NIOZ Science Plan 2014-2020

excellent marine research for society

Executive Summary

As second-largest institute of NWO, the *Netherlands Organization for Scientific Research*, NIOZ Royal Netherlands Institute for Sea Research performs fundamental and frontier applied marine research addressing important outstanding scientific and societal questions pertinent to the oceans and seas. In addition, NIOZ serves as marine research facilitator (MRF) for the Netherlands marine scientific community.

Inspired by the international 'grand challenges' to *live with warming oceans*, including e.g., rising temperatures, higher sea levels, ocean acidification, concomitant changing ecosystems, including ever increasing human impact, but also noting the rising need for sustainable ocean exploitation in terms of food, energy and minerals, NIOZ science aims at focused advanced fundamental and frontier-applied research with a longer-term, farther horizon, with high social and scientific relevance, and with high visibility; we call it our *Mission Blue Planet.*

The core, and strength of NIOZ research remains our multidisciplinary character and the ability to intrinsically cover the entire marine spectrum, from coasts to the deep sea. With this axiom, the new NIOZ science plan focuses on two selected, interlinked broad themes: *The changing Ocean system: past, present and future* and *Adaptability of marine ecosystems in a changing world*.

With these selection of themes, NIOZ research addresses important elements of the international societal grand challenges of marine research, while at the same time accommodating societal needs for improving sustainable use and management of the sea, as well as fostering industrial developments in close co-operation with private partners.

The science plan 2014-2020 provides a key element for required re-orientation and adaptations of the organization, including absorbing base-budget decline, and to delineate our national and international role.

Introduction - NIOZ in a changing world

As second-largest institute of NWO, the *Netherlands Organization for Scientific Research*, NIOZ Royal Netherlands Institute for Sea Research performs excellent fundamental and frontier applied marine research addressing important outstanding scientific and societal grand challenges pertinent to the role and functioning of oceans and seas, and does so at two locations, Texel (TX) and Yerseke (YE). Furthermore, NIOZ serves as marine research facilitator (MRF) for the Netherlands scientific community.

Marine research is multidisciplinary and international. NIOZ covers the main disciplines of marine science: physics, geology, chemistry, microbiology, ecology and paleoceanography, and invests in the development of multidisciplinary research approaches to the marine system. NIOZ also bridges between the Dutch marine research and the international community, both in terms of research and with respect to logistics and research infrastructure. NIOZ represents The Netherlands in international organizations devoted to the study and use of the sea at European and global levels (e.g. European Marine Board, and POGO). The institute can do this from a clear and well-defined national position amidst universities, other national research institutes and Dutch industry ‘topsector’ initiatives.

A changing world

Planet Earth is blue. The oceans cover most of the surface of the globe and are a major player in the coupled biogeoclimatic system. Global change, as well as different forms of exploitation of the world’s seas, and related direct Human impact rapidly change the oceans and jeopardize the crucial services provided by the marine system to mankind at alarming rates. Yet, by 2013 and despite all efforts, we must admit that many marine environments and processes, especially in the deep sea, are still only poorly known. We only scratched the surface; short, but notably longer-termed consequences of human interference are likely large, but remain poorly studied and effects difficult to predict.

From a Dutch perspective, in our low-lying country, the sea is both a blessing and a curse. While the Dutch economy is traditionally strongly dependent on maritime sectors, our very existence, particularly safety against flooding involves extensive coastal management and investments. Only recently have we come to realize that also for the oceans and seas in general, sustainable and responsible use implies improved governance and management, and thus an improved scientific understanding. Crucially, the oceans will increasingly offer new opportunities for human use and exploitation. Maritime transport, maritime energy sources, and the intensifying exploitation of living and non-living marine resources will increasingly provide for the needs of the growing and developing global population. However, at the same time, blue growth will involve profound changes in and to the marine system. These, combined with effects due to climate change, overfishing and pollution, as well as coupled biodiversity change will have a serious impact on the economic development and human welfare in The Netherlands and elsewhere.

In order to cope with these future scenarios in a sustainable and responsible fashion we need to further advance our fundamental knowledge on the seas to better understand system Earth to drastically improve our ability to predict adaptation of the natural system to these rapidly changing conditions.

Ocean exploration is lagging behind the exploration of space; new discoveries are made continuously and more is to be unveiled. Our capability to record and observe, understand, and model marine systems past and present 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 the planet is changing, and processes not witnessed for millions of years are returning due to elevated concentrations of atmospheric greenhouse gasses, in conjunction with more direct, and rapid human induced changes. Sustained living with a warmer, more acidic and stagnant ocean, higher sea levels, changed biodiversity and more pressure on marine resources thus poses a grand challenge to society; NIOZ has this in the heart of its mission. The major research questions of NIOZ scientists are thus determined by the grand scientific challenges posed by the changing world's oceans.

Grand challenges in international marine research

The European Marine Board recently published a science brief entitled, *Navigating the Future IV* (McDonough, editor, *MB position paper* 20). The paper provides a state of the art account of both recent progress in European marine research as well as the current grand challenges in a global context. It identifies future research needs and priorities for gaining a more complete knowledge of marine systems, how they are changing in space and time, and the provision of benefits to humans. NIOZ scientists have contributed significantly to this position paper. It provides a roadmap for the various research priorities and strategic recommendations to guide future marine research in Europe, and, as such serves as a baseline roadmap for European marine research institutions like NIOZ, based in The Netherlands. Recent reports e.g., by the International Panel for the State of the Oceans (IPSO) further underscore the need to cope with the 'deadly trio', the combined effects of overfishing, pollution and climate change.

The oceans are an integral part of system Earth and are intimately linked to the atmosphere and bio-geosphere. Marine processes are critical in climate regulation. Unraveling the fundamental links and feedbacks between the different components of the global marine system, both in the past and in the present, is therefore not only scientifically challenging; it is also essential to understand the future of our planet.

It is now commonly accepted that human-induced climate change poses one of the main challenges faced by society in the coming decades. Global warming and high CO2 levels are driving changes in, for example, sea-level, patterns of air temperature, precipitation and extreme weather events. In addition, changes in sea temperatures, ocean circulation and ocean chemistry (e.g. acidification and oxygenation) are expected to affect the species abundance, diversity and distribution in the open ocean and, in turn, the removal of atmospheric CO2 by the ocean, with unknown consequences. The impacts of climate change and ocean acidification may also affect commercial fishing as a result of changes in the size and distribution of fish stocks. Although large climate changes occurred during the geological past and even the last century was characterized by natural climate fluctuations, the present *rates* of change are, in terms of geological time-scales, unprecedented. Moreover, there is no certainty regarding the precise nature and rate of future climate change.

Apart from being affected by long-term environmental change, many coastal seas and oceans are prone to more direct, short-term effects of anthropogenic influence – overfishing, pollution, and eutrophication are examples. To mitigate these effects, paving the road to responsible use of the marine realm in a warming world, more fundamental knowledge of the complex and dynamic causes- and effects relationships on biodiversity, biotic communities and ecology is urgently needed.

Scientific research has already significantly contributed to an improved understanding of the underlying processes, and analyses of current and future potential impacts of climate and anthropogenic influenced change on the marine environment. But we are still far from being able to predict future changes accurately; this is a necessity for reducing uncertainty and facilitating the planning of appropriate adaptation and mitigation responses to expected changes. Research is also critical to unlock some of the potential opportunities and societal benefits, which may be presented by changes in the marine environment.

At the same time, the oceans are also a region for exploration. The deep sea provides more than 90% of the total habitable volume of Earth and contains an extensive but largely undiscovered biodiversity. Over the past decade there has been a drive for ocean exploration leading to the discovery of many new species. Even in better studied coastal estuaries and in the North Sea, recent discoveries have shown entirely new microbiological processes that fundamentally affect nutrient cycles and the functioning of sediment systems. Oceans and seas remain underexplored, but rapidly developing new technology promises to lead to major breakthroughs in this exploration, with increasing use of Remotely Operated Vehicles (ROVs) and, more recently, Autonomous Underwater Vehicles (AUVs), or cabled underwater observatories bringing internet and continuous data streaming to and from the sea floor. By the same token, new, emerging notably biochemical and biomolecular technologies open new frontiers of knowledge for deeper understanding of natural oceanic systems. In the past decade, NIOZ has contributed to these technological developments by construction of Ultra-Clean Conductivity-Temperature-Depth (CTD) systems that provide the world standard for accurate measurements of water properties. NIOZ also developed chains of hypersensitive thermistors that provide much more detail on deep-sea internal wave breaking and mixing, and bottom landers, a deep-sea deployment system for a neutrino detector cabled network, bird-detection equipment and instruments for measuring mussel activity.

With an increasing world population and depletion of land-based resources, the global importance of marine ecosystem goods and services to human life is gaining importance. These services range from climate regulation, bioremediation, primary production and oxygen generation and supply of food, to minerals, gas hydrates and genetic resources currently explored in the deep sea. In order to responsibly use these resources, the study of marine systems in a changing world is a challenge of major societal relevance. Urgent needs include improving the baseline knowledge of marine biodiversity from genes to ecosystems and at all relevant temporal and spatial scales.

Furthermore, it is vital to better define the controls and limits of ecosystem resilience, including predictive capacities for regime shifts and adaptation. Ecosystems are complex adaptive systems that organize and react at different levels of organization. Understanding and predicting this dynamic behavior requires a hierarchy of ecological models up to the full development and use of a suite of integrated, next generation models. Such models must be based on sound theoretical and conceptual developments and on observational and experimental, *sea-going* empirical knowledge for calibration and validation.

The above includes the need to (1) improve observational and measuring technologies, and increase information forming the backbone of (2) improved understanding, e.g. in biogeochemical-transport models, models linking such changing ecosystem functioning with biodiversity, and ultimately with ocean resources in terms of food, energy and minerals, and (3) models that integrate this information across social, economic, environmental and ecosystem dimensions.

NIOZ' expertise

NIOZ expertise covers the major disciplines in marine and (paleo) oceanographic sciences required to investigate the marine domain from estuaries and coasts up to the deep ocean. There is a strong tradition and expertise of multidisciplinary research on important marine processes along the full depth continuum from coast to deep sea, based on internationally acknowledged observational as well as modelling studies, and from seabirds down to the smallest marine organisms. Moreover, NIOZ' strengths include placing the presently changing conditions in perspective of both short- as well as long-term (paleo-) fluctuations, e.g., with a world-leading research group in organic biogeochemistry and with independently acknowledged strengths in isotope chemistry, marine microbiology, internal waves and many other fields. Furthermore, uniquely in The Netherlands, NIOZ has the knowledge, and the logistic and technological abilities, including a dedicated marine research fleet to encompass the study of processes and systems along this full gradient. For instance, from 1860-1962, NIOZ has performed daily measurements of Wadden Sea temperature and salinity, quantities now sampled routinely at 1 Hz. NIOZ can transpose process knowledge, field methods and models from shallow to deep systems and back, thus creating a global framework for coastal studies and providing relevant knowledge for coastal management from global ocean studies.

Besides its continuous quest to measure and analyze coupled abiotic and biotic marine processes on a global scale, NIOZ has established unique regional long-term time series (> 40 yrs, some >100 years), e.g., on the Wadden Sea, S.W. Delta area, North Sea, but also of large parts of the world ocean, notably around Africa, and the Caribbean and the Indonesian regions on e.g., biochemistry, water properties and primary producers, benthos, fish and beached birds. These are instrumental in e.g. revealing the consequences of historical management measures such as oil spill reduction and eutrophication. They are also essential to monitor the impacts of future governance of coastal and oceanic waters, e.g., with regard to the impact of climate change, overfishing, and pollution ('*the deadly trio*'). NIOZ' scientific strategy will include maintaining these activities for the benefit of scientific research and societal needs, but focus them on selected topics among the grand challenges.

The new science plan entails combining continuous innovation of our excellent science with focused fundamental and frontier-applied research with high societal relevance and visibility. Moreover, it focuses on merging important elements of the current grand international challenges in marine sciences discussed above with our national, and seagoing role and our specific strengths and potential. In addition, at a national level, NIOZ science is a key factor in several of the economic Dutch top sectors, implying active stimulation of valorization and relations with industry.

New science plan 2014-2020

Anno 2014, NIOZ is confronted with a number of changes that force the institute to reconsider its general strategy, internal organization, and external relations. Key in this process is a visionary new science plan, inspired by the aforementioned grand scientific challenges, as well as the changing role of the institute in society.

Inspired by the international 'grand challenges' to *live with warming oceans*, including e.g., rising temperatures, higher sea levels, ocean acidification, concomitant changing ecosystems, including ever increasing human impact, but also noting the rising need for sustainable ocean exploitation in terms of food, energy and minerals, the new science plan will aim at focused advanced fundamental and frontier-applied research with a longer-term, farther horizon, and with high social and scientific relevance, and with high visibility; we call it our *Mission Blue Planet.*

The core, and strength of NIOZ research will remain our multidisciplinary character and the ability to intrinsically cover the entire marine spectrum, from coasts to the deep sea. With this axiom, the new NIOZ science plan focuses on two selected, interlinked broad themes: *The changing Ocean system: past, present and future,* and *Adaptability of marine ecosystems in a changing world*. With this selection, NIOZ research addresses important elements of the international societal grand challenges of marine research, while at the same time accommodating societal needs for improving sustainable use and management of the sea, as well as fostering societal, policy and industrial developments in close co-operation and in concert with private and public sector partners.

The science plan 2014-2020 provides the framework for required re-orientation and adaptations of the organization, including absorbing base-budget decline, and to delineate our national and international role.

Two focused research themes

Together, the above drives our scientific direction 2014-2020 into the aformentioned two selected broad research themes, within which focused research topics are defined below. Through these two themes, and on the basis of our internationally acknowledged multidisciplinary advanced fundamental and frontier applied marine scientific capabilities, we aim to generate the expertise and knowledge needed to underpin and improve longer-term sustainable and responsible marine management, from fundamental understanding of key-processes to promoting innovative solutions to the coming challenges of sustainable, and responsible use of the seas and oceans.

For each theme a set of specific research topics and objectives is identified for 2014-2020. These act as our research focal point and corresponding projects will be actively pursued and developed from national and international academic, additional governmental, and industrial funding sources, with additional dedicated NIOZ baseline budget support, and 'seed funding'. A new arrangement and composition of multidisciplinary scientific departments making use of the unique NIOZ capabilities and infrastructure will tackle these, as laid out in the strategic plan, and many projects will be carried out in close concert with our national and international partners and stakeholders.

Theme 1: the changing Ocean system: past, present, and future

The oceans are an integral part of system Earth and are critical in climate regulation. Unraveling the fundamental links and feedbacks between the different components of the coupled, and currently rapidly changing global climate-marine system, both in the past and in the present, is therefore not only scientifically challenging; it is also essential to understand the future of our planet. Changes in sea temperatures, ocean circulation and ocean chemistry (e.g. acidification and oxygenation) are expected to affect the species abundance, diversity and distribution in the open ocean and, in turn, the removal of atmospheric CO_2 by the ocean, with unknown consequences. The impacts of climate change and ocean acidification may also affect commercial fishing as a result of changes in the size and distribution of fish stocks. Apart from being affected by long-term environmental change, many coastal seas and oceans are prone to more direct, short-term effects of anthropogenic influence – overfishing, pollution, and eutrophication are examples. To mitigate these effects, paving the road to responsible use of the marine realm in a warming world, more fundamental knowledge of the complex and dynamic causes- and effects relationships on biodiversity, biotic communities and ecology is urgently needed.

Our understanding of the interaction of deep and shallow ocean dynamics and biota needs to be augmented, including improved knowledge of the impact of sea level change and exchange processes in a stratified ocean. Moreover, in order to understand the functioning and consequences of changes in the physical and biochemical marine system, global fluxes and variability of material involving land runoff, air-sea exchange, benthic-pelagic coupling, transport within the ocean, as well as the different biological, chemical and geological processes regulating these transfers must be better understood and predicted. Important lessons may be learned from past ocean dynamics, notably from ancient warm intervals. Further development of proxies with respect to states and to processes, are essential in improved reading and interpreting the ocean climate archive.

Combining these aspects is a truly multidisciplinary endeavour and is an intrinsic capability of NIOZ, involving exploring processes at different scales of space and time. Within this theme, the following key topics are identified, viz:

- *Past ocean dynamics.* How to derive process information from the geological record from proxy records, including ancient changes in ocean temperature, oxygenation and acidification, aiding predictions of future developments
- *Ocean circulation and sea-level variability.* Exploring shallow and deep oceanic physical processes and dynamics relevant for coastal and deep sea futures and exploitation of the deep.
- *Exploring changing marine biogeochemical cycling.* Probing the dynamic biogeochemical cycles, including relationships with vertical and horizontal exchange processes, changing pelagic food webs, and benthic-pelagic coupling, and eecological consequences, through combining gathering field data and modeling.
- *Assessing the impact of human activities on ocean systems, the issue 'plastic soup'*. Better understanding of human-induced, rapid changes to the ocean will aid improved and responsible future environmental management. Unique for the truly oceanic, offshore environments, is the ever increasing, and even geologically unprecedented presence of macro to nano-sized plastics in the system. The ecological dynamics and impact of this aspect are largely unknown and need dedicated study.

Past ocean dynamics

The ocean system operates on a variety of timescales. Past climate and related oceanographic changes have been archived in marine sediment deposited at the ocean floor. By improving our existing capability and through developing novel tools to better generate, analyse, and interpret the paleoproxies derived from the oceanic archive at all conceivable timescales, we will increase our understanding of past, modern, and therefore future climate change. Related research goals include the innovative use of state-of-the-art technology in creating and interpreting new high resolution organic and inorganic paleoproxy records, particularly from warm past climates, aiding improved future predictions. Testing of newly developed proxies in present-day ocean systems forms an integral part of this effort.

Ocean circulation and sea-level variability

Increased atmospheric temperatures and changes in the hydrological cycle in our present-day climate influence ocean temperature and salinity. This has subsequent effects on e.g., ocean density contrasts, hence thermohaline circulation, wave-driven vertical exchange processes and sea-level, due to the thermal expansion of sea water. Atmospheric circulation patterns driving the large-scale surface ocean circulation are expected to change in a changing climate, and hence affect ocean currents, eddy and internal wave variability, and mixing. Cryospheric responses, e.g. mass loss from Greenland and Antarctic ice sheets, to a warming atmosphere and ocean are expected to increase and hence supply freshwater to the ocean. Increased understanding of the fundamental processes of ocean-atmosphere-cryosphere interactions is needed in order to advance coupled climate models and hence improve future projections of climate change and sea-level rise. Sea level change has mainly been dealt with and interpreted as a world-wide uniform phenomenon. However, regional sea level variations during a particular period of time can differ up to an order of magnitude from the uniform, world-wide spatial average, value and can even have an opposite sign region-wise. This relatively new insight is an essential innovative element in interpreting, modeling and projecting sea level variations and their consequences. At the same time, the resulting new inverse technique of fingerprinting is used to identify and separate the sources of regional sea level variations.

Exploring changing marine biogeochemical cycling

The ocean has an important role in controlling atmospheric CO2 by take up and sequestration and transport to the deep sea. Besides the global carbon cycle, the global cycles of other biologically active –trace- elements are essential for understanding marine systems and biological functioning. Chemical components are consumed, mineralised and changed by biota, whereas microbial activity is in turn controlled by the presence of bio-essential chemical components. Distributions of a number of elements in the ocean are extremely low and are known to limit primary production. The distribution and stable isotopes signature of these metals can be used to elucidate and quantify their sources, cycling, fate and impact on marine ecosystems. The study of these elements enhances our understanding of the marine sources, sinks and processes (both biological and chemical) responsible for bio-essential element concentrations. Results of this research will provide insight in the mechanisms controlling uptake and biological function in phytoplankton and higher trophic levels and hence clarify the regulating role of Fe, Zn, Cu and possibly Cd for marine ecosystems and the carbon cycle in the world oceans.

The oceans have absorbed about one-third of the anthropogenic CO_2, which has already noticeably lowered the average oceanic pH by from pre-industrial levels. According to the Intergovernmental Panel on Climate Change (IPCC), continuing CO2 emissions according to projected trends could make the surface oceans up to 150% more acidic by 2100 than they were at the beginning of the Anthropocene. Ocean acidification is a serious threat due to its effects on marine ecosystems, especially marine calcifying organisms, and marine resources and services upon which human societies largely depend such as energy, water, land use, and fisheries.

***Assessing the impact of human activities on ocean systems, the issue 'plastic soup'*.**

Superimposed on longer-term effects of climate change, human activities invoke short-term, often profound changes to the ocean ecosystem with yet unknown consequences. Better understanding of human-induced, rapid changes to the ocean will aid improved and responsible future environmental management. Unique for the truly oceanic, offshore environments, is the ever increasing, and even geologically unprecedented presence of macro to nano-sized plastics in the system. The ecological dynamics and impact of this aspect are largely unknown and need dedicated study.

***Theme 2, Adaptability of marine ecosystems in a changing world*.**

In the same context of global climate change and increasing anthropogenic pressure, it is also vital now to better define the controls and limits of ecosystem resilience, including the prediction of regime shifts and adaptation at different (ecological to evolutionary) time scales and in an explicit spatial context. This requires a thorough understanding of ecosystem dynamics and the improvement of modelling capacity. In general, such knowledge has been more central in coastal research than in oceanic science, but the comparative study of several systems and the confrontation of conceptual frameworks across different systems is highly promising for this type of research. Within this theme, the following key topics are identified, viz:

- *Changing habitats.* The two-way interaction between organisms and their habitat structure, and consequences for system dynamics
- *Changing marine food webs and connectivity.* Exploring food web structure and function in changing ecosystems, including biotic and abiotic connectivity
- *Exploring deep marine microbiology*. Exploring the components and dynamics of the marine microbial foodweb, and consequences for higher trophic levels is still in its infancy. Notably the role of viruses and parasites across different oceanic realms and deep-shallow gradients needs to be better studied and understood on the various spatial and temporal scales.
- *Evolving seafloor ecosystems.* The human imprint on seafloor ecosystems is sharply increasing, both in shallow waters as well as in the deep sea. Improved understanding of processes involved, spatially as well as in terms of rates of change, and ecosystem-resilience is urgently required.

Changing habitats

Marine habitats are under continuous stress and change as the result of ever increasing external forces and related changing internal dynamics. Small changes in e.g. temperature, salinity, nutrient delivery, etc., or invasive species can result in large effects on ecosystem characteristics (e.g., presence and role of filter-feeding bivalves) and ecosystem functions (e.g., nursery function of coastal waters). At different spatial and temporal scales, underwater 'sea-scapes' self-organize as a consequence of 'ecosystem engineering' processes, i.e. effects of organisms on their physical environment, with an ensuing feedback on the fitness of the biota. Understanding how this leads to the organization of ecosystems, both coastal (where most of our current expertise is built up) and in deeper water, is a prerequisite to explore adaptive capabilities of marine ecosystems, and thus their resilience to anthropogenic change, ranging from coastal infrastructural works to global warming or ocean acidification.

Research in this field is dependent on multidisciplinary co-operation between ecological, physical and geological sciences. It involves modeling at different levels of resolution. A distinguishing feature for NIOZ research in this domain is the ability to do (field) experimental work and to make observations in large running seawater facilities, including flumes and diverse mesocosm setups.

Changing marine food webs and connectivity

Natural food webs have multiple, reticulate connections between consumers (predators) and resources (prey). Yet, current environmental change related to Global Change and human impact invoke asymmetrical changes in these connections. Changes in the movement of nutrients, detritus, benthic communities, and apex consumers among landscape variables, and spatial heterogeneity for food web dynamics must be better understood. Food web modelling aims at quantitative and qualitative predictions about the expected patterns of population dynamics. These predictions are tested by comparing population dynamics in simple food chains of different architecture under controlled conditions. Comparisons of predator-prey population dynamics in relation to the size of particular resources can be used to infer the consequences in ecological and demographical terms in marine, coastal and estuarine ecosystems.

Marine ecosystems are generally, as compared to terrestrial ecosystems, open systems in terms of biotic and abiotic components. Because of the lack of strong physical barriers, organisms, materials and energy can flow freely from place to place, although this openness may also be overestimated. Openness implies that ecosystems can only be fully understood when viewed in their spatial context. Connectivity, and changing connectivity, is best studied by a combination of field studies on migratory behavior, comparative analyses of connected systems, molecular genetics, chemical tracers and biophysical modelling. Further improving and further integrating our existing studies on migratory birds, coastal fish, marine bivalves, phytoplankton, parasites and suspended particles will increase our knowledge on the connectivity between coastal systems and the connectivity between the land and the sea.

Exploring deep marine microbiology

Coastal seas and oceans continue to be affected by global climate environmental changes such as warming, freshening, stratification, acidification, and anoxic events, which consequently affect marine ecosystem dynamics. The resulting shifts at population level can occur due to physical intolerance to the new environment, altered dispersal patterns, and changes in species interactions in the microbial foodweb, for example changes in growth, competition, losses, and pathogen (disease) dynamics. Particularly the impact on Arctic and Antarctic deep ecosystems needs to be investigated because of the sensitivity of these systems to global climate change.

In addition, the sea is full of viruses and parasites, and it is becoming increasingly apparent that their impact goes well beyond the direct effects on infected hosts. The narrow host range of most viruses indicates their importance in controlling the composition of planktonic communities, and as important means of horizontal gene transfer viruses increase biodiversity. Moreover, viruses are a major force behind biogeochemical cycles and affect the efficiency of the microbial food web. Likewise, parasites can not only affect host population dynamics but also mediate community composition and the structure and dynamics of marine food webs. The relationship between pathogen or parasite and host is affected by environmental factors. Studying temporal and spatial (horizontal and vertical) differences, and resolving the consequences of anthropogenic impacts (e.g. global climate change and pollution) will significantly improve our understanding of the ecological role of viruses and parasites in seas and oceans. Expanding existing model systems, and integrating molecular approaches and state-of-the-art technologies will further help to comprehend underlying mechanisms.

For a comprehensive forecast of changes in pelagic ecosystems under change, a multi-species approach must be undertaken, including laboratory and field process ecosystem studies, manipulative experiments, and modeling from small-scale process simulations to large-scale coupled biophysical models.

Evolving seafloor ecosystems

The seafloor harbors a wide range of ecosystems and plays an important role in the ocean's global biogeochemical cycles. Over longer time scales, marine sediments regulate the atmospheric concentrations of CO_2 through carbonate compensation and atmospheric O_2 levels through organic matter burial. In addition, continental shelf sediments are an important site of denitrification, thus regulating the bio-available nitrogen and primary production within the ocean. Soft sediments cover vast expanses of the seafloor, and contain highly diverse faunal communities, which strongly impact sediment biogeochemistry. Locally, structurally complex ecosystems can be found, such as cold water coral reefs, sponge fields, cold seeps and hydrothermal vents, which form hotspots of biodiversity in the deep ocean. At the same time, the top layer of the seafloor is characterized by steep geochemical gradients, which sustains a great variety in microbial metabolism, and results in sharp transitions of microbial communities over only centime-scale distances. The microbial ecology of the seafloor is not well explored, and entirely new forms of microbial metabolism like filamentous electrical bacteria have only been recently discovered.

The human imprint on seafloor ecosystems is sharply increasing, both in shallow waters and the deep sea. Arctic, temperate and tropical coastal ecosystems suffer from increased nutrient inputs, higher risk of hypoxia, and ongoing ocean acidification, which may lead to strong and rapid changes in element cycling and food web functioning. Even deep-sea ecosystems, like cold water coral reefs and sponge fields, are being impacted, most notably from bottom trawling, oil exploration, and the shoaling of the aragonite saturation horizon due to on-going ocean acidification.

The study of these ecosystems in the context of a rapidly changing world requires adopting a multi-disciplinary perspective combining ecology, geochemistry, and microbiology. The scope goes from the deep sea to the coast, from the arctic to the tropics, and from filamentous electrical bacteria that thrive in anoxic sediments, over microbial mats and soft-sediment ecosystems, up to coral reefs. As part of NIOZ, we can combine state-of-the-art data acquisition techniques in ecology, geochemistry, and microbiology, ranging from stable isotopes and high-resolution microsensor profiling with various 'omics' approaches. To make the most of our data, field observations and experimental results should be combined with mathematical model analysis. To this end, new modeling tools should be developed, such that they find analogous application in the fields of biogeochemistry, food web analyses and systems microbiology.

Valorization of NIOZ research

While this new science plan outlines the NIOZ focal points of scientific and societal relevant academic research, its output will aid ensuing and concomitant frontier applied studies; in concert, this will lead to significant valorization of our efforts, with close links to topsectors (water, agro/food, energy, technology) and industry, nationally and internationally.

Already, following changes in the Dutch national research policy described above, NIOZ has actively engaged in frontier-applied research that contributes to industrial, technical and governmental responses to the grand challenges posed by global change. In order to ensure the effectiveness of this innovation-oriented research (e.g., the NIOZ Seaweed Research centre, the NIOZ Deep Sea Science and Technology centre), the institute is intensifying contacts and cooperation with industry, generally framed within the topsector initiatives. An important topsector for NIOZ is the sector Water, and notably the maritime and delta-technology sub sectors.

Other NIOZ activities are more closely related to the sectors HTSM and Agro/Food. Outside this framework, NIOZ is, and will continue to develop bilateral contracts with industrial partners where possible. To this end, the institute is currently establishing multidisciplinary virtual centers of excellence on broad topics of societal and industrial interest, such as the Netherlands Deep Sea Science and Technology Center that is already operational, and the forthcoming Seaweed Research Center, to be opened in Spring 2014.

NIOZ as a central hub in marine research and education in The Netherlands

As dedicated NWO institute, NIOZ is the national hub for excellent fundamental and frontier applied marine sciences in The Netherlands. Close co-operation is maintained with the principal Dutch universities with marine programs, notably, but not exclusively with the universities of Groningen (RUG), Nijmegen (Radboud), Utrecht (UU), Amsterdam (UvA and VU), Delft (TUD) and Twente (TUT). Many NIOZ scientists are tied to these institutions as professors, assist in teaching and MSc programs or act as (co)promotors of PhD theses. Strong ties also exist between NIOZ YE and the universities of Antwerp, Brussels and Ghent, Belgium. NIOZ aims to strengthen and expand these relationships further, expanding also to other universities.

To promote and support marine sciences in The Netherlands and abroad, NIOZ organizes a national MSc course 'introduction to marine sciences' open for MSc students from all Dutch universities. This course will be opened for more participants and participation from foreign universities is envisaged. In addition, at our various locations, including the CNSI at St Eustatius, NIOZ organizes topical summer schools for PhD students to promote national and international scientific exchange.

Through internships and participation in teaching programs, NIOZ takes a role in the education at universities and 'technical universities' (and Hogescholen). With the increasing role of the latter in applied research programs, NIOZ will participate in common projects, in order to ensure a flow of knowledge and expertise between fundamental and applied research programs.

NIOZ is, and will maintain its role as a node in communication within the Marine Masters (MaMa) program, aiming at organizing marine curricula for students over the different Dutch universities. NIOZ has taken the lead for this program and will intensify it in the future. NIOZ will also play a crucial role in providing topical studies and supervision at BSc and MSc level.

Facilities for (Dutch) marine research

NIOZ 'Marine Research Facilities' (MRF) provides national and international logistic support and maritime platforms for the Dutch community of marine scientists at universities, institutions, and industry. To this aim, NIOZ maintains a diverse fleet that covers the marine waters, from coast to deep sea. NIOZ develops, acquires and implements advanced instrumentation for marine research. The capability of sea-going research, in particular for ocean waters, is essential to maintain scientific presence of The Netherlands in international waters. It is also essential for innovative (TOP sector) valorization of marine research and participation in recent trends for deep-sea exploration and exploitation. In the coming years, NIOZ will maintain and strengthen these research facilities, as well as broaden their use, as part of her national role in marine research.

NIOZ is part of several international, mainly European initiatives to coordinate sea-going marine research. The institute acts as the portal for European and global scientific cooperation via organizations such as the European Marine Board, POGO, OFEG, IODP, MARS, EurOceans and others. This international role provides Dutch scientists access to research platforms worldwide, as well as ensuring international crews on RV *Pelagia*. In this respect, the operation of *Pelagia* is crucial in obtaining exchange with foreign vessels.

NIOZ offers onshore facilities for marine field and experimental research at its two locations in The Netherlands, as well as in the recently founded center at Sint-Eustatius in the Caribbean (CNSI). The CNSI is still in full development; it will serve the Dutch research community at large in Caribbean studies and in monitoring of the overseas territorial waters. The facilities at Texel and Yerseke offer climate controlled experimental rooms, current and wave flumes, a greenhouse, permanent measurement stations and facilities for regular water sampling, laboratory facilities for fieldwork, field measurement devices. Through diverse co-operation programs, these facilities are already used by several other universities and institutes; such use will be further stimulated in the future.