NIOZ Science Plan 2008-2012

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Contents

Executive Summary

The NIOZ Science Plan has been written with the aim of providing a general framework of research defining important questions and encouraging both curiosity-driven and societal relevant disciplinary developments within departments and disciplines, and multi-disciplinary thematic cooperations between the departments. The primary goal for NIOZ remains excellence in basic research.

However, NIOZ has also a broader perspective. Especially for developing and executing complex multidisciplinary research projects, NIOZ has established strategic alliances and created added value for the marine scientific community in the Netherlands and abroad. Nationally, NIOZ will further develop the cooperation with the Netherlands Institute of Ecology NIOO-KNAW in the FOKUZ program and actively contribute to the National Marine and Coastal Research Program of ALW-NWO in which cooperation with the relevant partners in marine research in the Netherlands is now being established. NIOZ will also contribute to higher education in the Netherlands. Internationally, NIOZ aims at remaining a trusted and wanted partner in large EU and ESF projects, and NIOZ science must remain at the forefront of scientific development in Europe and globally.

The structure of the research program also forms the basis for infrastructure development, the renovation of the building with an upgrading of laboratory and technical facilities, the reallocation of technical staff and the appointment of new scientific and supporting staff. Five multidisciplinary research themes have been defined; three of them concern geographic areas (the open ocean, the sea floor, and wadden and shelf seas), whereas the other two address the main changes in marine ecosystems today due to climate change and biodiversity loss. These themes will represent NIOZ research efforts for the next five years (2008-2012) and must be sufficiently broad to accommodate new developments and discoveries. Each of the themes requires a substantial effort and the five departments contribute according to the following scheme:

Table 1. Scientific effort in fte's of tenured and non-tenured scientists of the five departments in the five multidisciplinary research themes (Dec 31, 2007).

	Open Ocean	Dynamic Sea Floor	Wadden and Shelf Seas	Climate Variability	Biodiversity	Total	**Tenured/ non-tenured**
Physical Oceanography	5.0	0.5	1.8	2.5	0.5	10.3	**4.7/5.6**
Marine Geology	1.7	5.5	2.3	3.2	0.0	12.7	**2.9/9.8**
Marine Organic Biogeochemistry	3.3	2.3	0.0	9.5	3.7	18.8	**3.5/15.3**
Biological Oceanography	4.5	1.0	5.5	0.0	2.7	13.7	**6.5/7.2**
Marine Ecology	0.5	1.5	17.9	2.0	1.5	23.4	**9.0/14.4**
Total	**15.0**	**10.8**	**27.5**	**17.2**	**8.4**	**78.9**	**26.6/52.3**

To increase the cooperation between the departments, two PhD positions will be awarded to new inter-departmental themes in 2008. Besides, NIOZ has started a system of tenure tracks in 2008, with new positions opening also in 2009 and 2010.

NIOZ is running a long-term measurement series of physical, chemical and biological measurements in the Marsdiep tidal inlet of the Western Wadden Sea from its own jetty. In 2007 an entirely new jetty was built; with a platform which has been elevated 2.7 m above the level of the old jetty. This proved to be high enough to withstand the extremely high-tide at 9 November 2007. Photos: Jan Boon (NIOZ).

Introduction

"Our blue planet".

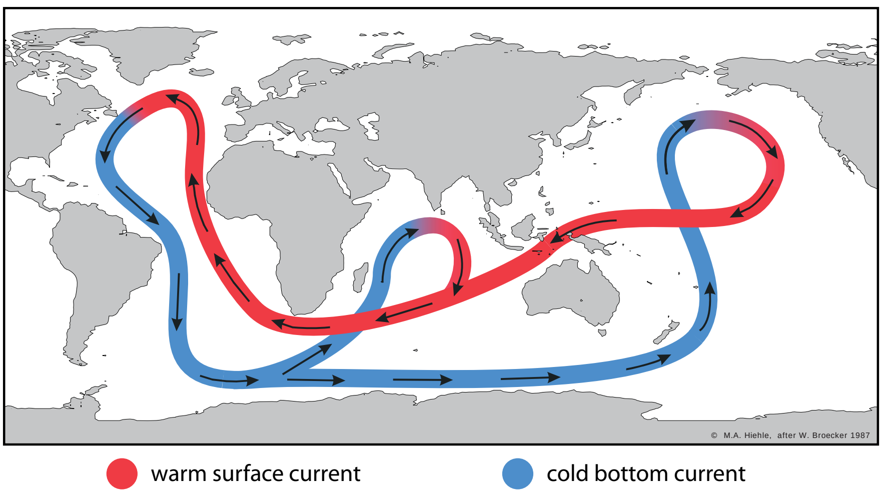
Earth is a blue planet. The seas and oceans cover 71% of the surface of the globe and are major actors in the Earth's climate system. Still, the marine environment is by-and-large unknown and unfamiliar to most people. Scientific knowledge of the seas, remained restricted to the coastal and surface waters until the first oceanographic expeditions in the 19th century opened an entirely new world, one that covers most of our planet.

It is in low-lying countries such as the Netherlands that the sea is most clearly experienced as part of daily life, and where the economic importance is greatest. For over a thousand years, in a constant struggle, land was repeatedly lost and reclaimed again from the sea. The sea was an important source of food and wealth. Holland became a maritime nation of world importance during the 17th century. Still today the economy of the Netherlands is strongly dependent on the maritime sectors. We are big users of the seas.

Only recently have we come to realize that using the seas also implies governance and management, and these require knowledge of the seas. The seas are changing: climate change and sea-level rise, as well as biodiversity loss will have a direct impact on the economic development in The Netherlands and elsewhere. Therefore, we need to further advance our basic knowledge about the seas to better understand system Earth and to support the development of strategies to mitigate the effects of global change.

Coastal research has been stimulated worldwide by local problems of coastal protection, harbour development, pollution, eutrophication, and overfishing. In contrast, research in the open ocean has been limited to a small number of countries because it is expensive and because the open ocean is beyond national jurisdiction. Hence it is outside the interest of most nations. Still, oceanography has gone through a knowledge explosion over the last decades when major discoveries were made based on new technologies such as synoptic ocean observation with satellites, deep-water observation with submersibles and remotely operated vehicles, deep sea-floor drilling, as well as the use of increasingly sophisticated molecular and other analytical methods.

The global oceanic thermohaline circulation.
After W. Broecker, modified by M. Hiehle (NIOZ).



These tools led to major advances in all scientific disciplines of oceanography and contributed to a better understanding of the global ocean circulation and water mass transport, seafloor processes, and the biogeochemistry and biology of the ocean. Such advances in marine science have demonstrated that man-made substances have reached the deep ocean, that natural climate change may occur within decades, that pulses in melting of land ice increased the sea level by up to one meter per year in the past, and that ocean currents may shift rapidly in interaction with global climate forcing.

Our capacity to observe, understand and model marine systems has increased dramatically, which should allow us to better constrain future changes and their consequences for the global ocean and ultimately for the Earth system. At the same time we have realized that we need to learn a lot more before we can fully integrate our knowledge for the protection, conservation and sustainable use and exploitation of the marine resources we will increasingly need in the future.

The NIOZ research fleet:

- The RV Pelagia for the oceans and the open North Sea. The RV Pelagia participates in the European Ocean Facilities Exchange Group (OFEG). This group of European marine institutions exchanges ship time of each other's research vessels to optimise their use.
- The RV Navicula for the Wadden Sea and the coastal area of the North Sea.
- Our water taxi RV 'Stern' (Tern) for research on the intertidal flats of the Wadden Sea.
- The 'vlet' (flat boat) 't Horntje for emptying our long-standing fish-fike in the Mok bay in the western Wadden Sea.

Photo's: Jan Boon, Bert Aggenbach (NIOZ)

NIOZ Royal Netherlands Institute for Sea Research: Mission, Ambitions and Organisation

NIOZ Royal Netherlands Institute for Sea Research is the national oceanographic institute of the Netherlands. Our mission is to gain and communicate scientific knowledge on seas and oceans for the understanding and sustainable development of our planet, and to facilitate and support marine research and education in the Netherlands and Europe. To do so, NIOZ covers the major disciplines in marine science required to understand natural processes and human impacts in the Wadden Sea and North Sea that are both essential to the Netherlands, and the open oceans, which are a common heritage of mankind.

NIOZ is located on the south-eastern tip of the island of Texel. Background: the institute's harbour. Photo: Bert Aggenbach (NIOZ).

Marine research is international and multidisciplinary. The ambition of NIOZ is to be a key player in marine research in Europe and worldwide. To achieve this ambition, a number of scientific and strategic alliances have been started (Annex 1, p. 31). At the national level, there has been a significant clustering of marine research. In the coming years the research program of NIOZ will be developed together with the Netherlands Institute of Ecology, Centre of Estuarine and Marine Ecology in the new collaborative program FOKUZ (Fundamental Research of Coast and Seas) (Annex 2, p. 35). NIOZ has many ties with the Dutch universities and NIOZ scientists are professors at Dutch and foreign universities (Annex 3, p. 39). In the applied field, long-standing cooperation is now further developing within the Programme of Marine and Coastal Research and two new institutes, Wageningen-IMARES for living resources and DELTARES for geology, physics and aquatic engineering. At the international level NIOZ participates in many regional collaborative projects and in projects of the European Science Foundation and the European Union.

On a regional scale, NIOZ is actively seeking increased cooperation with Germany and, within FOKUZ, with Belgium. In the European Union a large number of long-standing cooperations have been established with scientific teams from all member states. NIOZ scientists collaborate worldwide with a large number of colleagues and institutions and in the large international programmes such as IMBER, LOICZ, CoML, CLIVAR, IODP etc. (Annex 4: List of Acronyms, p. 41).

The four basic disciplines of oceanography are chemistry, biology, physics and geology.

Science at NIOZ is carried out within scientific departments that are structured following the classical disciplines: physics, chemistry, geology and biology. For organizational and historical reasons biological studies are performed in two separate departments. Some thirty permanent scientists and about an equal number of non-permanent scientists work in these five scientific departments. This organizational structure is continued to ensure a daily environment in which scientific communication, and the use and development of techniques is optimal.

However, addressing many of the important questions in marine research requires input from different disciplines. Scientific and technological developments over the last decades have strengthened this. At NIOZ this has also resulted in a growing collaboration between different disciplines. In order to formalize these developments and further strengthen this approach, NIOZ has decided to structure the science plan of the institute according to five broad research themes in which the classical disciplines collaborate. The contribution of the departments is shown in Table 1. Multidisciplinary scientific projects contributing to these themes will be stimulated in the coming years.

Multidisciplinary Research Themes

Theme 1: Open Ocean Processes

Introduction

The dynamics and variability of oceanic processes and their impact on the Earth system remain poorly known. Direct observation of the ocean surface has demonstrated large variability on all spatial and temporal scales in characteristics such as sea surface temperature and ocean colour. Also in the deeper parts of the ocean, where observations are very limited, the spatio-temporal variability is much larger than previously thought. Besides the natural variability, it has become clear that open ocean systems are subject to significant anthropogenic changes. Examples are changes in stratification due to global warming, shifts in limiting nutrients for primary production due to alterations in the atmospheric input of dust and the dramatic consequences of the invasion of fossil fuel-derived CO_2 for the calcifying organisms inhabiting the oceans. Pelagic fisheries are changing the oceanic food web top down by removing the large predatory bony and cartilaginous fish.

The Titan CTD and water sampler is made of titanium and has been designed and constructed in a close cooperation between the departments of Biological Oceanography and Marine Technology. It is used to study the influence of iron on plankton growth in the open oceans.

Observing, describing and understanding the changes in the oceans and predicting their consequences for the changing climate and human use of oceanic resources is limited by the incapacity of oceanographic research worldwide to obtain sufficient observations that cover the immense oceans adequately. Oceanographic research is therefore essentially international, largely performed within global programs. It is the ambition of NIOZ to remain an important player in international oceanography by participating in international programmes and by maintaining and improving its research vessels and its technical and analytical infrastructure.

Upper Ocean Processes

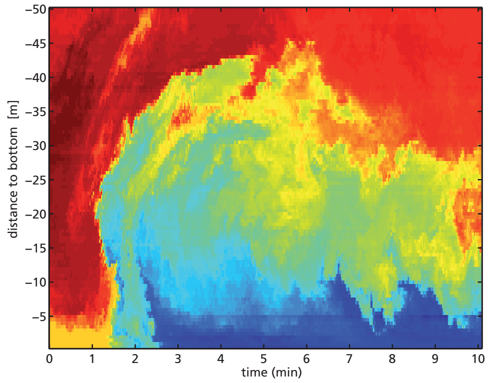
Ocean surface waters are the major conduit for the transfer of solar and wind energy into the oceans, and the interface for exchanging water vapour, trace gases, contaminants, and aerosols with the atmosphere. Marine primary production equals that on land and is the basis for the energy flow in virtually all marine ecosystems.

The microbial food web consisting of pico-autotrophs and -heterotrophs (eukaryotes, bacteria, archaea), micro-zooplankton as well as viruses, pivots around dissolved organic matter (DOM) and performs as a relatively stable closed ecosystem. Yet, under the right conditions this small food web is superimposed by blooms of larger eukaryotic phytoplankton such as diatoms. Other cosmopolitan algae are the haptophytes, notably the colony-forming *Phaeocystis* and the calcifying coccolithophorids, e.g., *Emiliania huxleyi*. Haptophytes are a major link in the ocean carbon cycle and the production/transformation of climate-relevant biogasses.

The bivalve *Lima spp*. can be found on the cold-water coral reefs of the continental slope. Photo: Marc Lavaleije (NIOZ).

Currently, environmental conditions are rapidly changing. The supply of iron from continental dust (aerosols) has increased up to twofold due to changes in land use (desertification). Iron stimulates growth of larger diatoms. Moreover, the invasion of anthropogenic CO_2 into the oceans causes major changes. By the year 2050, the pH is anticipated to have dropped by 0.3-0.4 units and carbonate ion concentration $[CO_3^{2-}]$ will be half of its pre-industrial value. Recently, it was realized that the rates of many biological processes might be severely affected, potentially leading to major biological changes of the oceans in a high-CO_2 world.

NIOZ will address the interactions between physics, chemistry and biology in the upper ocean. Variations in turbulence, transfer of heat and water and the basin-wide circulation strongly affect availability of light and (trace) nutrients for the plankton ecosystem. Natural plankton assemblages of the Southern Ocean and the North Atlantic are studied both at sea and in the laboratory down to the molecular level.



Internal waves cause an intensive and rapid vertical mixing between the sea surface and the deep sea near the continental slope. Image: Hans van Haren & Martin Laan (NIOZ).

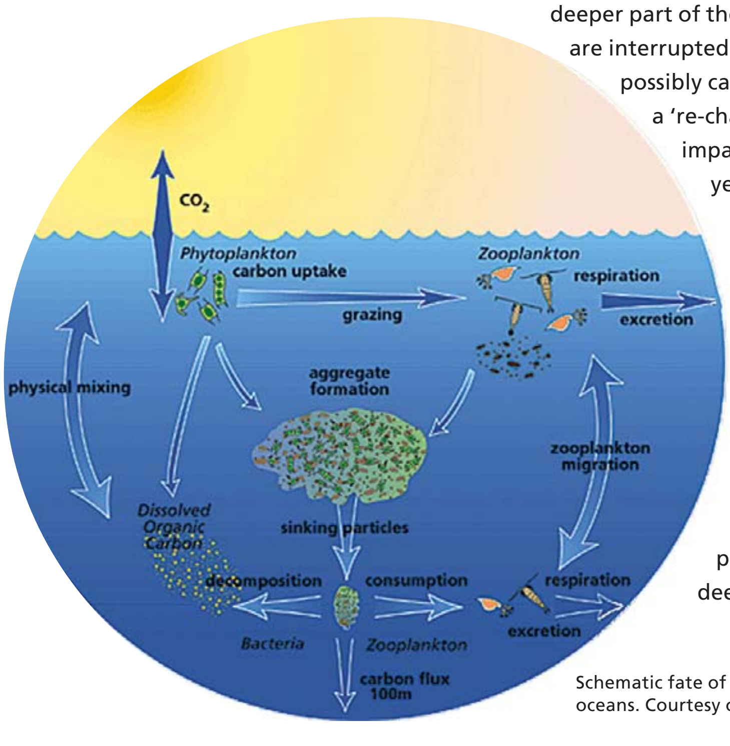
Deep Ocean Processes

The meso- and the bathypelagic oceanic realms are, in terms of volume, the largest but least explored oceanic subsystems.

Small-scale mixing in the deep ocean is not only driving the large-scale Meridional Overturning Circulation (MOC), but also plays a major role in the transport and redistribution of dissolved matter. Recently, it has become clear that there is a large spatial (and possibly temporal) variability in this mixing. The presence of a non-uniform internal wave field in the deep ocean could be the cause of this variability. However, a satisfying theoretical framework based on, and validated by observations is lacking, which severely hinders the further development of general circulation models.

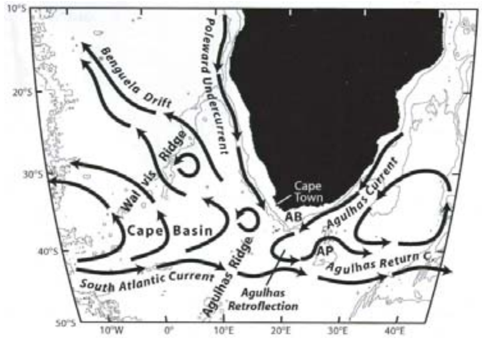
Moreover, it has also been noted that in the North Atlantic Deep Water, i.e., the deeper part of the MOC, slow gradual changes in the rate of biogeochemical cycling are interrupted by sudden changes. These abrupt changes at distinct 'hotspots', possibly caused by localized and vigorous diapycnal mixing, lead obviously to a 're-charging' of the biogeochemical cycling in the MOC. The overall impact of these hotspots on the global ocean's carbon cycling remains yet to be assessed.

Even the deep ocean is subject to environmental change. Evidence has been presented, based on modelling approaches, that anthropogenically introduced carbon into the deep ocean may have a profound impact on the oceanic carbonate system. Yet, deep ocean biogeochemical fluxes have been estimated from geochemical mass balance calculations and models only. Direct measurements of cycling processes and metabolic rates are not available. Consequently, we lack a mechanistic understanding of the functioning of the deep water food web and of the ecology of the prokaryotes as the main drivers of the biogeochemical cycles in the deep ocean.



Schematic fate of particulate and dissolved organic carbon in the surface and deep layers of the oceans. Courtesy of JGOFS programme.

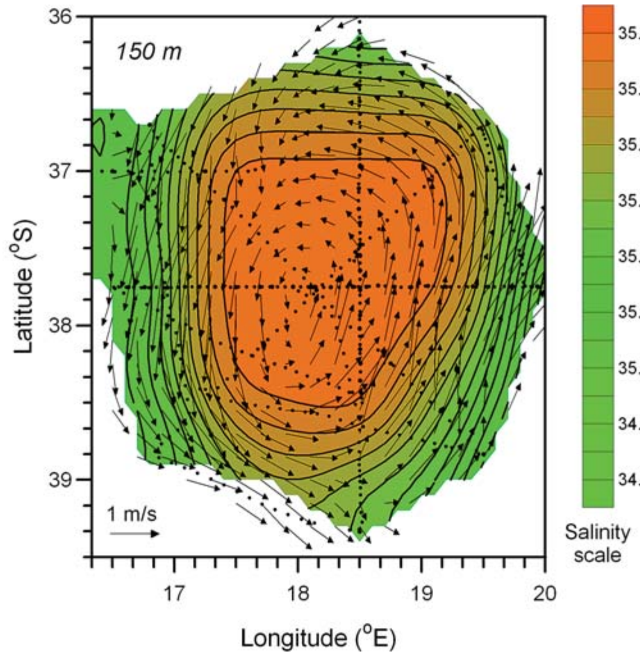
NIOZ will address major unsolved aspects of the deep oceanic circulation and mixing and their influence on the biogeochemical cycling of carbon. Metabolic rate measurements of microbial communities and the community composition will be linked to the major deep water masses in the North Atlantic. Key steps in the carbon (chemoautotrophy, enzymatic activity) and nitrogen cycling (denitrification, nitrification) in the deep ocean will be determined by combining rate measurements with a genomic approach to resolve the ecology of the main drivers of these fluxes.



Currents in the Indian and South Atlantic Oceans near South Africa. Image: PhD thesis Astrid van Velthoven (2005).

Turbulent Mixing Processes

On a large scale, the oceans feature an intricate interplay between wind-driven circulation and the MOC. The strength of these two circulations is determined by differential heat, freshwater and momentum fluxes across their boundaries. However, a major role in the redistribution of heat, momentum and dissolved substances is played by small-scale dynamics, such as the advection and mixing due to eddies, waves and turbulence. The contribution of these small-scale dynamics to biological productivity and to the large-scale circulation and the climate development is a challenge to decipher for ocean-observers, as well as experimentalists and theorists.



Salinity distribution (coloured) and current velocity field (arrows) at a depth of 150m in Agulhas ring 'Astrid', as observed from the RV Pelagia in March 2000. Image: PhD thesis Astrid van Velthoven (2005).

NIOZ will study small-scale dynamical processes at representative ocean sites by means of observations using a set of innovative instruments, and by examining idealized versions of these small-scale processes in both the laboratory and in theoretical model configurations.

Scheme of a mooring with, from bottom to top: anchor weight, acoustic release mechanism, sediment trap, current velocity meter, acoustic Doppler current profiler and a floater to keep the cable in an upright position. Image: Harry de Porto (NIOZ).

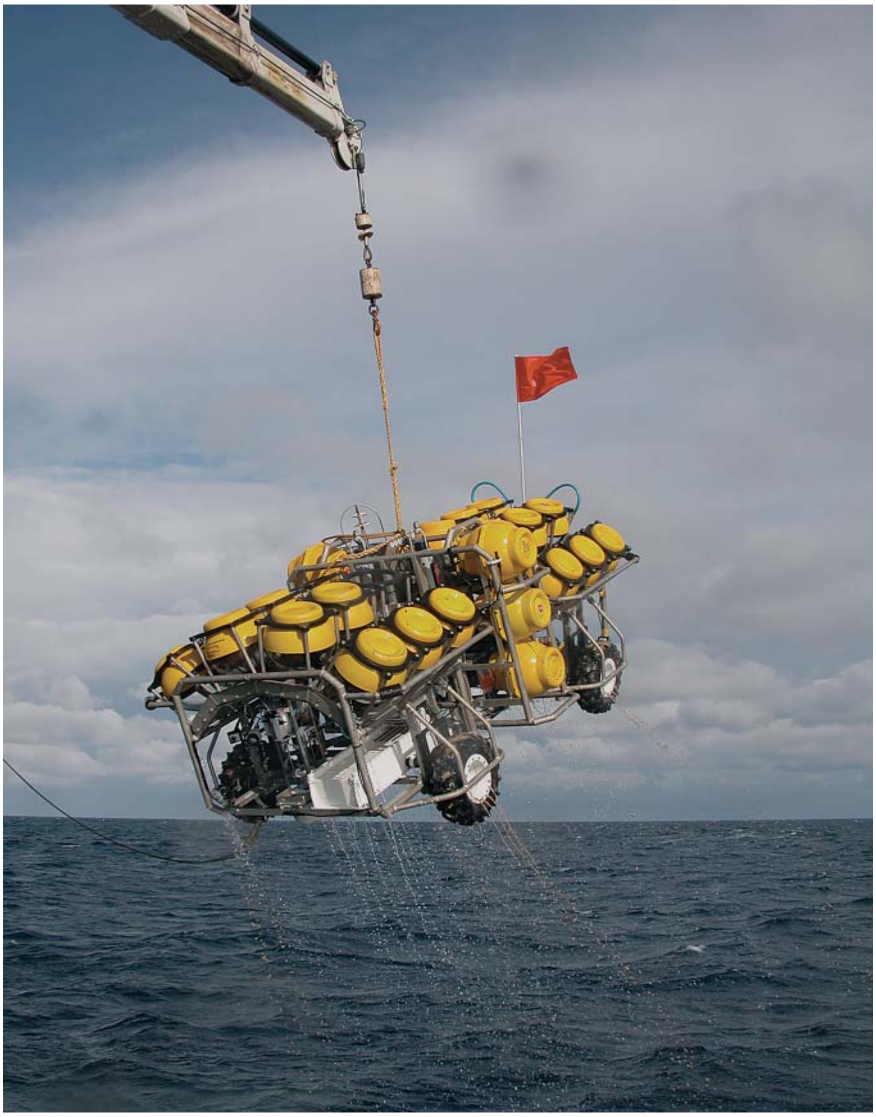
Theme 2: Sea Floor Dynamics

Introduction

The deep sea floor forms a complex environment where the geo-, bio-, and hydrosphere interact. Especially the continental margins, extending from the shallow coastal seas to the deep abyssal plain, display a wide variety of benthic ecosystems. They are important sites for exchange processes between the continents and the open ocean and contain sedimentary archives of past changes in ocean-climate interactions. The temporal and spatial variability of these systems and processes have been studied only to a limited extent and their role in the global system needs to be better defined.

Particle fluxes play a fundamental role in global element cycling and in the ocean's carbon budget (organic and inorganic) and consequently, in deep-sea ecosystem development. Settling, transport, deposition, and resuspension of particles derived either from the surface ocean or from the continents are controlled by reactive properties of the particles themselves, by the dynamics and characteristics of the water mass, by near-bed hydrodynamics, and by the geomorphology and biology of the extant seabed. These complex interactions determine the spatial and temporal variability of the margin with respect to climate forcing of sediment composition, accumulation and architecture, and benthic ecosystem development.

The newly developed MObile underwater VEhicle MOVE; a mobile lander for measurements at the seafloor.



Lander with two ALBEX units to measure the respiratory activity of an enclosed part of the sea bottom. Photo: Gerard Duineveld (NIOZ).

The seabed in shallow, and increasingly also in deeper, waters is altered by human activities. These include bottom trawling, harbour and industrial development, dredging, and oil, gas and, potentially, deep sea mining and gas hydrate exploration. Future seabed system research should therefore focus on a better assessment of the role, functioning and importance of benthic systems to provide the scientific base for adaptive management including sustainable exploitation and conservation of the seabed. To define the impact of anthropogenic changes, baseline studies and knowledge of natural conditions and processes affecting seabed systems are essential.

Moreover, the effects of global change resulting from changing primary productivity and changing current systems are also visible on the seabed. To better define and understand the mechanisms forcing the diversification and dynamics of seabed systems, long-term in-situ time series measurements above, at and below the seafloor are essential. In combination with short-term high-resolution measurements, seabed observatories, mobile landers and ROVs should disclose benthic variability and diversity with respect to hydrodynamic forcing, biogeochemical cycling and sediment accumulation through time.

Seabed System Dynamics

Over the past decade, continental margin studies have mainly focused on long-term processes controlling the exchange of matter between productive shelf seas and the deep ocean. It is now recognized that high energy episodic events may dominate sediment resuspension and redistribution, and affect the development and functioning of benthic systems on much larger spatial and temporal scales than hitherto assumed. Tracing and resolving the frequencies and effects of these short-term hydrodynamic events is difficult and therefore, their impact is still largely unknown.

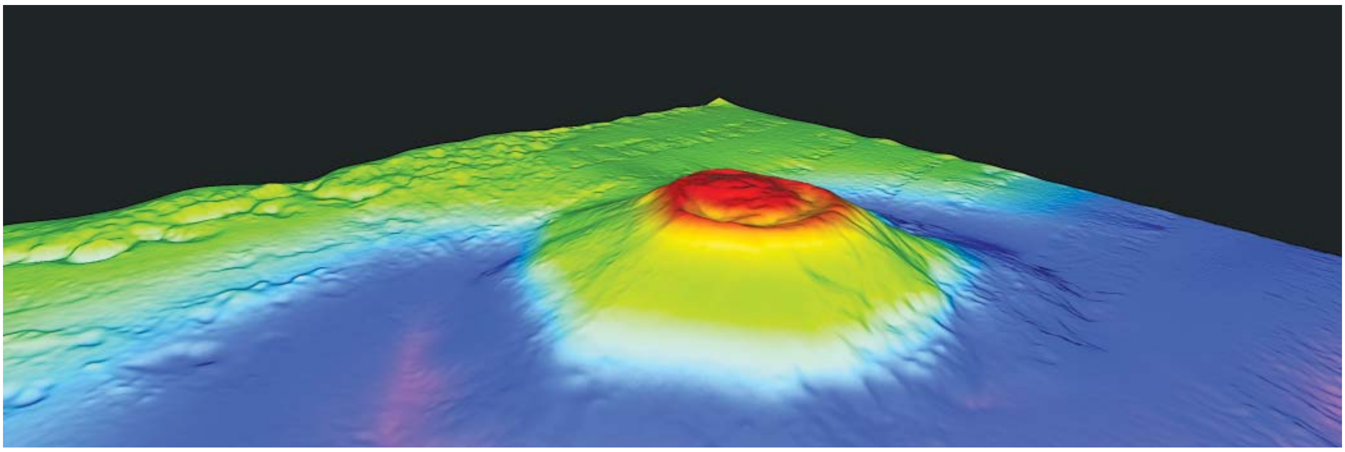
NIOZ will focus on the forcing exerted by near-bottom hydrodynamic, sedimentological, biological and chemical processes on the functioning of modern benthic systems as well as on their spatio-temporal variability and on the reconstruction of forcing mechanisms in the past.

"Burning ice". Gas hydrates are solid ice-like formations with methane and other hydrocarbon inside. When gas hydrate decomposes, it releases methane that can be burned (flame in upper right hand corner). Sample was taken from the Kazakov mud volcano in the Sorokin Trough, NE Black Sea. Courtesy of Prof. M.K. Ivanov, Training through Research programme, Moscow State University, Russia. NIOZ contributor: Alina Stadnitskaia.

Complexity in Benthic Ecosystem Functioning

Benthic ecosystems result from the interplay between physical and sedimentary processes driving the abiotic differentiation of the seabed, which is inhabited, modified and engineered by the biota. Understanding the role of structural and biotic complexity in benthic ecosystem functioning is a challenge in ecological research because these ecosystems are unique on Earth. Besides the vast sedimentary and basaltic sea floor habitats, covering more than half of the Earth's surface, a number of smaller but very specific habitats have been discovered over the last decades, including hydrothermal vents, cold-water coral reef communities, cold seeps, carbonate mounds and mud volcanoes. Even more exotic is the deep sub-seafloor biosphere that has only recently been discovered.

NIOZ will study the factors and processes that control the initiation, development, stability, and eventual decline of the various biological communities of the sea floor, focusing on soft bottoms, coral reefs, and cold gas and fluid seeps. NIOZ will study how the various stages in community complexity affect biogeochemical and sedimentological cycles and the nutrient and energy flow within the system, and, vice versa, to which degree the energy input and sedimentary processes affect the complexity of the community.

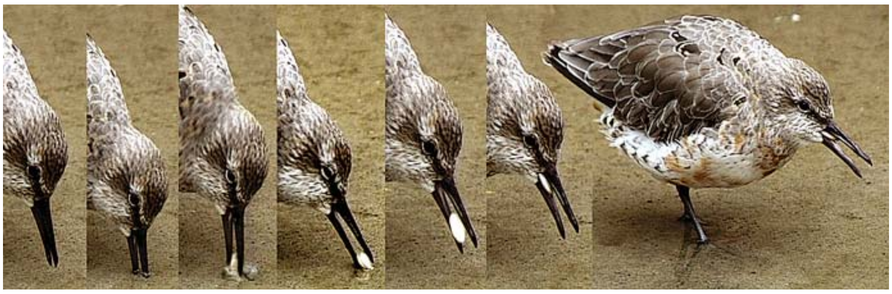


Multi-beam image of the Al Idrisi mud-volcano in the Gulf of Cadiz (Spain) as acquired with the Kongsberg multi-beam unit of the RV Pelagia. Vertical exaggeration 5 times; (true) height is 250 m, diameter 3.7 km.

Theme 3: Wadden and Shelf Sea Systems

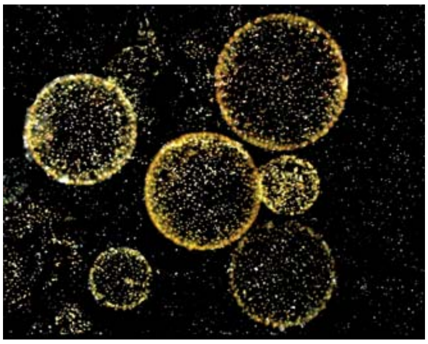
Introduction

Coastal and shelf ecosystems are the most important marine ecosystems from the human perspective and they are extensively used worldwide. Consequently, marked changes at all trophic levels have taken place in coastal and shelf ecosystems all over the world during the last decades. On the one hand, there have been dramatic changes in nutrient concentrations. On the other hand, many fish, shellfish and bird species have decreased dramatically in numbers, whereas some others have increased. These changes have been attributed to increasing temperatures, changing nutrient loads and especially fisheries that have greatly intensified over the last decades, causing the loss of biogenic structures and disturbance of the seafloor. Ecosystems have changed as well by the natural or anthropogenic introduction of exotic species at various trophic levels.



A knot (*Calidris canutus*) swallows its staple food, the bivalve *Macoma balthica*. Photos: courtesy of Jan van de Kam and Jan Drent (NIOZ- below).

Understanding of the relationships between changes in the abiotic environment and changes at all trophic levels in coastal and shelf ecosystems and evaluation of the effects of anthropogenic pressures requires a comprehensive approach combining field observations, appropriate experiments and the development of adequate models. The Wadden Sea and the adjacent southern and shallow zone of the North Sea are well suited to achieve these goals because of the huge body of existing knowledge, their accessibility within easy reach of the coast and their special importance to the Netherlands. Moreover, Wadden and shelf systems worldwide serve similar functions, such as nursery areas for fish and crustaceans and refuelling areas along the flyways of millions of migrating birds.



Microscopic photo of the foam algae *Phaeocystis globosa*. This species forms an important part of the spring bloom of algae along the Dutch coast and succeeds the initial diatom bloom. The species can occur as colonies which can be a few mm in size and as single cells (tiny dots) of about 5 micrometer. Photo: Jolanda van Iperen (NIOZ).

Long-term Changes in Coastal Ecosystems

Ecosystems change in often unpredictable ways. Modern ecological theory has predicted the existence of alternative stable states and of hysteresis loops when driving forces change the system from one state to another and sometimes back. The accelerated impact of drivers such as fisheries or climate change necessitates the continuous observation of coastal ecosystems on the appropriate spatial and temporal scales, i.e. regional and landscape scales over decades. Automated observation of driving forces in ecosystems is only starting now. Such observations have to be put into context by analyzing them in the framework of long-time and large-scale ground truthing and by modelling efforts. Besides allowing 'on line' information on the state of ecosystems, also the development of models and their validation and calibration require an extensive and well-balanced long-term observational program, supplemented with well-designed field and laboratory experiments on various spatial and temporal scales.

Population Dynamics in Coastal Ecosystems

The study of population dynamics should be based on detailed knowledge on individuals. Birth, death and migration rates, which determine changes in population size, are ultimately the result of morphological (e.g., size), physiological (e.g., energy reserve) and behavioural (e.g., susceptibility to interference) characteristics of the individuals. Changes in the state of an individual depend upon its environment (characterized in terms of food, competitors, predators, abiotic factors). The environment in turn is affected by the actions of individuals. This feedback loop between the state of individuals and the environmental conditions they experience is of vital importance in determining population dynamics.

In order to document the changes in the coastal seas of the Netherlands, we will implement a set of field studies within a well-designed system of sustained observations and observatories. These studies are needed to validate model assumptions and predictions. Emphasis will be on the western Wadden Sea and the southern zone of the North Sea. Existing long-term time series on biotic and abiotic variables from the Wadden Sea will be further supported and expanded to provide the data required to validate our model results. The development of ecosystem observatories that combine measurements of physical parameters such as sediment transport, with semi-continuous measurement of primary production, remote sensing of plant pigments, and monitoring of benthos, fish and bird populations is currently being undertaken in the Marine and Coastal Research Programme of NWO/ALW.

The functioning of foodwebs, and the basis of biodiversity, cannot be understood without due recognition, or indeed the actual study, of evolutionary processes. Current species compositions of marine communities strongly reflect historical events, and the assessment of selectively neutral genetic marker structure can help us to map these historical events in space and time. At the same time, the decades-long longitudinal studies on actual ecological interactions, for example the studies of trophic interactions between benthic invertebrates on the one hand, and crabs, fish and birds on the other, are inspired by explicit evolutionary thinking.

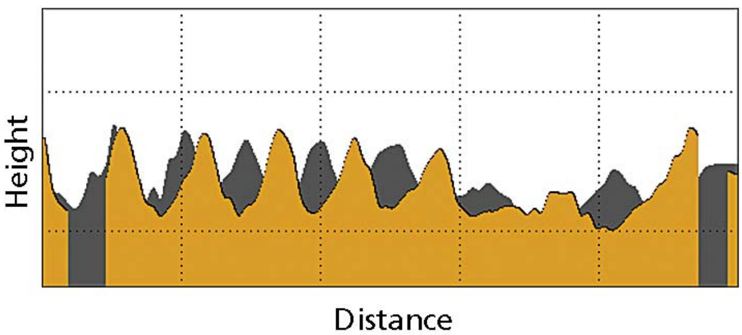
Sampling benthic invertebrates for the long-term monitoring series of the Balgzand intertidal flat in the western Wadden Sea. Photo: Jan Boon (NIOZ).

Ecosystem Dynamics

Many questions concerning the basic physical processes in the ecosystem, such as the net transport of suspended matter between the Wadden Sea and the coastal zone and, within the tidal basin, between the tidal channels and the tidal flats are still largely unanswered. The same holds for the problem of understanding the long-term (seasonal, inter annual) variability in the net flux of suspended matter and the nutrient loads at the different sites. A better appreciation of these physical processes is a prerequisite to understand their effect on the light climate, and hence on primary productivity. Similarly, the interaction between physical processes and biogenic structures such as oyster and coral reefs, deserves further attention.

In the past, mainly two approaches have been followed to model ecosystems: a process-functional approach with an emphasis on physical forcing and biogeochemistry (e.g., EMOWAD for the Wadden Sea and ERSEM for the North Sea) and a population-community approach in which the ecosystem is viewed as a network of interacting populations (e.g., the oystercatcher population model). Unfortunately, no clear-cut relationship exists between the two approaches. The challenge is to find the most simple, but appropriate state-space description of the ecosystem linking the forcing functions (whose effects are often more easily understood in terms of the functional approach) to effects on specific populations at the higher trophic levels (the centre of the population-community approach).

NIOZ will continue to develop ecosystem models where physical, chemical and biological variables and processes are included. The biological compartments of such models will focus on organismal structural size and storage as the most promising representations of function. The theory of dynamic energy budgets (DEB) says that the most important ecological processes (such as food intake rate or growth rate) are related in a specific way to structural size or storage. In order to account for the evolutionary flexibility of populations, the adaptive-behavioural approach could be incorporated, for example by allowing mutational changes in species-specific parameters.

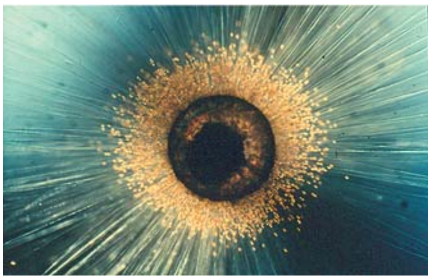


The measurements from the TESO ferries have proven that sand transport from the North Sea to the Wadden Sea by means of 3-5 m high sand dunes on the seabottom are an important mode of transport besides suspended particles. The time difference between the first (dark) and the last (light) situation is 15 months. Image: Frans Eijgenraam (NIOZ).

Theme 4: Climate Variability and the Sea

Introduction

We are faced with rapid climate change resulting from the present-day impact of humans on the conditions on Earth. To be able to predict our future climate there is a strong need to understand the character, controls and mechanisms of natural and anthropogenic climate change. During the evolution of our planet, climate has changed continuously as a consequence of changes in the incoming radiation, the composition of the atmosphere, continental drift and the evolution of life. Also at shorter time scales, inter-annual to centennial, natural changes of the climate, including the state of the ocean, have been reported. At these time scales, feedbacks due to interaction between different components of the climate system play a major role. These natural climate variations on a wide variety of time scales need to be observed and understood before the anthropogenic influence can be assessed.



The calcareous shells of single-celled planktonic foraminifers are often used in paleoceanographic research on climate change.

The oceans play a crucial role in the climate system of the Earth. Firstly, they store vast amounts of energy in the form of heat that can be transported through ocean currents. The uneven distribution of incoming solar radiation creates temperature differences in both the ocean and atmosphere that drive ocean currents and atmospheric winds. In turn, wind patterns also drive ocean currents. Secondly, the oceans act as both a source and sink of greenhouse gases (water vapour, carbon dioxide, methane and nitrous oxide). About 90% of the carbon dioxide is stored in the ocean and about half of the primary production (an important sink for carbon dioxide) on Earth takes place in the oceans.

Global change already affects the oceans and their life to a large extent. Warming of surface waters of the ocean and coastal seas results in changes in species composition with potential consequences for mankind. Human use of fossil fuels has caused a steep increase in carbon dioxide and consequently, acidification of the surface ocean and shallow seas with potential consequences for calcifying marine life. Climate change may also result in a change in the current pattern of ocean circulation which may locally modify the effects of global warming. Warming of the ocean results in thermal expansion and concomitant sea level rise, in addition to melting of land ice.

Past Climate Change as a Key to the Future

The settling particle flux in the ocean gives rise to the accumulation of sediments at the sea floor. These sediments form an archive of past marine ecosystems and ocean processes that can be used to assess marine evolution and climatic change. In order to do so, the proxy signals preserved in the sedimentary record have to be decoded. Biomarkers, organic molecules derived from algae, (cyano-)bacteria, archaea and higher plants, are so specific that they can be used as tracers for these organisms in past oceans. Together with the skeletal carbonate and silica as well as lithogenic minerals, they provide information on specific physical (e.g., temperature, current strength), chemical (e.g., nutrient and oxygen concentration) or biological (e.g., species diversity and productivity) properties of past ocean systems. There is, at present, a strong need for more and quantitative proxies to improve our understanding of the functioning of past ocean systems and their role in climate change.

The piston corer is used to collect sediment cores of up to 15 m length. The sea floor is the archive of the oceans, which may be many millions of years old.

Surface ocean proxies for the meridional overturning circulation are perhaps the most challenging to develop and validate, as they run from the surface to the deep ocean, across their interfaces and the benthic boundary layer, forcing the ultimate sedimentary signal over about six orders of magnitude in time. The study of present-day ocean systems is essential for the understanding of biological and physical controls on the formation of proxy signals, the impact of changing environmental variables, the transport pathways and fluxes to the seafloor and the effects of diagenesis. Proxy development and validation is therefore an ideal target for research at a multidisciplinary marine research institute such as NIOZ, requiring the input from marine biologists, geologists, chemists and physicists to access the sedimentary archive and address past ocean-climate variability in its widest sense.

NIOZ will put a strong emphasis on proxy development and validation for the reconstruction of marine evolution, the functioning of past marine ecosystems, climate variability, marine productivity, organic and carbonate carbon burial and quantification of terrestrial carbon input into the marine environment. NIOZ will apply time-series measurements to verify and trace the mechanisms and consequences of ongoing and past climate change.

Present Climate Variability

During the World Ocean Circulation Experiment (WOCE) in the early 1990's, it became apparent that the state of the ocean and the general circulation exhibit large changes on inter-annual to decadal time scales. Via several feedback mechanisms such changes can form an important mechanism in the generation of climate variability. The determination and explanation of this climatic variability in the ocean has become a major issue in climate research.

While repeat surveys provide a basin wide view of the ocean, the possible temporal resolution is determined by operational and financial limitations. Apart from contributing to a world-wide effort to develop a global ocean observing system, analyses based on these monitoring programs will serve to address research questions as defined in the Upper and Deep Ocean themes outlined above.

NIOZ has obtained a set of self-recording instruments to monitor currents, temperature and salinity through the Long-term Ocean Climate Observations (LOCO) project, representing a consortium of physical oceanographers from various institutes in the Netherlands (KNMI, IMAU). These mooring arrays determine the hydrographic variability at eddy time scales to decadal time scales. Variability in the near bottom currents probably affects the re-suspension and deposition of sediment. Thus, sediment properties reflect past changes in near-bottom currents. Therefore, sediment-trap moorings are deployed close to the Eulerian mooring arrays.

The RV Pelagia meets an iceberg near the southern tip of Greenland (background). Every other year, NIOZ surveys a standard section between Scotland and Greenland to monitor the behaviour of the large scale hydrography in the North Atlantic Ocean. Photo: crew RV Pelagia.

In 2007, larger quantities of southern fish species usually occurring only south of the North Sea were caught in the NIOZ fike in the western Wadden Sea. The gilthead sea bream *Sparus auratus* was even a new species for the Netherlands. In Mediterranean countries it is known -and highly appreciated- as 'dorade'. Photo: Kees Camphuysen (NIOZ).

Consequences of Climate Change for Marine Life

Climate change will have direct and indirect effects on marine plants and animals, and consequently on marine food webs. Temperature changes will affect metabolic and developmental rates in many animals, and processes such as photosynthesis and respiration in plants. Shifts in metabolic balances in poikilothermic organisms (e.g., invertebrates and fish) will lead to geographical redistributions. Climate-related alteration of life cycle events may result in decoupling of trophic interactions. Acidification may affect plankton species composition and the strength of the biological pump in open oceans, and lead to dissolution of bivalve shells in coastal temperate waters.

The population dynamics of many species of marine invertebrates and fish are driven by recruitment processes. Benthic communities contain many species with a pelagic larval stage existing prior to settling to the sea floor and subsequent metamorphosis into juveniles and adults. If warming results in an advancement of the timing of reproduction, there might be a mismatch in timing of the recruits and their main food source (phytoplankton) and their predators. This will inevitably lead to shifts in marine community composition, biodiversity, and ecosystem functioning and services. An understanding of larval ecology is therefore central to understanding how climate change affects marine life.

NIOZ studies the nature and rate of consequences of climate change by means of continuous long-term field observations which are unique on a global scale, due to their consistent methodology, their length of over 35 years, and the range of marine organisms. Recently, NIOZ started to study the seasonal dynamics of phytoplankton blooms and reproduction of marine bivalves in the Wadden Sea and North Sea, using newly developed molecular probes to distinguish between morphologically identical pelagic larvae.

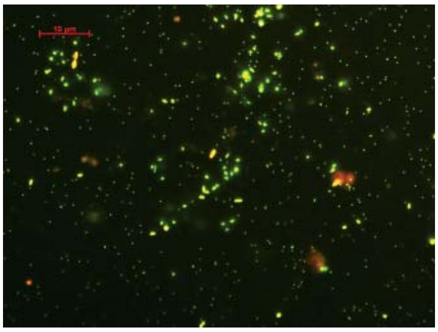
Theme 5: Biodiversity and Ecosystem Functioning

Introduction

At present, about 230,000 species of marine plants and animals and a few thousand prokaryotes have been scientifically described. The known biodiversity, however, only represents a small fraction of the number of species existing. Exploration of the marine environment constantly yields new species and will continue to do so for decades if not centuries to come. These species occupy a wide variety of niches and trophic levels in the food web. Through their activities, especially of the unseen majority of microbes, they also exert a major influence and control on the major biogeochemical cycles. However, even basic knowledge does not exist on the relationship between the specific characteristics of species, their genetic make-up, biochemistry, physiology, and behaviour and ecosystem structure and especially functioning for the vast majority of species.

Mixed bed of Japanese oysters, blue mussels and periwinkles in the Wadden Sea. The Japanese oyster escaped from aquaculture experiments in the early eighties of the last century. Its population in the Wadden Sea has been rapidly expanding ever since. Is this purely negative of is there a positive side too? Photo: Bert Aggenbach (NIOZ).

Moreover, the conceptual and theoretical framework describing the relationship between biodiversity and ecosystem functioning, stability and resilience is almost entirely based on observations and experiments on land. Only a few studies exist for the marine environment and they are restricted to intertidal, easily accessible areas. Simple experiments in which species were added to or removed from artificially assembled or defaunated natural communities have shown that species number and composition have an impact on the rate of ecosystem processes. However, the fundamental question whether all species or only a subset of species is required to maintain ecosystem health and functioning has not been answered yet. Solving this question will have important consequences for protection, preservation and management of biodiversity and ecosystems as a whole.



Epifluorescence microscopy picture of bacteria (large dots of about 1 micrometer) and algal virusses (small dots of about 0.1 micrometer). The nucleic acids of the micro-organisms have been coloured with the dye Sybr Green I. Photo: Govert van Noort (NIOZ).

If the relationship between biodiversity and ecosystem functioning is poorly known for macro-organisms, the challenge is even more daunting for microbes. Major discoveries during the last decade have come from the use of molecular methods both to elucidate microbial biodiversity itself and to link it to ecosystem functioning. Examples are the discovery of the widespread occurrence of archaea and their role in nitrification, and the discovery of bacteria able to oxidize ammonium anaerobically and thought to be responsible for at least half of the denitrification in the ocean.

Unravelling the Diversity of the Microbial World

Research on microbial diversity and function encompasses prokaryotes, viruses and protists, thus essentially covering all members of the microbial food web. Major progress has been made in elucidating the carbon and matter flux through microbial communities in marine systems over the past three decades using largely a 'black box' approach. The composition, particularly of prokaryotic communities, has only been addressed efficiently since the advent of molecular biology approaches in microbial ecology. Since their introduction, our knowledge on prokaryotic phylogenetic and functional diversity has increased exponentially. Applying fingerprinting techniques, it became apparent that the prokaryotic community composition changes in a predictable manner in coastal temperate waters over seasonal cycles similar to the phytoplankton successions.

Recently, high-throughput sequencing approaches have revealed an enormous diversity of prokaryotic species. We do know now that the prokaryotic community composition is highly stratified in the water column and hence, apparently well adapted to the composition of the substrate and in delicate balance with its main predators, the protists and viruses. Remarkably, it appears that changes in prokaryotic community composition do not result in changes in the major ecosystem functions such as remineralization of organic matter. Apparently the rich microbial biodiversity allows multiple food-web structures for a given environment.

Testing ecological concepts, such as the diversity – stability relation, the area – species relation, and even the neutral theory, which is hard to test with macrobial members of ecosystems, is possible in microbial communities. The great advantage is that microbial populations react quickly to changing conditions and change their genetic inventory within a few thousand generations, hence within months. In an evolutionary context, the occurrence of ecotypes and the role of viruses in evolutionary sweeps of ecotypes are tractable in microbial systems.

NIOZ will apply the tools that are now available to integrate microbial ecology into the general science of ecology, as the microbial food web provides unique opportunities to identify ecological patterns and processes common to all forms of life. To arrive at a mechanistic understanding of microbial diversity and its impact on major ecosystem functions, metabolic rate measurements and phylogenetic analyses of the bulk prokaryotic community with single cell techniques will be combined.

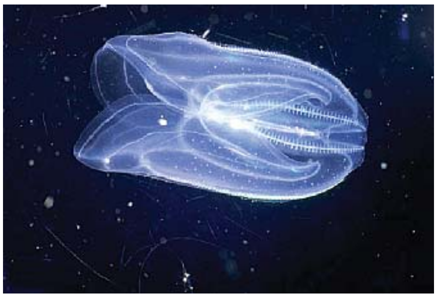
The slightly curved American jacknife *Ensis americanus* which came to Dutch waters in the nineteen seventies with ships' ballast water has virtually outcompeted the original and completely straight species *Ensis siliqua*. Meanwhile eider ducks (*Somateria mollissima*) have learned to feed on the juveniles. Photo: Bert Aggenbach (NIOZ).

Invasive Species

On a global scale, and certainly also in the marine environment, the number of non-indigenous species is increasing exponentially. Because the appearance of invasive species is often accompanied by economic damage, alteration of the local biodiversity, or even threats to human health, this topic has been subject of intensive studies.

Biodiversity can influence the ability of exotic species to invade communities through either the influence of traits of resident species or some cumulative effect of species richness. Early theoretical models and observations of invasions on islands indicate that species-poor communities are more vulnerable to invasion because they offer more empty niches. However, studies of intact ecosystems find both negative and positive correlations between species richness and successful invasion events.

Invading species will be monitored by NIOZ through the long-term sustained observation series of NIOZ in the Wadden Sea. The ecological consequences of invasions and range extensions such as by the Japanese oyster and several fish species in the Wadden Sea will be studied experimentally and by using ecosystem models.



Another ballast water intruder from America is the comb jelly-fish *Mnemiopsis leidyi*. This species had a severe impact on the Black Sea ecosystem. In recent years, it has also been found along the Dutch coast. Will it cause similarly dramatic changes here or will it merge gently with the existing ecosystem?

Changes in the distribution of species may be the result of large-scale climatic events or changes in anthropogenic pressures. However, ships are one of the main vectors responsible for the introduction of invasive species. With increasing tonnage, number and speed of vessels, it is likely that this vector will increase in importance in the future. To halt the transport of non-indigenous organisms by ship's ballast water, the International Maritime Organization (IMO) has recently adopted a convention. This states that from the year 2012 onwards, ships must treat their ballast water in such a manner that it is free of living organisms at discharge. This challenges not only industry to develop whole new concepts of cleaning ballast but also research on the efficient mitigation of invasive organisms transported by ships.

NIOZ is one of the five leading institutes worldwide which can meet the international standards for testing clean ballast water treatment technologies for final certification. The Institute also has the capacity to assess how the chemicals used impact the receiving ecosystem at discharge, from viruses to macroplankton.

Scientific Departments

The Department of Physical Oceanography

The physical state of the ocean, its natural and enforced changes, as well as key processes in this system, are the topics of study at the Department of Physical Oceanography (FYS). Since physics is an empirical science, ocean observations play an essential role in this department, despite the worldwide increase in the use of numerical ocean circulation models. The research themes of the FYS department focus on regional observational oceanography of oceans and coastal seas and on process studies by means of mathematical-physical modelling, laboratory experiments and in situ observations. Thereby the NIOZ physical research programme is complementary to that of the other main physical oceanography groups in the Netherlands (IMAU and KNMI) where numerical Ocean General Circulation Models are a major research tool.

The physical state of the sea forms a dominant environmental factor for biological, chemical, ecological, and morphological processes in seas and oceans. Paleoceanographic proxies aim to reconstruct the physical state of the ocean. Therefore it is evident that scientists from the FYS department are strongly involved in multi-disciplinary research.

Regional oceanography focuses on the oceanographic processes in a geographical context. One of the focal points is the oceanography of the western Wadden Sea, where presently research is carried out on transport of water and suspended matter, with sensors mounted in the TESO ferries. It is envisaged that this research will expand in the near future to other subjects by the development of a numerical model and an extended monitoring system. These will also play an essential role in the implementation of multi-disciplinary research of the Wadden Sea.

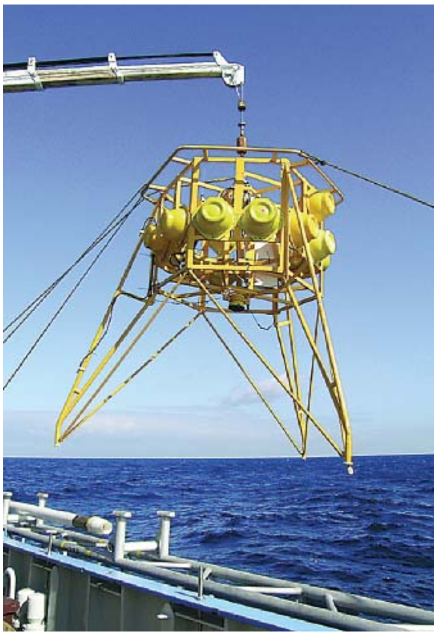
The equipment to measure current, temperature, depth, turbidity, fluorescence (chlorophyll pigment of phytoplankton) in the Marsdiep tidal inlet between Den Helder and Texel has been installed on both TESO ferries. These high frequency measurements over a number of years have revealed many new details about the system. Photo: Jan Boon (NIOZ).

In the open ocean, regional oceanographic studies will deal with the temporal variability of the ocean on climatic time scales, especially in the northern North Atlantic Ocean. Hydrographic variability in this region may have important consequences for the MOC, and thereby be important for the European climate. Hydrographic knowledge is also of prime importance for the setup and interpretation of research of open ocean ecosystems and ocean chemistry research. Additionally the department will participate in cooperative climate related ocean research projects with IMAU and KNMI. In those cooperative projects NIOZ will take the lead in the observational studies.

A wide variety of small-scale processes contribute to major transports of heat and matter in the sea. Examples are turbulent mixing and wave breaking in the deep ocean and topography-induced residual currents in shallow seas. While the first are very important for the maintenance of the meridional overturning circulation, transport of inorganic and organic nutrients, and erosion of the seabed, the latter determine the transport of suspended matter and small organisms like larvae, and also play an important morphological role in coastal seas. The essentials of ocean processes can generally be described with a mathematical model. However, the interpretation of in situ observations is often hampered by the presence of a multitude of different processes. Therefore the existing laboratory capacity of hydraulic experiments will be extended to allow direct tests of theoretical results. The support of theoretical and laboratory results will facilitate the interpretation of in situ experiments, which will reveal the role of specific processes in the actual ocean.

The Department of Marine Geology

Research carried out within the department of Marine Geology (GEO) is directed towards identification of processes and parameters defining present and past climate forcing of ocean margin seabed systems, including formation and sedimentation of marine particulate matter, paleoceanography and burial and diagenesis.



A BOBO lander is retrieved from the sea bottom.

Ocean and climate controls on particle export from the water column are expressed in the temporal and spatial variability of settling of particulate matter, and form the main aim of studies done under this topic. Particle export is traced laterally and vertically in the water column, to establish the magnitude and rate of transformation, decomposition and transfer, to define the forcing processes. Primary data are obtained through water column profiling and sediment sampling, in combination with time-series sampling by moored sediment traps, equipped with current profilers and turbidity sensors, complemented with measurements of near-bed fluxes and hydrodynamic constraints at and just above the seabed by long-term deployed seabed BOBO and other seabed observatories.
Finally, transported sediments are deposited and accumulate on the seafloor within specific sedimentary deposits which in their sedimentary record thus contain archives of their forcing parameters, hydrodynamic constraints and (paleo) oceanographic conditions. Research in GEO is directed towards definition of the (paleo) oceanographic conditions and forcing parameters of sediment transport and deposition in open ocean and continental margin settings and their relationship towards the functioning of benthic ecosystems.

GEO participates in themes 1-4. In theme 1, there is strong involvement in addressing the interactions between the ocean surface chemistry, hydrography and settling and formation of sinking particles, both in open ocean and continental margin settings to trace effects of variability of forcing parameters and define (paleo) oceanographic changes as a result of climate change (theme 4). The interaction of the seabed with dynamic processes may force actual food streams towards deeper benthic communities. This is of direct interest to a better understanding of the building of coldwater coral mounds along the NE Atlantic Ocean margin. In theme 2, GEO measures variations in near-bed hydrodynamic conditions and their effects on mass fluxes to the deep sea, as well as their temporal and spatial variability and interplay with seabed ecosystem functioning. GEO will also contribute towards a better understanding of processes controlling benthic community development around cold gas and fluid seeps especially sedimentological cycles. In theme 3, GEO will contribute towards definition of processes driving primary production variability and their effects on sea bottom processes and energy transfer in wadden and shelf systems.

The Department of Marine Organic Biogeochemistry

The composition of organic matter in marine organisms, seawater and sediments is the topic of study at the Department of Marine Organic Biogeochemistry (BGC). We study both natural and anthropogenic forms of organic matter in the marine environment, which is sampled by an array of sampling techniques. The department is equipped with new (built in 2004) wet chemistry and instrumental labs, providing work space for as many as 25 researchers, and has state-of-the-art organic analytical equipment to perform analyses at the cutting edge, including mass spectrometers coupled to gas and liquid chromatographs and stable isotope mass spectrometers. For some of these techniques and their application, BGC is a world leader.

The analytical laboratory forms the heart of this department. To avoid cross-contamination, all practising scientists have their own fume hood to work-up their samples. Photo: Bert Aggenbach (NIOZ).

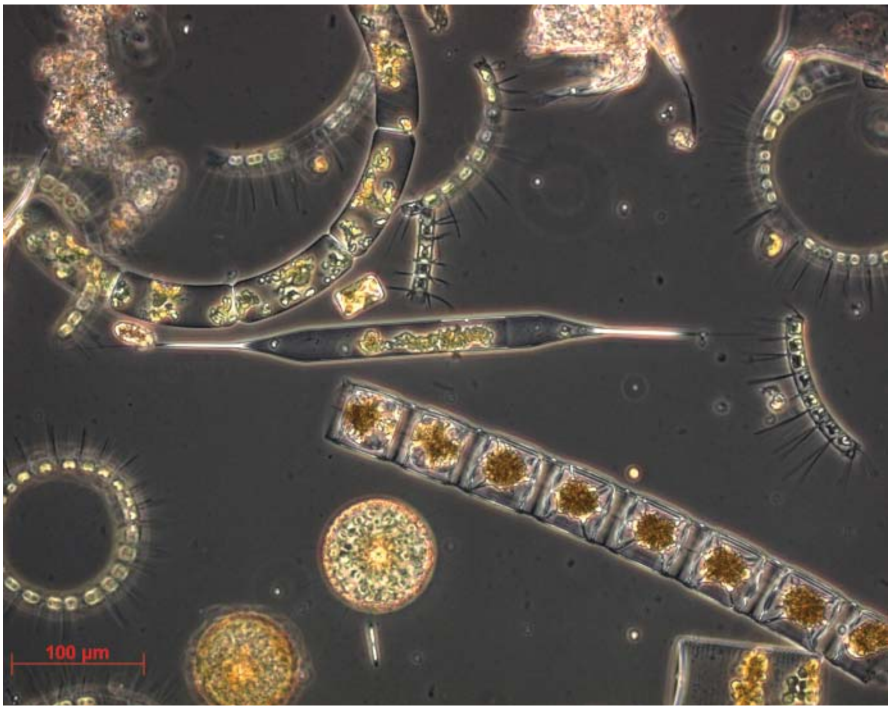
Organic matter forms an important part of the carbon cycle in marine systems but its study is complicated by the fact that it comprises a myriad of components. Our overarching goal is to open up the "black box" of organic matter by analyzing specific organic chemicals that provide information on the presence of specific organisms (e.g. by searching for organism-specific lipids) or processes (e.g. organic matter transport from the continent to the ocean by soil organic matter tracers, transport of anthropogenic chemicals to the deep sea) in the marine environment. We also use preserved organic matter in marine sediments to reconstruct past depositional environments and climate as far back in time as 150 million years. For this type of work, we use so-called organic proxies from which indirectly certain physical parameters of the geological past can be reconstructed. Development and biological validation of organic proxies through field, mesocosm and culture studies form an integral part of our work. This is ideally situated in the multidisciplinary setting provided at NIOZ.

BGC will actively participate in four of the five multidisciplinary research themes defined in this science plan. In theme 1, BGC will apply its expert knowledge on archaeal membrane lipids to further study the physiology of marine archaea. It will also study the transport of organic contaminants to the deep sea, a process with wide implications for marine life in this largest but unexplored oceanic subsystem. We will also develop methods for the analysis of CFCs as tracers of water masses. In theme 2, we will contribute by the study of microbial life at the sea floor at sites where methane and other hydrocarbon gases escape. A significant part of our activities will fall under theme 4. We will use our new proxies to study the climate of the past in unprecedented detail and will unravel how continental climatic variations are affected by those at sea. These studies will help to understand natural climate variations and guide predictions of our future climate. In theme 5, we will use specific membrane lipids to shed light on marine microbial diversity and the role these tiny organisms play in the biogeochemistry of the ocean, in particular in the carbon and nitrogen cycles. Most of the BGC research is thus embedded in the multidisciplinary research matrix provided by the science plan.

The Department of Biological Oceanography

The lower planktonic food web in the marine environment comprising auto- and heterotrophic eukaryotes, prokaryotes, viruses and mesozooplankton is the main research topic of the Department of Biological Oceanography (BIO). Besides that, the role of prokaryotes as symbionts in sponges, ascidians and corals is studied. The main focus of research on the lower food web is the role of these organismal groups in the biogeochemical cycling of carbon, nitrogen, phosphorus and trace elements in the ocean and the interaction between the different components of the microbial food web. Using molecular tools, the diversity of the microbial community, particularly of prokaryotes and viruses, is determined and related to abiotic and biotic parameters. The overarching goal is to arrive at a mechanistic understanding of the microbial food web and its dynamics in the marine environment. To accomplish this goal, BIO has state-of-the-art instruments such as flow cytometers, microscopes with image analysis, HPLCs and fully equipped laboratories for molecular biology, trace metal analyses and radio-isotope work. Major parts of the laboratories and offices of BIO were remodelled in the years 2007-2008.

Research on the lower trophic levels of the marine food web was until two decades ago mainly oriented towards determining the carbon flux from phytoplankton to the heterotrophic microbial community using a 'black box' approach as the prokaryotic community composition could not be determined. With the advent of molecular tools, the microbial community composition can now be determined. Single cell approaches provide information on the metabolic rates on a single cell level. The notion that viruses play an important role in maintaining microbial diversity and



Microscopic picture of algae (diatoms).
Photo: Jolanda van Iperen (NIOZ).

stimulate carbon cycling added a new facet to bio-oceanographic research. The discovery of unexpected metabolic pathways in novel marine prokaryotes, such as ammonia-oxidizing Crenarchaeota, continues to lead to revisions of our view of material cycling in the ocean. Within BIO, measurements at sea are performed during research expeditions combined with detailed laboratory experiments on the influence of various physical and chemical parameters (acidity, inorganic and organic nutrients, trace metals) on particular groups of organisms relevant for the main biogeochemical fluxes in the ocean.

BIO participates in four of the five multidisciplinary research themes of the Science Plan. In theme 1, BIO will focus on the carbon dioxide dynamics in surface waters including the sea surface microlayer as influenced by phytoplankton and heterotrophic processes and on the role of iron availability for primary production in the Southern Ocean. The role of viruses in regulating phytoplankton dynamics is studied in the North Atlantic and the North Sea. In the dark ocean, the microbial communities and the dissolved organic matter remineralization are investigated in relation to the main water masses of the North Atlantic. Metabolic rate measurements are combined with phylogenetic analyses of the microbial communities including viruses. In theme 2, BIO will study the interaction between corals, ascidians and sponges and prokaryotes. In theme 3, BIO contributes to the long-term time series and studies population dynamics of phytoplankton, viruses and prokaryotes. The main contribution of BIO to theme 5 is the assessment of the prokaryotic and viral diversity, both phylogenetically and functionally, and performing research towards the development of methods to assess the efficiency of ballast water treatment installations on board ships.

The Department of Marine Ecology

The department of Marine Ecology (MEE) aims to obtain a mechanistic understanding of the structure and dynamic behaviour of marine populations and communities, whether they occur on the shelf margin or the intertidal. Taking up one of the great challenges in modern ecology, we try to understand the properties of populations and communities on the basis of characteristics of individual organisms. We focus on the role of bottom-up (food input and competition for food and other resources) as well as top-down (predation) processes in structuring benthic communities. Extensive field work by a variety of methods ranging from traditional observations to high-tech lander technology is combined with laboratory experiments in state-of-the-art unique indoor facilities.

Scientists curiously look at the content of a boxcore from the cold water coral reefs at Rockall Bank. This research topic is a close collaboration between the departments Marine Ecology and Marine Geology. Photo: Henk de Haas (NIOZ).

The study of population dynamics should be based on detailed knowledge of the individual. Recruitment, death and migration rates, which determine changes in population size, are ultimately the result of morphological (e.g., size, allometry), physiological (e.g., energy reserve) and behavioural (e.g., susceptibility to interference) characteristics of the individuals. Changes in the state of an individual depend upon its environment (characterized in terms of food, competitors, predators, abiotic factors). The environment in turn is affected by the actions of individuals. This feedback loop between the state of individuals and their environment is of vital importance in determining population dynamics. The functioning of foodwebs, and the basis of biodiversity, cannot be understood without due recognition, or indeed the actual study, of evolutionary processes. Current species compositions of marine communities strongly reflect historical events, and the assessment of selectively neutral genetic marker structures can help us to map these historical events in space and time. At the same time, the decades-long longitudinal studies on actual ecological interactions, for example the studies of trophic interactions between benthic invertebrates on the one hand, and crabs, fish and birds on the other, is inspired by explicit evolutionary thinking.

MEE participates actively in four of the multidisciplinary research themes defined in this science plan. In theme 2, MEE will study the complexity and importance of very specific habitats of the sub-seafloor biosphere such as hydrothermal vents, cold-water coral reefs, and mud volcanoes, and focus on the time scales of their initiation, maturation and decline. A major part of the research activities of MEE are related to theme 3. Studies on population dynamics of key species, in combination with monitoring activities to document long-term changes in coastal ecosystems (Wadden Sea, North Sea), are the basis for our innovative aim to include size- or stage-structured populations in ecosystem models. In theme 4 MEE concentrates on the consequences of climate change for marine life focusing on the coastal zone with the aim to improve the existing projections of its impacts. Deploying new technologies and analysis techniques for process-oriented studies supported by well-designed field and laboratory experiments will be combined with ecosystem models. In theme 5, MEE will focus on the analysis of the relationships between biodiversity and habitat diversity in the coastal zone by developing (GIS-based) dynamic habitat modelling. Insight into the functioning of food webs will also be crucial to predict the impacts of the increasing influx of invasive species into our seas.

Annex 1: National and International Collaboration

Theme 1: Open Ocean Processes

National level
This theme has strong links to several ALW-NWO funded projects. Intensive collaboration with the Pelagic Systems Group of the Marine Biology Department at the University of Groningen is reflected by several PhD thesis projects. The monitoring part of the activities is carried out in close collaboration with physical oceanographers from IMAU and KNMI (LOCO program) and is supported by NWO. Related to LOCO, several PhD and Postdoc studies are performed.

International level
European Union
Members of this program are actively involved in the Network of Excellence projects MarBEF and EurOcean and in the Integrated Project CarboOcean.

Other international cooperation
Contributions are made to the Global Ocean Observing System (GOOS) and the international program of biodiversity science, DIVERSITAS (via MarBEF). It also addresses key aspects of the IGBP program IMBER (Integrated Marine Biogeochemistry and Ecosystem) which will be combined with the Global Ocean Ecosystem Dynamics program (GLOBEC) to the OCEANS program (Ocean Biogeochemistry and Ecosystems Analysis) in 2009. In addition it also contributes to the International Census of Marine Life Initiative 'International Census of Marine Microbes (ICoMM)', the program Surface Ocean Lower Atmosphere Study (SOLAS) of the International Geosphere-Biosphere Program (IGBP), GEOTRACES program of the Scientific Committee on Oceanic Research (SCOR), and the International Polar Year organized by the Scientific Committee on Antarctic Research (SCAR). The monitoring part of the program contributes to the WCRP-CLIVAR program and is embedded within the internationally coordinated OceanSITES group. NIOZ is an active member of POGO, the partnership for the observation of the global oceans. POGO promotes the installation of a global measurement network in the ocean.

Theme 2: Sea Floor Dynamics

National level
The research under this theme is linked to the research at NIOO-CEME, at the University of Utrecht (the faculty of Geosciences), the Vrije Universiteit Amsterdam, and at the Institute for Biodiversity and Ecosystem Dynamics the University of Amsterdam. Part of the research is funded through ALW-NWO grants and embedded in the national BSIK (Klimaat & Ruimte) initiative. NIOZ collaborates with FOM/NIKHEF and their European Astrophysical and Elementary Particles Physicists in ANTARES observations, and as sub-contractor in the KM3NeT NWO large investment application by FOM/NIKHEF.

International level
European Union
Research is being carried out in the integrated EU-program HERMES (Hotspot Ecosystem Research on the Margins of European Seas), in the Network of Excellence project MarBEF and in the ESF project EURODEEP.

NIOZ further participates in the ESF programs Microsystems and CARBONATE and is involved in the further developments of (networked) seabed observatories as partner in the EU-funded ESONET NoE demonstration mission KOSTOBS and in the associated EMSO project. Occasionally NIOZ contributes to programs led by European colleagues, recently e.g. in NERC program SLOPEMIX (led by J. Huthnance, POL, UK) and in the near future the Norwegian polar program BIAC (led by I. Fer, Ubergen, Norway).

Other international cooperation
Cooperation agreements with Trinity College Dublin (C. Rocha) and with Moscow State University (M. Ivanov) in the framework of an NWO/Russian cooperation program relate to organic carbon exchange processes over the sediment-water interface. They ensure access to additional samples and data regarding mud mounds. Within the same framework NIOZ and Russian colleagues investigate the effects of tidal bottom friction near critical (polar) latitudes. Occasionally NIOZ contributes to programs led by non-European colleagues, in the near-future e.g. in the UWA program on the North-West Australian Shelf (led by G. Ivey, SESE, University of Western Australia) and to a program in the Gulf of Mexico (submitted to NSF by S. Ross, University of North Carolina).

Theme 3: Wadden and Shelf Sea Systems

National level
The program incorporates several ALW-NWO and BSIK funded projects. Major parts of the program take place in intensive collaboration with NIOO-CEME within the framework of FOKUZ, the Center of Ecological and Evolutionary Studies at the University of Groningen, the Vrije Universiteit Amsterdam and partners from the NCK (Utrecht University, Delft University). The program directly or indirectly contributes to many applied programs by Wageningen-IMARES. Parts of the long-term series are carried out in close collaboration with the Ministry of Transport, Public Works and Water Management ('Waterdienst').
In 2008 the national NWO program Marine and Coastal Research (ZKO) has started with an important research effort focusing on carrying capacity of the Wadden Sea. NIOZ participates in several projects and coordinates a large monitoring effort in the western Wadden Sea.

International level
European Union
Participants in this program are actively involved in the network of excellence project MarBEF.

Other international cooperation
Several studies are being performed in close cooperation with foreign institutes (AWI, IFREMER, CALM in Perth) and universities (Lund, Aberdeen, Toronto). The program perfectly fits in the LOICZ II themes 2-4. In 2007, NIOZ signed an agreement with the National Authority for the Protection of the Banc d'Arguin to conduct joint research on the Banc d'Arguin, an extensive wadden system in Mauritania.

Theme 4: Climate Variability and the Sea

National level

The theme has strong ties with the research goals of ALW-NWO, the Buys Ballot Research School, and the Darwin Centre for Biogeology.

International level

NIOZ contributes to the International Ocean Drilling Programme. The monitoring part of the program contributes to the WCRP-CLIVAR program. The Eulerian observatories are embedded within the internationally coordinated OceanSITES group.

Theme 5: Biodiversity and Ecosystem Functioning

National level

NIOZ is linked to the National Platform on Biodiversity, to the NL-BIF committee and has cooperative links with the Museum of Natural History 'Naturalis' in Leiden.

International level

European Union

NIOZ contributes to databases and related management activities as coordinated within the EU Network of Excellence Marine Biodiversity and Ecosystem Functioning (MarBEF) for benthos and plankton (MACROBEN, Manuela, Largenet, Daisies). These are part of the Ocean Biogeographic Information System (EurOBIS). NIOZ also cooperates in several European research programs studying the biodiversity of the cold-water coral reefs (e.g. HERMES).

Other international cooperation

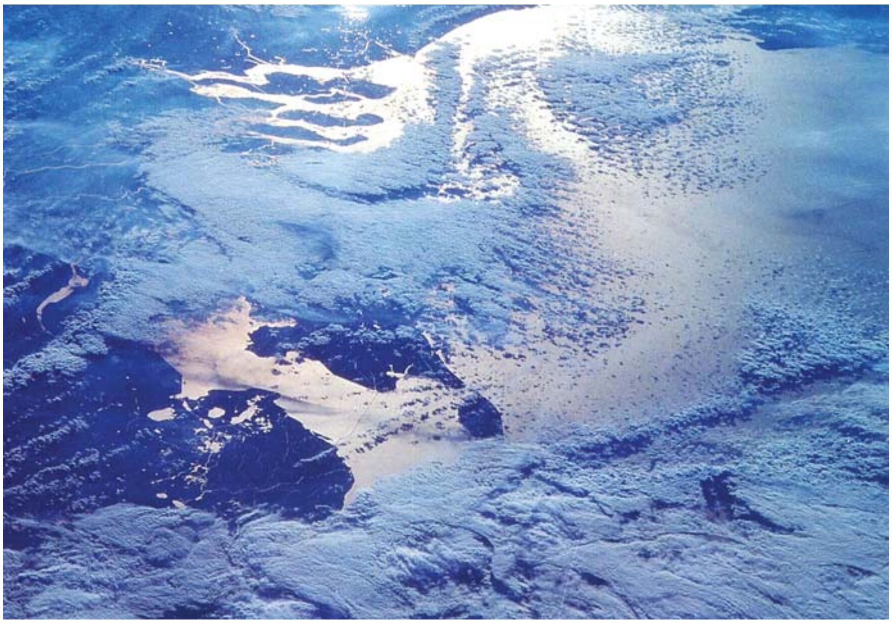
The NIOZ coordinates the Field Program ICoMM (International Census of Marine Microbes) of the Census of Marine Life together with the Marine Biology Laboratory at Woods Hole, USA, and together with NIOO-CEME operates the provisional project office for the Marine Biodiversity Cross Cutting Network of DIVERSITAS.

Annex 2: FOKUZ Coastal and Marine Research NIOZ-NWO and NIOO-KNAW

New FOKUZ logo designed by Monique Beijaart (NIOO-KNAW).

What is FOKUZ?

FOKUZ is a cooperative program between NIOZ Royal Netherlands Institute of Sea Research of NWO and the Netherlands Institute of Ecology (NIOO-KNAW). It has been created following an agreement between the Royal Netherlands Academy of Arts and Sciences (KNAW) and the Netherlands Organisation for Scientific Research (NWO). The goal of FOKUZ is to strengthen fundamental marine research in the Netherlands and internationally, by making optimal use of available scientific and technical expertise, infrastructure and financial means. The Netherlands has a long tradition of excellent marine research and is recognized as an international player in this field. FOKUZ has been created to maintain this position and to strengthen it in order to gain the knowledge required to understand the seas and oceans and to support the sustainable use of the natural resources in estuaries, the seas and the oceans, to help protecting marine biodiversity and to understand the consequences of climate change for the Netherlands and the world.



Focus on the FOKUZ research area. The picture was taken from 325 km altitude above Denmark towards the southwest by ESA scientist and astronaut Wubbo Ockels during the spacelab-D1 mission. Photo: ESA/NASA.

Objectives of the Cooperation Agreement

- The institutes will gradually develop a common research program, aiming at creating synergies and based on the scientific complementarity and the facilities of both institutes.
- FOKUZ will act on behalf of the institutes in matters of fundamental marine research relevant to NWO and KNAW, government departments and institutes in the Netherlands, and international organizations such as ICES, Marine Board, ESF, the EU and POGO.

- The institutes will act together in cooperative research agreements with universities, other institutes, the private sector and other organizations active in marine research and related activities.
- The institutes will act together in partnerships with universities in the field of education in marine sciences.

How to achieve the objectives

Common Research

A large number of cooperative research projects already exist between NIOZ and NIOO:

a. NIOZ-NIOO Cooperation Program financed by KNAW and NIOZ.
b. Darwin Centre of Biogeology: four projects with participation of both institutes
c. International Census of Marine Microbial Life: European coordination by NIOZ and NIOO-KNAW.
d. Cooperation within the EU Network of Excellence MarBEF (Marine Biodiversity and Ecosystem Functioning).
e. EU Integrated Projects and Networks: EurOceans, CarboOcean and HERMES.
f. ESF Eurocores Project Eurodeep.
g. Support of the Diversitas Marine Biodiversity Cross Cutting Network and EuroCoML.
h. Monitoring.

The new common program will be developed around three themes of societal relevance.

Sediments and effects of sediment transport

The biogeochemistry and ecology of shallow marine waters such as the North Sea, the Dutch Delta and the Wadden Sea are determined to a large extent by the characteristics of the sediments and their transport. Erosion and sedimentation are extremely important processes that are impacted by physical and biological factors alike. The effect of cycles of sedimentation and resuspension on pelagic and benthic ecosystems is poorly known. This is of importance to understand the carrying capacity and the productivity of ecosystems and the resilience of coastal systems to increasing turbidity and sea level rise.
Application: coastal protection by sand- suppletion, effects of dredging (maintenance of shipping channels, harbour extension, artificial islands), sand and gravel exploitation, mitigation of salt marsh erosion etc.

Biogeochemical cycles in relation to climate and eutrophication

The biogeochemical cycles of elements such as carbon, nitrogen, phosphorus, sulphur and iron are impacted by human activities. Globally, the increase of greenhouse gases and the resulting changes in weather, currents and sea level play an important role. Increasing CO_2 concentrations also cause acidification of the oceans. Locally, effects of disturbed nutrient balances (nitrogen, phosphorus, silicon) are still increasing and create dead zones and toxic algal blooms and changes in carrying capacity. Biogeochemical cycles are determined mainly by micro-organisms, and the application of new chemical and molecular methodologies to understand their role is rapidly increasing knowledge in this area.
Application: understand global cycles, effects of climate change, application of EU directives, carrying capacity.

Biodiversity and ecosystem-functioning

The biodiversity of the oceans is poorly known and exploration of the seas remains an important activity. This is even more true for micro-organisms and the deep sea.

For higher organisms the erosion of biodiversity also occurs in the marine environment and is a global consequence of increasing human pressure on marine ecosystems. This can be seen in the food web as top predators are fished away with cascading effects through the whole food web. Another effect is the ever increasing maritime transport and the break-up of biogeographical barriers with the accelerated appearance of invading species, such as the Japanese oyster, that can create large changes in marine ecosystems in some cases.
Application: ecosystem approach in fisheries, marine protected areas, marine microbiology.

Infrastructure
Both institutes have an extensive and modern instrumentation for chemical, physical, geological and biological analyses and an extensive infrastructure, including a flume tank at NIOO, climate and culture chambers in both institutes and three research vessels (RV Navicula for the Wadden Sea, RV Luctor for the Delta, and RV Pelagia for the open North Sea and the oceans, serving also as a national facility). NIOZ is responsible for the Marine Research Facilities of NWO, supporting national oceanographic research in the Netherlands and increasingly in the European Union. NIOZ is a member of the OFEG consortium where exchange of shipping time between seven European countries is arranged. NIOZ and NIOO have guest rooms for students and research scientists in the 'Potvis' ('t Horntje, Texel) and the 'Keete' (Yerseke, Zeeland).

Cooperation in Education
A number of staff of NIOZ and NIOO are appointed as professors in several departments and universities in the Netherlands and abroad (see annex 3 for NIOZ). Nearly all fundamental research areas are represented. Together with a number of universities (Utrecht University (UU), University of Groningen (RUG), University of Amsterdam (UvA), and the Vrije Universiteit Amsterdam (VU)), NIOZ and NIOO are actively involved in organizing courses that allow students to obtain a notification 'Marine Scientist of the Netherlands' on their regular MSc diploma of their own university. An essential part for obtaining this notification is their participation in seagoing marine research. For this purpose NIOZ and NIOO will jointly organize a course with field work on board RV's 'Navicula' and 'Luctor'.

National and International Representation
FOKUZ is presented as such in the national Marine and Coastal Research programme of NWO in which various departments and institutes are represented. This programme is strongly developing at the time of writing (2008) and the first projects have already been allocated.

FOKUZ will represent both institutes in national and international organizations, such as the Census of Marine Life, Diversitas, SCOR (Scientific Committee on Oceanic Research), SCOPE (Scientific Committee on Problems of the Environment), SCAR (Scientific Committee on Antarctic Research), ICES (International Council for the Exploration of the Sea), IGBP (IMBER), the Marine Board of the European Science Foundation, and the Partnership for the Observation of the Global Ocean (POGO).

The existing regional cooperation between NIOZ and Bremen (NEBROC) and between NIOO and Flanders (VLANEZO) is due for renegotiation in the near future.

What will FOKUZ do?

The following activities will be supported during the first few years:

- Organization of the FOKUZ structure with a small secretariat responsible for supporting scientific exchange between departments, scientific workshops and common project proposals.
- Starting a common research program in the North Sea in 2008-2009 focusing on physical transport processes and their effects on the ecosystem. This has been submitted to ZKO of NWO.
- Developing a PR strategy including coordination of contacts with the press, a website linked to already existing ones, fact sheets etc.
- Elaboration and propagation of an expertise centre and a monitoring consultancy.
- Marine Masters course from 2009 onwards.

Annex 3: Professorships of NIOZ Scientists (1 January 2008).

NIOZ senior scientists occupy the following chairs at Dutch and foreign universities:

Carlo Heip	'Estuarine Ecology' at University of Groningen 'Biogeochemical Cycles' at University of Ghent (Belgium)
Herman Ridderinkhof	'Physics of Sediment Transport in Coastal Waters', University of Utrecht
Leo Maas	'Wave dynamics of the Ocean', University of Utrecht
Jef Zimmerman	'Physical Oceanography', University of Utrecht
Jaap van der Meer	'Population Ecology of the Marine Environment', Vrije Universiteit Amsterdam
Theunis Piersma	'Animal Ecology', University of Groningen
Rolf Bak (emeritus)	'Tropical Ecology', University of Amsterdam
Gerhard Herndl	'Biological Oceanography', University of Groningen
Hein de Baar	'Oceanography', University of Groningen
Tjeerd van Weering	'Paleoceanography' at the Vrije Universiteit Amsterdam 'Marine Geosciences International', University of Bremen (Germany; deputy professor)
Jaap Sinninghe Damsté	'Molecular Palaeontology', University of Utrecht
Jan de Leeuw	'Organic Geochemistry', University of Utrecht 'Molecular Biogeology', University of Utrecht

Annex 4: List of Acronyms

Acronym	Full Name
ALBEX	Autonomous Lander for Benthic EXperiments
ALW	(NWO division of) Earth and Life Sciences
ANTARES	FOM/NIKHEF programme ‘A cosmic neutrino observatory’.
AWI	Alfred Wegener Institute for Polar and Marine Research (Germany)
BGC	NIOZ dept. marine organic BioGeoChemistry
BIAC	Bipolar Atlantic thermohaline Circulation (IPY proj. Univ.of Bergen, Norway)
BIO	NIOZ dept. BIological Oceanography
BOBO	BOttom BOundary (lander designed and used by NIOZ)
BSIK	Decisions Subsidies Investments Knowledge Infrastructure (of the Netherlands)
CALM	Department of Conservation And Land Management of Western Australia
CARBONATE	ESF Project on carbonate mounds
CarboOcean	EU project on fate of carbon dioxide in seas and oceans
CEME	Centre for Estuarine and Marine Ecology (of NIOO-KNAW)
CFC	Chlorofluorocarbon
CLIVAR	Climate Variability and Predictability
CoML	Census of Marine Life
DEB	Dynamic Energy Budget
CTD	Conductivity, Temperature, and Depth (sensor)
DIVERSITAS	International Programme of Biodiversity Science
EMOWAD	Ecological MOdelling WADden Sea
EMSO	a European Multidsiciplinary Seafloor Observatories Research Infrastructure
ERSEM	European Regional Seas Ecosystem Model
ESF	European Science Foundation
ESONET	The European Seafloor Observation Network
EU	European Union
EurOBIS	European Ocean Biogeographic Information System (of MarBEF)
Eur-Oceans	EU Network of excellence for OCen Ecosystems AnalysiS
EURODEEP	Prog. Ecosystem functioning and biodiversity in the deep sea (of EUROCORES)
FOKUZ	Fundamental Research Coast and Sea (of NIOZ and NIOO-KNAW/CEME)
FOM	Foundation for Fundamental Research on Matter (of NWO)
FTE	Full Time Equivalents
FYS	NIOZ dept. Physical Oceanography
GEO	NIOZ dept. Marine Geology
GEOTRACES	Biogeochemical cycles of trace elements in the Arctic and Southern Oceans
GLOBEC	Global Ocean Ecosystem Dynamics (core project of IGBP)
GOOS	Global Ocean Observing System
HERMES	Hotspot Ecosystem Research on the Margins of European Seas
HPLC	High Performance Liquid Chromatography
ICES	International Council for the Exploration of the Sea
ICoMM	International Census of Marine Microbes
IFREMER	French Research Institute for Exploitation of the Sea
IGBP	International Geosphere Biosphere Programme
IMARES	Institute for MArine Resources and Ecosystem Studies (of Wageningen University)
IMAU	Institute for Marine and Atmospheric research Utrecht
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research
IMO	International Maritime Organization (UN)

Acronym	Full Name
IPY	International Polar Year
IODP	Integrated Ocean Drilling Programme
KM3NeT	Deep sea research infrastructre for a neutrino telescope
KNAW	Royal Netherlands Academy of Arts and Sciences
KNMI	Royal Netherlands Metereological Institute
KOSTOBS	ESONET NoE demonstration mission
LARGENET	Responsive Mode Project of MarBEF
LOCO	Long-term Ocean Climate Observations ('NWO-groot' project)
LOICZ	Land Ocean Interactions in the Coastal Zone
MACROBEN	Database of MarBEF for macrobenthos
MANUELA	Meiobenthic and Nematode Biodiversity Unravelling Environmental and Latitudinal Aspects
MarBEF	Marine Biodiversity and Ecosystem Functioning (EU network of excellence)
MEE	NIOZ dept. Marine Ecology
MOC	Meridional Overturning Circulation (of the oceans)
MOVE	MObile underwater VEhicle (of NIOZ)
NCK	Netherlands Centre for Coastal Research
NEBROC	Netherlands-Bremen Oceanography Cooperation
NERC	Natural Environment Research Council (UK)
NIKHEF	National Institute for Nuclear and High-Energy Physics (of FOM)
NIOO	Netherlands Institute of Ecology (of KNAW)
NIOZ	NIOZ Royal Netherlands Institute for Sea Research (of NWO)
NLBIF	Dutch node of the Global Biodiversity Information Facility (GBIF)
NoE	Network of Excellence
NSF	National Science Foundation (of the United States of America)
NWO	Netherlands Organisation for Scientific Research
OCEANS	Ocean Biogeochemistry and Ecosystems Analysis (currently: IMBER)
OceanSITES	WA worldwide system of deepwater reference stations
OFEG	Ocean Facilities Exchange Group
POGO	Partnership for the Observation of the Global Oceans
POL	Proudman Oceanographic Laboratory
ROV	Remotely Operated Underwater Vehicle
RUG	University of Groningen
RV	Research Vessel
SCAR	Scientific Committee on Antarctic Research
SCOPE	Scientific Committee on Problems of the Environment
SCOR	Scientific Committee on Oceanic Research
SESE	School of Environmental Systems Engineering (Univ. Western Australia)
SLOPEMIXING	Research proj. Cascading & Slope Mixing of POL (theme 3)
SOLAS	Surface Ocean Lower Atmosphere Study
TESO	Texel's own Steamship Company
UvA	University of Amsterdam
UWA	University of Western Australia
VLANEZO	Flanders-Netherlands cooperation in Sea Research
VU	Vrije Universiteit Amsterdam
WCRP	World Climate Research Programme
WOCE	World Ocean Circulation Experiment
ZKO	Marine and Coastal Research (programme of NWO)