environment. International collaborations are developed with the University of Queensland (Australia; Prof. Curt Wentrup & Dr. Ming Wah Wong, the Ecole Polytechnique (URA CNRS 1307, France; Prof. Guy Bouchoux), the Odense University (Denmark; Prof. C.Th. Pedersen), the Université Pierre et Marie Curie (Paris VI, France; Prof. J.P. Morizur), the McMaster University (Canada; Prof. J.K. Terlouw), the Instituto de Quimica fisica (Madrid, Spain, Prof. J. Elguero), the University of Trondheim (Norway; Prof. E.H. Morkved), and the Technical University of Berlin (Germany; Prof. H. Schwarz).

THE STRUCTURAL AND FUNCTIONAL BIODIVERSITY OF NORTH SEA ECOSYSTEMS

SPECIES AND THEIR HABITATS AS INDICATORS FOR THE SUSTAINABLE MANAGEMENT OF THE BELGIAN COASTAL SHELF

The diversity of ecosystems is an aspect of "biodiversity" which has recently become a popular notion. It refers to the diversity of life of all forms, beginning with the genetic heritage and extends to the ecosystems on which the biosphere is built (UNESCO, Rio de Janeiro, 1992). As a whole the various biological levels are marked by an alarming reduction in their biodiversity. Structural

biodiversity (in terms of numbers, biomass, the composition of species and the population structure of communities) and functional biodiversity (presented as series of interactions between the various trophic levels) are different concepts which most certainly must be related one to the other if one is to have a good understanding of how an ecosystem functions.

THE PROJECT

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There are two facets

- An analysis of the factors which determine the biodiversity of marine ecosystems and the changes in them.
- The translation of what is known into parameters which can serve as a basis for the policy to be implemented (for example, the species which serve as ecological indicators). Special attention will be paid to the benthos (organisms which live close to or at the

bottom of the sea) and the upper trophic levels (fish, seabirds and marine mammals) and their parasites.

ACTIVITIES

In the first phase a synthesis will be made of all the information available having to do with the spatial and temporal distribution (structural biodiversity) of the components mentioned above of the Belgian coastal shelf. The data will be used together with an analysis and interpretation of the connection between the biological indicators and the environmental variables to establish criteria for the selection of ecological indicators for sustainable development. Special attention will be paid to sandbanks, not only because of their extreme ecological significance, but also because they are greatly affected by human activities. Comparison with neighbouring areas (open sea, the Belgian East coast) will enable us to evaluate those characteristics which are peculiar to sandbanks. Maps will be made available for use by policy makers. They will not only

indicate the places where different species of bird, benthos, fish and their parasites occur, but also the vulnerable areas.

The connection between biodiversity and production is of fundamental importance in ensuring that ecosystems are efficiently managed. In this respect there are two different approaches which will have to be considered:

- maintaining the large "visible" species, which often occupy an important position in the food chain, and which, in the policy context, are easy to monitor as ecological indicators;
- reaching an understanding of the underlying biological relationships (predation, competition) and the structuring interaction with the abiotic environment.



The feeding ecology of the different components will be quantified and qualified with special emphasis on the trophic place of those species which serve as ecological indicators. The significance of the primary production of the water column in the benthos structure will be studied to quantify the direct interdependency between the pelagos and the benthos. Models of morphological variation do not always coincide with auto-ecological, molecular and biogeographical models. This is of crucial significance in ecological research, since it implies that morphological diversity does not necessarily correspond to functional diversity which latter can be either greater or less than the morphological diversity would indicate. We are basing ourselves on the principle that the population genetics of fish (biodiversity at the level of population) constitutes an essential element in understanding the ecosystem of sandbanks (biodiversity at the level of the ecosystem). The choice of which species to study will be determined by what is already known in the fields of ecology and genetics and their significance both as food for birds and the commercial fishery (for example gudgeon). The importance of parasites of fish and seabirds will also be considered as biological and genetic markers.

This research is of direct interest to policy makers at the Belgian Federal level for the following reasons:

- The implementation of the Ramsar agreement of 1971 covering water rich areas and in the framework of which the implementing decrees establishing a protected zone in the Flemish banks (coastal sandbanks) are overdue.

- The preparation of the next Conference on the North Sea (2000), at which the Belgian Government will draw on the expertise of its own researchers as regards the information available on eutrophication, the deterioration of the habitat, pollution, the extraction of sand and overfishing (including opinions on the proper management of genetic characteristics).
- The supply of basic information for the optimum management of the natural resources of the Flemish banks, if appropriate, by setting up a marine reserve.
- Establishing criteria for ecological monitoring of the sustainable development of the North Sea (with priority on the sandbanks).
- The application of the UNESCO convention on biodiversity signed in Rio de Janeiro (1992). So far none of it has been implemented on Belgian territory. The inventory of the fauna of the Belgian continental shelf is incomplete.
- The intention of the Federal and Flemish governments of setting up a data bank as a management instrument and including an information system based on geographical coordinates.

will study the genetic variation of a number of species which serve as indicators and the ecology of parasites.

The Institute for Nature Conservation of the Flemish Community (Prof. Dr. E. Kuijken, Prof. Dr. P. Meire and Drs J. Seys) will be responsible for the upper trophic levels such as birds and marine mammals and drawing up maps of the distribution of benthic communities.

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Coordinator

The Marine Biology Section of the Department Biology of the University of Gent has been involved in ecological and systematic research of marine ecosystems from 1970 onwards. The research started with the investigation of North Sea benthic communities, with special focus on the macro- and meiobenthos. From 1980 onwards, research was expanded to include the hyperbenthic and epibenthic compartments. Research is still going on in the North Sea and adjacent estuaries (OSTC and FWO programmes). European estuaries have been investigated in the framework of international programmes such as EC-MAST I-JEEP92, EC-ENVIRONMENT-MATURE, EC-ENVIRONMENT-ECOFILAT, EC-CONCERTED ACTIONS-ESTUARINE FISHERIES. Since about ten years, other geographical areas have been included : Deep-sea areas in the Atlantic Ocean (EC-MAST I, II and III),

Partner 1

In the early 1970s the knowledge on the distribution and abundance of top-predators, like seabirds and marine mammals, was limited. The demand for additional data of seabirds grew in the early 1980s. In 1986, the Institute of Nature Conservation (IN) started with systematic aerial surveys in the Belgian coastal zone. These counts are of great value for determining the total numbers of sea ducks, but can not be used for counting seabirds further offshore. After strandings of big numbers of oiled seabirds on the Belgian coast the Institute of Nature Conservation commenced in 1992 with shipbased surveys in the Strait of Dover and the Belgian Continental Shelf, funded by World Wide Fund for Nature and later by the Management Unit of the Mathematical Model of the North Sea (MUMM).

Partner 2

The Laboratory of Ecology and Aquaculture is involved in fundamental and applied research in the fields of aquatic biology, ecological genetics and population genetics. Our expertise on marine systems deals with population genetics of gobies and fish parasites, ecology of estuarine and tropical fish, microbiology (pasteurellosis), marine parasitology, ecotoxicology and endocrinology. The following staff members are currently involved:
National financing organisations are the University of Leuven, IWT, FWO, OSTC,

Biology of the Antarctic meiobenthos (OSTC-ANTAR III and IV; FWO), Ecology of tropical estuaries and lagoons (FWO), Population dynamics of macrobenthos of coastal sandbanks (AMINAL, Flemish community) and several Ph.D projects.
Next to the biological subjects (for which the marine biology section is equipped with the best microscopes and a very complete library) also more geochemical characteristics are determined and analysed : grain size of sediments (Coulter Particle Size Analyser), Organic C and N, Nutrients (SKALAR), Pigments (HPLC), Redox profiles of sediments, oxygen. All chemical methods are adapted for analysis within the sediments. Microbial aspects (radio-active labelling) and experimental microcosmos research (culture chambers and respiration chambers) are available.

The Institute participates in the 'European Seabirds At Sea (ESAS) coordinating group' and gives assistance to the development and updating of the ESAS-database (development of atlases of the North Sea).
The IN has an international co-operation with the Netherlands Institute for Sea Research (NIOZ) at Texel (the Netherlands), the Institute for Forestry and Nature Research (IBN-DLO) at Texel and Ornis Consult at Copenhagen (Denmark) for the ship-based and aerial surveys. For determining the vitality of breeding populations of seabirds along the Belgian coast we get expertise from the Institute for Forestry and Nature Research (IBN-DLO) at Arnhem (the Netherlands) and the Ministry of Transport, Public Works and Water Management, Tidal Water Division (RIKZ) at Middelburg (the Netherlands).

AMINAL. Funds also come from international organisations like the European Commission and the European Science Foundation. Next to these the industry and own funds further sustain our research.

THE PARTNERS

The Department for Marine Biology of the University of Ghent (Prof. Dr. M. Vincx, Drs J. Vanaverbeke, Dr. A. Cattrijsse and ir. D. Van Gansbeke) already has thirty years of experience in research on benthos in general and in the North Sea in particular. It will provide data on the biodiversity of the different benthos components.

The Laboratory for Ecology and Aquaculture of the Catholic University of Leuven (Prof. Dr. F. Ollevier and Prof. Dr. F. Volckaert)



BIRDS AND MARINE MAMMALS OF THE NORTH SEA: PATHOLOGY AND ECOTOXICOLOGY

In winter large colonies of pelagic birds settle on the Flanders Banks. In the past they were also largely frequented by marine mammals. Now they are only rarely to be seen and every year, some of them and many hundreds of birds are washed up along the Belgian coast. These species should be protected and the purpose of this research project is to study the state of health of these populations, trends over time, the pathologies observed and the pollutants

associated, as also the possible causes of abnormal deaths. The most significant damage to seabirds caused by human activities seems to be the pollution by hydrocarbons, but the actual reasons why birds which are not poisoned by oil fuel wash ashore and the rarity of mammals are still unknown (heavy traffic shipping routes, other chemical pollution, decrease in the availability of food, disease, etc.).

THE PROJECT

To examine the greatest possible number of seabirds and mammals which wash up on the Belgian coast: perform autopsies and take the samples needed to determine what pathogenic agents and pollutants are present.

To examine individuals, insofar as possible, animals accidentally caught in fishing nets, to determine how representative the individuals collected from the beaches are of the natural population.

To study wild populations, in the field, so as to reach a better understanding of their ecology and behaviour and estimate the actual impact of hydrocarbons on the seabird population.

To study, in the laboratory, the effects of the various toxic substances to which these animals are subjected (hydrocarbons, heavy metals, etc.) and the efficacy of any physiological detoxification mechanisms which such animals develop in response to pollutants.

information

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THE PARTNERS

The research network consists of the following research teams:

- **The Oceanology Laboratory** of the University of Liege (Professor J.-M. Bouquegneau, coordinator);
- **The Laboratory for Ecotoxicology and Polar Ecology** of the (Flemish) Free University of Brussels (Professor C. Joiris);
- **The Pathological Anatomy Department** of the University of Liege (Professor F. Coignoul);
- **The Institute for Nature Conservation** of the Flemish Community (Professor E. Kuijken).

ACTIVITIES

To conduct such research successfully requires a multidisciplinary approach, i.e. one which involves the cooperation of specialists from various disciplines. The multiplicity of examinations to be effected on single animals is an original aspect of the research network's approach.

Lesions will be studied by veterinarian anatomo-pathologists (Dr. T Jauniaux of the Department of Pathological Anatomy), ecotoxicologists will study levels of contamination and the effects of pollution (V. Debacker and S. Pillet from the Oceanology Laboratory and Dr. L. Holsbeek from the Laboratory for Ecotoxicology and Polar Ecology) and observations in the field will be performed by ecologists (J. Van waeyenberg from the Institute for Nature Conservation). The following will also be involved in the

research: Dr. J. Van Gompel, a veterinarian who will cooperate in collecting samples and in necropsies; J. Tavernier of the Royal Institute for Natural Science of Belgium (IRSNB) and Dr. T. Jacques of the Management Unit of the Mathematical Model of the North Sea (MUMM) who will cooperate in collecting samples in the field and for the MUMM itself in developing a database.

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Coordinator

The Oceanology Laboratory has long been involved in marine ecology and ecotoxicology. The production and recycling of the organic matter is studied in several environments, mainly in the Mediterranean basin, through biomass and primary production measurements, and delineation of carbon and nitrogen transfers in the ecosystems using stable carbon and nitrogen isotopes determination. The mechanisms of uptake, toxicity and detoxification of heavy metals are studied in marine organisms, mainly in seabirds and marine mammals. Regular international

contacts at different levels as well as participating in network discussion groups and intercalibration programs, allows the Oceanology Laboratory to exchange ideas and materials with other teams working in the same field (collaboration with Professor A. Abarnou -Brest, France- for the study of heavy metals contamination in bottlenose and common dolphins from the French Atlantic; collaboration with Professor A. Viarengo -Genova, Italy- to study metalloprotein determination in avian and marine mammals tissues, ...).

Partner 1

The department is currently engaged in three research areas: xenotransplantation of pigs kidneys, pathogenesis of emphysema in cattle, and pathology of marine mammals and seabirds.

Techniques available are quantitative evaluations of organs and tissues through image analysis, cell populations identification by histochemistry and immunochemistry (DNA adducts evaluation and PCR are in the process of acquisition).

Partner 2

The Laboratory for Ecotoxicology & Polar Ecology displays activities in two main areas:

- Behaviour and impact of stable pollutants (PCBs, organochlorine pesticides, heavy metals) on the different trophical levels of marine ecosystems (phytoplankton, zooplankton, benthos, fish, birds and mammals) with special interest for background concentrations (levels in Arctic and Antarctic areas). Impact of stable pollutants on populations of birds and marine mammals. Fluxes of pollutants through the food webs.

Partner 3

The impact of oil pollution on the North Sea ecosystem became obvious from the large numbers of beached seabirds that were oiled. Already in the sixties an international monitoring scheme of beached birds was setup in order to assess the impact of oil pollution on their populations. In Flanders these counts started in 1962 and are coordinated by the Institute of Nature Conservation (IN) since 1992 as part of a European network.

In 1986, the IN started with systematic aerial surveys in the Belgian coastal zone. These counts are of great value for determining the total numbers of sea ducks, but can not be used for counting seabirds further offshore. In 1992 the IN started with ship-based surveys in the Strait of Dover and the Belgian Continental Shelf, funded by World Wide Fund for Nature and later by the Management Unit of the Mathematical Model of the North Sea (MUMM) and at present by the OSTC. This work gives us insight in the populations sizes of seabirds at the Belgian Continental Shelf.

The Department works in collaboration (international network for marine mammals) with the Harderwijk Marine Mammals Park, Harderwijk, The Netherlands (Dr. Kastelein), with the National Museum for Natural Sciences, Leiden, The Netherlands (Dr. Smeenk and Ms Addink), with the Duisburg Zoo, Duisburg, Germany (Dr. Garcia Hartmann), with Zoological Society, London, United Kingdom (Dr. Jepson), with the NAUSICAA, Boulogne sur mer, France (Dr. Bourgain) and with the Marine Mammals Research Center, La Rochelle, France (Dr. Collet).

- At sea study of the distribution of marine birds and mammals: seasonal variations of distributions, linkage with hydrographical regimes, estimations of population sizes and densities. Estimations of food demands and energy fluxes through higher trophical levels of the marine ecosystems.

International contacts include long standing collaborations with the Murmansk Marine Biological Institution, European marine mammal network collaboration schemes and the coordination of a research program on marine mammals of the Black Sea involving Ukrainian, Bulgarian and Georgian teams.

The Institute also participates in the "European Seabirds At Sea (ESAS) coordinating group" and gives assistance to the development and updating of the ESAS-database (development of atlases of the North Sea). The IN has an international cooperation with the Netherlands Institute for Sea Research (NIOZ) at Texel (the Netherlands), the Institute for Forestry and Nature Research (IBN-DLO) (the Netherlands), Ornis Consult at Copenhagen (Denmark) and the Ministry of Transport, Public Works and Water Management, Tidal Water Division (RIKZ) at Middelburg (the Netherlands).

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IDOD: INTEGRATED AND DYNAMICAL OCEANOGRAPHIC DATA MANAGEMENT

Any kind of scientific work quite obviously must be based on structured, validated knowledge. This is particularly so as regards the marine environment. Any future policy or decision determined with a view to the sustainable management of the North Sea

would lack any basis if there were no validated and readily accessible measurements or experimental data. Building an integrated oceanographic database is therefore a key action in the programme for "Sustainable Management of the North Sea".

THE PROJECT

The purpose of this five-year project is to establish, manage and promote a marine environmental geographical information system, ensuring a smooth and scientifically sound flow of data between the data producers (scientists in the field and in the laboratory, modellers, public authorities, etc.) and the end users (policymakers, scientists, sea professionals and the general public).

The categories of data to be considered cover a wide range of natural processes and human activities connected with the North Sea. Up to date Quality Control procedures will be followed in entering and processing the information to be included in the database. The tools and products to be

developed in the course of the project will make it possible to gain a better understanding of the structure and functioning of the marine ecosystem and the influence upon it of human activities, by providing a basis for scientific assessments in the perspective of the definition of a sustainable management policy of the North Sea. This is a basic need for the fulfilment of Belgian commitments under the International Conferences on the Protection of the North Sea and the Paris and Oslo Conventions. Lastly it should be noted that an important part of the project involves data gathering and supplying information from and to scientific teams working in the framework of the other topics covered by the programme.

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ACTIVITIES

The project can be divided into six different but highly interdependent activities: Initially an inventory will be made of relevant data sets and databases.

Procedures for the incoming flow of data will be defined and implemented. This covers not only the practical aspects of the transfer of information but the very important matter of quality control of data.

The design of the database itself will be analysed in depth, in function of the intrinsic characteristics of the data and in order to meet the present and future needs, ensuring the viability and the usefulness of the tool over the years.

In order to understand the processes driving the marine phenomena "hidden" in the data, a set of data analysis tools will be developed.

Various approaches will be used: statistical techniques, geostatistics and spatial analysis techniques, space and time "corrections" of data sets by means of advection-diffusion models. It is also expected to take advantage of the information given by these tools to improve the quality control on the incoming data.

Given their two important characteristics –namely their capability of simulating and forecasting processes and events– we believe that mathematical models also are an important source of information for the project. Suitable validation procedures will be defined and the results of relevant (and validated) models will be incorporated in the database.

Lastly, since one of the most important objectives of this project is to supply useful

and scientifically sound information to a broad range of users, derived products will be developed (maps, tables, reports, etc.) that meet the specific requirements and levels of expertise of the various categories of users.

It should be emphasised also that the network supporting the project consists of teams with a high level of expertise

in physical, chemical and biological oceanography, statistics and geo-referenced data analysis, ensuring a coherent and comprehensive force to bring the project to a successful conclusion.

The University Centre for Statistics (Professor J. Billiet & Dr. J. Van Dyck) of the Catholic University of Leuven will develop the quality control procedures to apply on the incoming flow of data. They will bring their experience in statistical analysis to bear on the development of data processing tools.

The Management Unit of the Mathematical Model of the North Sea (MUMM) (Dr. ir G. Pichot), the Federal department for the management of the marine ecosystem, co-ordinates the project. More specifically it will take care of the effective implementation of the developed tools, of providing information to the database and of the production of "value added products" for use by policymakers, sea professionals and the public.

The SURFACES Laboratory (Dr. ir J.-P. Donnay) of the University of Liège will be more particularly involved in developing analysis and geo-referenced data processing tools and in the conceptual design of the database.

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Coordinator

The Management Unit of the Mathematical Model of the North Sea (MUMM) is a federal government scientific institution with activities in marine research, monitoring and management. Research at MUMM focusses on providing the necessary knowledge and tools for scientific management of the North Sea ecosystem based on mathematical modelling, remote sensing and in situ measurements. MUMM intensively co-operates with other

Partner 1

The Laboratory SURFACES at the University of Liège was created in 1988 to promote fundamental and applied researches in the domains of digital cartography, geographical information systems (GIS) and satellite remote sensing. The main part of the fundamental research and several feasibility studies are granted by the national programme, so called TELSAT, under the direction of the Office for Scientific, Technical and Cultural

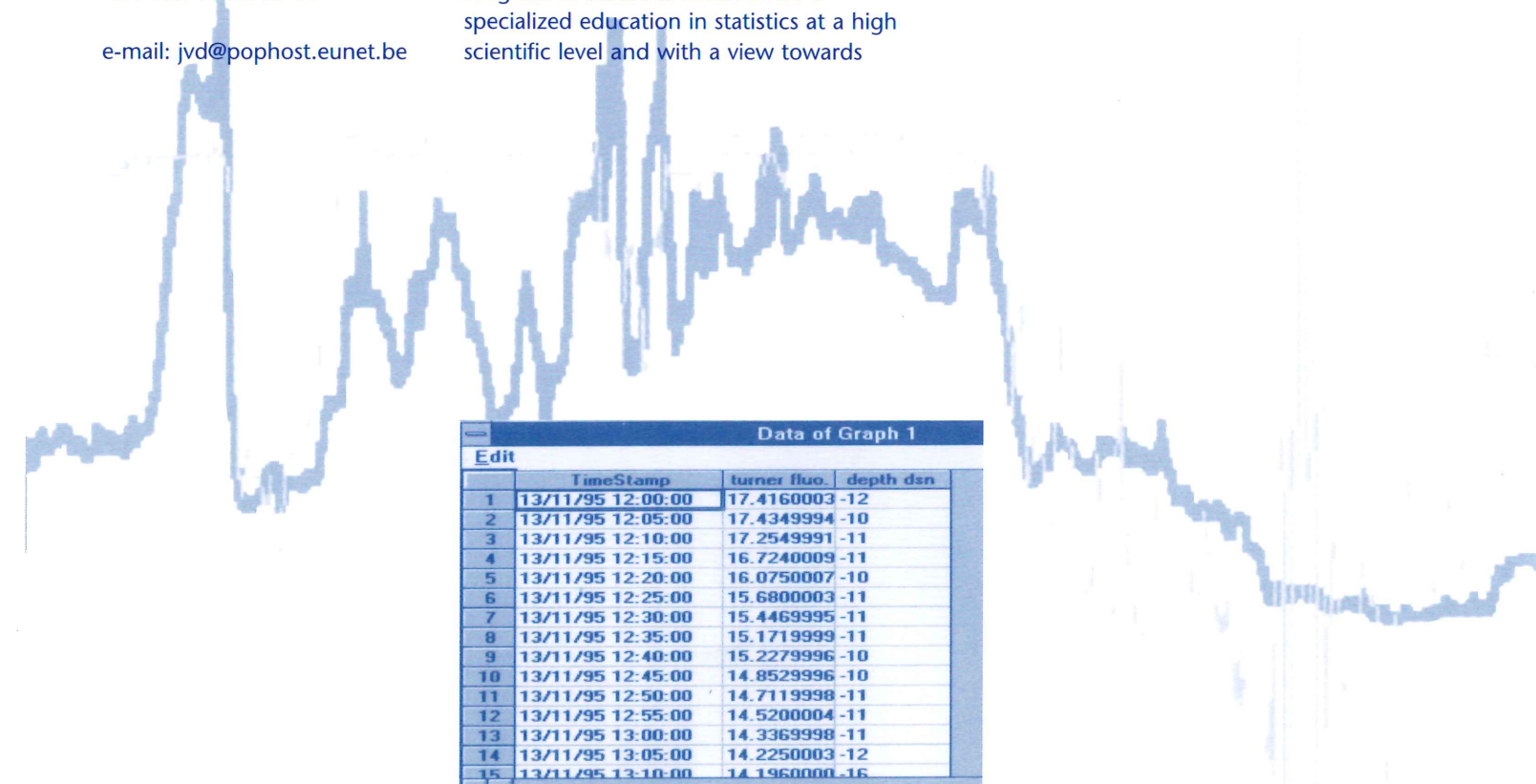
Partner 2

The University Centre of Statistics (UCS) is a centre that merges the know-how and research of statisticians at the different departments and faculties of the Katholieke Universiteit Leuven. UCS has a longstanding and extensive experience with data mining techniques and has executed a wide variety of statistical consulting projects. UCS also organizes an International Study Program in Statistics which offers a specialized education in statistics at a high scientific level and with a view towards

European and non-European oceanographic laboratories and governmental institutions. Co-operation of relevance to the IDOD project includes, for instance, environmental management activities in the frame of the Oslo and Paris conventions for the prevention of marine pollution and participation in co-ordination efforts of the European oceanographic data centers in the frame of the MAST programme sponsored by the European Union.

Affairs (OSTC). Many applications, notably in environment concern fundamental research : integration of high spatial resolution imagery in remote sensing, land country planning, GIS, contribution to the seamless cartography of the Walloon Region, etc. The CONGOO formalism specifically designed for geographical databases and GIS conceptualisation was developed at the laboratory.

important fields of application. Program participants are intensively trained in statistical theory and its practical use in problem-solving.



MARE-DASM: MARINE RESOURCES DAMAGE ASSESSMENT AND SUSTAINABLE MANAGEMENT OF THE NORTH SEA

To be assured of a high standard of living riparians of the North Sea make different uses of the North Sea. In order to achieve a sustainable use of the North Sea, it is necessary to restrict the harmful use of it. In recent years a lot of national and international measures and principles to protect the ecosystem of the North Sea were adopted. In the new OSPAR Convention of

1992 all North Sea states and the European Commission agreed to use the precautionary principle and the polluter pays principle for the protection of the marine environment. The implementation of these measures and principles often causes practical problems. The research done in the framework of MARE-DASM will propose a solution for these problems.

THE PROJECT

The project has two main objectives who have a different goal but the results of the first objective (theme 1) will partly be integrated to obtain the second objective (theme 2).

propositions of measures to be taken by the government to guarantee a sustainable use of the sea for the future generations (*Maritime Institute, Prof. Dr. F. Maes*).

Theme 1: the socio-economic cost of a degradation of the marine environment

The first objective of the project is to make an identification and quantification of different factors contributing to the degradation of the marine environment in the Belgian part of the North Sea (*Laboratory of Environmental Toxicology and Aquatic Ecology, Prof. Dr. C. Janssen*). This identification and quantification must be the basis for the evaluation of the direct and indirect economic and social costs of degradation, accidentally or permanently (*Maritime Institute, Prof. Dr. F. Maes, with subcontractor Environmental Consultancy and Assistance (ECOLAS), Dr. P. Vanhaecke*). The cost of degradation will be compared with the economic and social profits of the use of the Belgian part of the North Sea by the current generation, in order to come to

Theme 2: The risk of the accidental oil/chemical pollution of the marine environment

The second objective of the project aims at making an estimation and prediction models of the potential damage of the ecosystems of the Belgian part of the North Sea caused by oil and other chemical products, as well as the socio-economic impact of this damage in a number of selected cases (*Management Unit of the Mathematic Models of the North Sea, Dr. G. Pichot*). The mathematical determination of the damage must enable the development of technical and legal procedures that allow to evaluate the degradation of the marine environment and to recover it financially on the polluter (*Centre for Environmental Law, Prof. Dr. H. Bocken (national law) and Maritime Institute, Prof. Dr. F. Maes (international law)*).

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ACTIVITIES

Task I "identification and quantification of different factors contributing to the degradation of the marine environment" will study, next to the identification and quantification, the distribution of the contaminants in the environmental compartments in order to fine-tune the Biological Effects Submodel for the long term effects. The results of task I should enable to estimate the degradation of the marine environment. This estimation is a starting

point for a part of the research that will be done in task II "the development of socio-economic assessment criteria to determine in an objective way the cost of degradation", namely the quantification of damage to the environment based on use values. For the socio-economic assessment criteria the quantification of environmental damage based on option and existence values (Contingent Valuation Method) will also be used. Research from tasks I and II will



contribute to the research in tasks III and IV. In task III "the development and evaluation of measures that need to be taken by the government in order to guarantee a sustainable use of the sea", measures will be proposed allowing Belgium to obtain an optimal integrated policy and sustainable use of the North Sea, taking into account the social costs and the political and legal-technical feasibility. The uses at sea will be set out on a priority scale in function of their degradation impact on the marine environment of the North Sea (cf. task I). The different uses will also be given an economic and social value, varying according to the different uses. Using the policy option "sustainable management" as a starting point, policy measures for every use will be proposed, taking into account the efficiency, the social costs and benefits that can be expected for the socio-economic groups and the possibility for the government to take action. The ecological effects (task I) and the defined socio-economic assessment criteria (task II) will be integrated into the

mathematical model (task IV "to develop and evaluate mathematical models assessing the risks bound to accidental spillage of oil and other chemicals at sea and the damage they can cause, at the environmental and socio-economic levels"). The mathematical model will be developed by the Management Unit of the Mathematical Model of the North Sea (MUMM), but is however limited to the assessment of risks for environmental damage in case of accidental discharges of oil and other chemical products. Task V contains "the development of technical and legal procedures that allow to evaluate the degradation of the marine environment and to recover it financially on the polluter". On the one hand we are dealing with national and international liability law, with the polluter pays principle as a starting point and on the other hand with legal-technical and administrative procedures in order to evaluate the degradation (environmental damage as well as disruption to the environment) financially and to recover it from the polluter.

The Maritime Institute of the University of Ghent is the coordinator and will work with ECOLAS (Environmental Consultancy and Assistance) as a subcontractor. Other partners are the Laboratory of Environmental

Toxicology and Aquatic Ecology of the University of Ghent, the Management Unit of the Mathematical Models of the North Sea (MUMM) and the Centre for Environmental Law of the University of Ghent.

The Maritime Institute is an independent research unit advising and carrying out studies for governmental administrations, non-governmental organizations and private companies. The staff of the Institute is

specialized in research topics concerning maritime law, law of the sea, marine environmental law, transport law and related policy studies.

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Partner 1

ECOLAS has been responsible for the implementation of research tasks concerning the development of socio-economic criteria to define damage to the marine environment (use values). To implement the results of this

Partner 2

The research within the Ecotoxicology unit of the Laboratory of Environmental Toxicology and Aquatic Ecology (LET) is aimed at the development and evaluation of methods for the effects assessment of contaminants on biota (present in water, sediment and soil). In a recent study a specific methodology was

Partner 3

The Management Unit of the Mathematical Model of the North Sea (MUMM) is a federal government scientific institution with activities in marine research, monitoring and management. Research at MUMM focusses on providing the necessary knowledge and tools for scientific management of the North

Partner 4

The Centre for Environmental Law of the University of Ghent conducts research on various aspects of environmental law and the influence of the European and Belgian institutional context on environmental law, compensation for environmental damage,

type of research, ECOLAS made good contacts with other organisations, in particular in the United States. ECOLAS is also appointed by the Belgian court as expert for the financial quantification of damage by pollution.

developed for the ecological impact assessment of contaminants in the marine environment. The Laboratory of Environmental Toxicology established throughout the years several contacts with international marine research institutes.

Sea ecosystem based on mathematical modelling, remote sensing and in situ measurements. MUMM intensively cooperates with other European and non-European oceanographic laboratories and governmental institutions.

soil sanitation, nature conservation and town and country planning. The Centre is also responsible for the elaboration of computerized information systems on legislation, jurisprudence and doctrine in the field of environmental law.