ID:	A- 6

1 A. Title:
Climate-related shifts in the NCP ecosystem, and consequences for future spatial planning

1 B. Coordinator (contact):

Person	Dr. Jaap van der Meer
Institute	Royal Netherlands Institute for Sea Research
Address	PO Box 59, 1790AB Den Burg, The Netherlands
Email	meer@nioz.nl
Website	www.nioz.nl

2. History and Background of the Research Proposal; Problem Definition (maximum 1 page):

Analysis of long-term weather observations in the Netherlands has revealed that the climate is warming up. Different climate scenarios for the Netherlands in 2100 all show increasing temperatures, an increase in precipitation, and an increase in the frequency of strong winds and storms. The changes in precipitation and evaporation in Europe will affect the expected discharge of the major rivers in winter. CO2 levels of the atmosphere have increased enormously and continue to increase.

Although the marine ecosystem of the North Sea has responded to climatic changes throughout its relatively short geological history, there is a growing concern about the present rapid rate of temperature increase and its effects on the ecosystem. Studies in other natural ecosystems have already demonstrated the occurrence of shifts in range boundaries, phenological shifts (i.e. shifts in seasonal patterns) and changes in species abundances in line with the predicted climate warming. Also in the North Sea ecosystem changes have been observed in the past decades that might be related to climate warming.

Climate change can affect the North Sea ecosystem in various ways. Temperature increase may cause changes in the performance and spatial patterns of species better adapted to warm or cold extremes. The invasion of anthropogenic CO2 into the sea causes major changes. By 2050 the pH will have dropped by 0.3-0.4 units and carbonate ion concentration will be half of its pre-industrial value. Rates of many biological processes will severely be affected, leading to major biological changes of the North Sea in a high-CO2 world. Notably the seasonality (spring bloom sequence of algae taxa) and spatial distribution of major bloom forming algae will change. Changes in weather patterns leading to changes in wind mixing and nutrient run-off will also affect the spatial distribution of algal blooms and the algae species involved.

These changes in primary production of pelagic algae have immediate consequences for the magnitude and distribution of secondary production (zooplankton, benthic fauna, fish fauna) in the North Sea. The benthic fauna i.e. organisms living in the sediment, transform up to 60 % of the pelagic primary productivity. Benthic organisms accelerate and contribute to the diagenesis of organic matter back into nutrients. They store another part of the primary production deposited on the seafloor as body mass that serves as food sources for higher trophic levels (demersal fish, birds and sea mammals). Hence, production of benthic fauna is a crucial aspect of the energy flow through the North Sea. The current project aims at assessing this benthic-pelagic coupling and changes thereof due to climate change.

Climate change may thus cause a fundamental change in the productivity patterns of the North Sea ecosystem with consequences for management. Some of the phenomena related to the climate change (e.g. nutrient run-off, CO2-emission) can, in principle, be partly mitigated via direct regulation. Others (e.g. temperature and weather) cannot be nullified by any human interaction. They call for the development of adaptive strategies to counteract changes in spatial productivity patterns. Adaptation might be needed with regard to allocation of fishing areas, marine reserves, offshore exploitation, wind parks. In view of adaptive management strategies to reduce impacts of future climatic changes, it is important to obtain detailed insight into the relationship between the spatial aspects of ecosystem functioning and key environmental variables affected by climate change.

3. Objectives (maximum 1 page):

We aim to provide a detailed spatial overview of the past, present and future ecosystem features of the North Sea (with an emphasis on the Nederlands Continentaal Plat (NCP), i.e. the Dutch part of the North Sea) in relationship to climate change. This aim will be achieved by describing and analyzing relationships between relevant environmental variables (e.g. temperature, nutrient load, turbidity, CO2) and indicators of ecosystem performance (CO2 exchange rates, the seasonal cycle of algal blooms, the abundance and production of widespread benthos species, the performance of commercially important fish species, and fisheries productivity). Knowing these relationships, scenario's of impacts of climate shifts on ecosystem productivity and biodiversity will be verified.

The large spatial and temporal scales at which ecosystem dynamics operate, the complexity of relationships, interactions between variables, and the obstacle that only few species (algae, larvae of benthic species) can be

cultured, precludes that progress in understanding environment-ecosystem relationship can be made solely by laboratory experiments. More promising are field measurements (both on the abiotic environment as on the living world) in combination with specific field and/or laboratory experiments on sub-processes (e.g. on the recruitment, growth and development of organisms in response to environmental variables). Such field observations (given that they are performed at the appropriate spatial and temporal scales) enable correlative (statistical) analyses and more structured formulation of hypotheses. Yet, if possible specific hypotheses should also be formulated in terms of mechanistic ecosystem models, such as ERSEM, in which the experimentally tested sub-processes should be incorporated.
In order to achieve our overall aim, we intend to integrate the following objectives:
1) Quantify changes in CO2 uptake by the North Sea via plankton blooms by means of field measurements, and quantify the role of climate change by ecosystem modelling
2) Quantify the seasonal and spatial changes of distributions of plankton blooms by satellite remote sensing.
3) Quantify the relationship between temperature, food quantity and quality and steering processes (such as reproduction and recruitment) of the population dynamics of benthic organisms, by means of field experiments using autonomous sampling and experimental devices.
4) Quantify the relationship between environmental conditions and benthic population dynamics over large temporal and spatial scales by modelling
5) Quantify the relationship between environmental conditions and the consumption and production of fish assemblages over large temporal and spatial scales by modeling
6) Develop a new management tool which should address the complexity and dynamic nature of the ecosystem in order to optimise planning and future use of the North Sea

4 A. Research Questions and scientific relevance (maximum 2 pages):
The proposed research pivots around six related key questions:
1) How does the net uptake of CO2 from the air into the North Sea change in the future; how does the increased dissolved CO2 in seawater affect blooms of major taxa of phytoplankton, how will seasonal and spatial changes of such plankton blooms in turn affect the net CO2 uptake capacity ?
2) What is the temporal and spatial variability in algal spring blooms in the North Sea, and how is this variability related to environmental variables such as temperature.
3) Do benthic species living in both the offshore zone and the coastal zone, which differ remarkably in temperatures and primary production (see question 2) differ in their reproductive output, the abundance of competent larvae, and ultimately in the number of recruits? These questions will be addressed in species that act as model for a larger species group.
4) What is the temporal and spatial variability in North Sea benthic populations and how is this variability related to environmental variables such as temperature? Can we understand differences in this variability between species on the basis of the answers from question (3)
5) What is the temporal and spatial pattern in the production and consumption of the benthic fish assemblage and how is this related to environmental variables such as temperature, river discharge and fisheries
6) How can the spatial and temporal information on different species groups and projected future use of the North Sea be integrated and presented in such a way that a useful and reliable tool for future management is obtained?
Hence, we propose to combine detailed and process-oriented shipboard surveys, which necessarily occur on limited temporal and spatial scales (see questions 1 and 3), with less-detailed observations on much wider spatial (the whole North Sea) and temporal (several decades) scales (questions 2, 4 and 5). Integrating both approaches by means of dynamic modelling (European Regional Seas Ecosystem Model ERSEM II) and statistical modelling (kriging and co-kriging to relate environmental variables to ecological variables) should lead to the development of a management tool addressing the complexity and dynamic nature of the ecosystem in order to conduct, evaluate, and refine management activities despite scientific uncertainty and changing conditions (question 6).

Based on climate predictions we anticipate the following scenarios regarding impacts of climate change on the structure and functioning of the NCP ecosystem:
1) Increased temperature or temperature variability exceeds the physiological tolerance of ‘cold water' species resulting in their disappearance. Under these circumstances ‘warm water’ species can invade the North Sea and replace them.
2) Climate induced changes in CO2 levels, precipitation and river run-off will lead to changes in algal species and to changes in spatial and temporal patterns of primary production. The effects of these shifts on the reproduction of benthic organisms could be twofold. Firstly, the type of algae (e.g. lipid composition) influences the development rate and survival of larvae as shown by studies on bivalves. Secondly, the timing of the blooms

of appropriate algae must match with the appearance of pelagic larvae.
3) Climate change is accompanied by a change in the frequency of strong wind and storms. Wind fields drive the circulation and therefore indirectly the temperature (see point 1). Wind velocity is also the major driver of the air/sea gas exchange of CO2 and other gases and strongly forces the timing of the plankton blooms. At the relatively shallow NCP, wind speeds greater than Bft 5 have also a direct impact on the seafloor and their inhabitants. Wind induced resuspension of food and of newly settled stages directly affects survival and dispersion of recruits. Indirectly, a decrease or increase in the frequency of resuspension alters the food availability for the breeding adults and their reproduction capacity.
The NCP offers possibilities to carry out a study on relationships between temperature, wind fields, and nutrients (including CO2,) on the one hand and gas exchange, algal blooms and primary production, and fundamental processes (such as recruitment) underlying secondary production on the other hand. The NCP encompasses sharply delimited habitats with different temperature and productivity regimes. Each habitat has a set of characteristic species next to species that occur over much wider areas. Knowing the spatial shifts in habitats as a result of climate change is needed in order to optimise future use of the NCP.

4 B. Relevant Publications (max. 10):

I. Thomas, H., Bozec, Y., Elkalay, K. & de Baar, H. J. W. (2004) Enhanced Open Ocean Storage of CO2 from Shelf Sea Pumping in the North Sea. Science, 304, 1005-1008
II. Bozec, Y., Thomas, H., Elkalay, K. & de Baar, H.J.W. (2004) The continental shelf pump in the North Sea - evidence from summer observations, Marine Chemistry (in press)
III. Van der Woerd, H.J. & Pasterkamp, R., (2004) Mapping of the North Sea turbid coastal waters using SeaWiFS data. Canadian Journal of Remote Sensing, 30, 44-53.
IV. Schlitzer, R. (2002). Carbon export fluxes in the Southern Ocean: results from inverse modeling and comparison with satellite-based estimates. Deep-Sea Research Part II-Topical Studies in Oceanography, 49, 1623-1644.
V. Witbaard R., Duineveld, G. & Bergman, M. (2001) The effect of tidal resuspension on benthic food quality in the southern North Sea. Senckenbergiana maritima 31: 225-234
VI. Duineveld, G. & Boon, A. (2002) Short-term variations in the fluxes and composition of seston in near-bottom traps in the southern North Sea. Helgoland Marine Research 56: 41-48
VII. Van der Meer J., Beukema J.J. & Dekker, R. (2001) Long-term variability in secondary production of an intertidal bivalve population is primarily a matter of recruitment variability. Journal of Animal Ecology 70: 159-169
VIII. Williams, I.D., Van der Meer, J., Dekker, R., Beukema, J.J. & Holmes, S.P. (2004) Exploring interactions among intertidal macrozoobenthos of the Dutch Wadden Sea using population growth models. Journal of Sea Research (in press).
IX. Rijnsdorp, A.D. & van Leeuwen, P.I. (1996) Changes in growth of North Sea plaice since 1950 in relation to density, eutrophication, beam-trawl effort, and temperature. ICES Journal of Marine Science 53: 1199-1213.
X. Lindeboom, H.J. (2002) Changes in coastal zone ecosystems. In: G. Wefer, H. Berger, K-E. Behre & E. Jansen (eds.).Climate Development and History of the North Atlantic Realm, pp 447-455. Springer, Berlin.

5. Description of the project; approach, methodologies and implementation plan (maximum 5 pages):

Question 1. Uptake of CO2 by the North Sea in interaction with plankton blooms
Approach. Assess interannual variability of CO2 uptake by the North Sea. Assess how current anthropogenic changes in temperature, runoff nutrients and dissolved CO2 affect phytoplankton community production, structure and function. Thermal stratification will favour Emiliania huxleyi blooms, silicate runoff favours diatoms with their silicious (opal) exoskeletons, the N/P ratio in runoff influences the success of Phaeocystis spp, and the lowering of [CO32-] will be detrimental for calcification of E. huxleyi. Concomitant shifts of rain rate ratio's Corganic/CCaCO3 and Corganic/opal towards the seafloor serve as input/forcing for below research question 3.
Methodologies. The research on the North Sea carbon cycle is in the fortunate situation to rely on a very recent and comprehensive carbon and nutrient data set obtained by the NIOZ (Thomas et al., 2004). The North Sea has been sampled repeatedly in 1-month cruises (8/2001,11/2001, 2/2002, 5/2002) taking some 23,000 surface water values of pCO2 and occupying each time 97 stations for sampling the complete water column for the CO2 system and a suite of 20 other parameters. In al four seasons it was found there is a strong south-north transition coinciding with the transition at the Frisian Front from shallow waters (<50 m) of the southern North Sea to deeper waters of the northern North Sea. In contrast, the gradients in east-west direction are modest. Thus here we propose a South-North repeat section at sea. This will be combined with basin-wide data of satellite remote sensing (see question 2) in order to extrapolate to basin-wide data for CO2 as well as phytoplankton abundance. This will be done for several years to study interannual changes and longer term climate change affecting both

the CO2 and the phytoplankton in the North Sea.
Implementation. The existing field observations (2001-2002 campaign) will be complemented by a South-North repeat section aboard a Voluntary Observing Ship (VOS) ferrying between Rotterdam and Bergen. In principle, there will be two dedicated cruises (4 weeks each) aboard RV Pelagia, one in August 2007 and a second cruise in August 2008.

The total Dissolved Inorganic Carbon (DIC) in seawater consists of several chemical species DIC = [HCO3-] + [CO32-] + [CO2aq= k.pCO2], where latter [CO2aq] includes a minor [H2CO3] pool. We directly measure both DIC and pCO2, which provides by calculation the other variables, with verification by combination with measured Alkalinity. Both the VOS line and the two cruises will observe pCO2 in surface waters and atmosphere, as well as DIC and nutrients and abundances of major phytoplankton species (i.e. diatoms, Phaeocystis spec., Emiliania huxleyi).

The rivers play a crucial role in balancing marine vs. terrestrial carbon cycles since rivers transfer terrestrial carbon to the sea and thus transform a terrestrial sink into a marine source. Moreover, riverine nutrient loads strongly affect the NCP carbon cycling and ecosystems. Changes of the nutrient loads and their (elemental) composition (i.e. N/P ratio) affect or alter coastal ecosystem structure (e.g. regime shifts). Cruises have been and continue to be done in CarboOcean context by the team of Prof. Michel Frankignoulle (University of Liège) for the CO2 system in the major rivers and estuaries around the North Sea, of which large parts were found to be strongly supersaturated in CO2, being a significant source of atmospheric CO2.

The knowledge gained through observational and mechanistic modelling activities will enable us to extend current ecosystem model ERSEM II of the North Sea. Past and future changes in ecosystem structure and the carbon cycle are assessed as consequences of (i) climate change, (ii) the current and future invasion of anthropogenic C into the North Sea, (iii)eutrophication and (iv) nutrient input reduction scenarios.

Our parallel leading role in EU CarboOcean Integrated Project (IP) will provide time series observations of accurate atmospheric CO2, O2 and the 13C and 14C of CO2, CO, and O2/N2 at one production platform in the central North Sea. These data will be exploited to resolve marine biological activity, as well as the average CO2 source/sink behaviour of the North Sea. Together with CarboEurope IP time series data at towers on land (see also 11A) around the North Sea this will provide the boundary conditions for the determination of the marine and terrestrial carbon balance for The Netherlands territory (land and NCP) and NW Europe using atmospheric inversion (top-down) models.

Question 2. Seasonal and spatial variations of major taxa in plankton blooms
Approach. Spatial planning in this area requires information with a high spatial resolution. Remote Sensing data in particular can spatially and temporally complement cruise-based observations and provide maps for the complete North Sea as to be able to extrapolate basin-wide. It was already shown that the oceanic primary production can be computed from the chlorophyll pigment concentration, detected by a spaceborne ocean color sensor. Furthermore, satellite-based primary productivity rates can be compared with estimates of export production and vertical carbon fluxes by a global ocean circulation, biogeochemical model.
However, within the shallow Southern North Sea matters are complicated by resuspension of sediments in storms. Firstly the more turbid waters permit less transparency of incoming sunlight, thus allowing less photosynthesis by algae. Secondly the signal of suspended sediment particles is also seen by the satellite and needs to be resolved from the Chlorophyll-a signal of the algae themselves. Also waters with significant river water component and/or strong local biological activity often exhibit absorption by Coloured Dissolved Organic Matter (CDOM). Moreover high levels of CDOM may hint at existence of surface films and slicks, which at calm weather are known to partly prevent air/sea exchange of gases.
Methodologies. Recently launched satellites like MERIS (ESA) and MODIS (NASA) are especially designed for the study of coastal waters since they can cope with more complex signals. It is now possible to make algae pigment maps with (validated) accuracy. In addition relevant products like the distribution of concentrations of suspended sediment and (coloured) dissolved organic mater (CDOM) are available. These concentrations can be used to determine the solar photosynthetic active radiation (PAR) available for phytoplankton growth in the North Sea.
The complete time/space coverage derived from the satellite is complementary to the ERSEM simulation modelling. The timing of plankton blooms is strongly forced by wind fields also driving the circulation, and sea surface temperature. Wind velocity is also the major driver of the air/sea gas exchange of CO2 and other gases. Therefore year-around remote satellite observations of plankton blooms (as bulk Chl-a and on class specific level), sea surface temperature, sea surface roughness (driven by and indicative of wind velocity) including percentage coverage by breakers (strong gas exchange) does provide several key factors in the plankton-CO2 concerted action of the North Sea.
There is reliable understanding of the seasonal succession as function of solar irradiance, vertical stratification and nutrients availability (Si, N, P) of key plankton species (diatoms, flagellates, Phaeocystis spec. and finally calcifying Emiliania huxleyi) from early March to late June. All these otherwise different functional groups of

algae do carry the same Chlorophyll-a and therefore can be observed by satellite. Moreover the multiple wavelength bands of new satellites will allow in principle to resolve the various taxonomically different groups from associated photopigment characteristics for each plankton species group.
Implementation. Satellite imagery will be converted to products in dialogue with end-users and will be integrated with the routine monitoring of the Dutch continental shelf, carried out by Rijkswaterstaat as part of the national monitoring programme. Satellite imagery will be compared with the ERSEM II model results (see question 1) on chlorophyll pigment and primary production level. Where possible, estimates of light availability from Remote Sensing will be used to improve ERSEM II modelling.
Products derived from satellite imagery will be translated to standardised indicators that are suitable to track long-term seasonal and inter-annual trends including conceivable effects of climate change through the concepts of climate scenarios. These indicators will be designed as to show changes in the future use of the NCP, and can be used as monitoring tools to quantify impact due to climate change. The indicators are initially a eutrophication-index and an index for primary production (combined with additional data), as well as indices for uptake of CO2 from the air. Secondary products are for example risk index-maps for increased chances on Harmful Algal Blooms (e.g massive blooms of Phaeocystis spec.), but also index maps for positive biological effects, like increased growth chances for fish larvae, fish, etc. The proposed research will work on the construction of indices based on expert oceanic/biological research and integration with earth observation products. Special emphasis will be on resolving which of the remote sensing indices are most predictive for air/sea transfer of CO2.
As important as the development of standard indices is the development of communication, through which the right information will reach the right interest group in time. Data will be made available and integrated with routine monitoring of the Dutch continental shelf, carried out by Rijkswaterstaat. We propose to present the major spatial functionality by means of GIS (see question 6). For this purpose internet based techniques will be used/developed (web-mapping) in dialogue with the end users.

Question 3. Reproductive output and recruitment of some representative benthic species in relation to a productivity gradient
Approach. We plan to study recruitment of selected species inhabiting both the coastal zone and the offshore silty sand habitat. The two habitats differ in seasonal temperature cycle, nutrient ratios, primary productivity and the types of algae present. The coastal zone represents the warmer eutrophic system where production is dominated by larger algae such as diatoms. Summer temperatures at the deeper offshore site are lower while the summer plankton is dominated by small flagellates. Both habitats are also important from the perspective of economic interest and natural value. One target species in our study is the bivalve Spisula subtruncata which lives along the Dutch coast as well as in offshore silty sand. The species attains highest densities in the coastal zone where it is subject to commercial fishery and where it also forms an important food item for overwintering seabirds. Spisula subtruncata can be used as a model for other bivalves living in both habitats (e.g. Abra alba, Chamelea striatula). Another target species is the brittle star Ophiura albida which is a common epifaunal species throughout the greater part of the southern North Sea. We will use this species as a model for the group of epifaunal echinoderms represented by organisms such as the starfish Asteria rubens and Astropecten irregularis.
Methodologies. At each location we will measure the seasonal cycles of the bottom water temperature and the vertical flux of phytoplankton species in conjunction with the abundance and sizes of ripe gonads in adults, competent larvae, and recruiting settlers. In order to sample the larvae and recruits over long time intervals in these subtidal habitats and to make simultaneously high frequency observations of environmental variables, we will employ innovative autonomous benthic landers. These instruments allow filling the time gaps traditionally occurring with shipboard sampling from pre-scheduled vessels thus providing better coverage of event driven processes (e.g. blooms, storms). Each autonomous system consists of a device for trapping and counting relevant size classes of pelagic larvae and a series of in-situ mesocosms for entrapping competent settling stages. The collected larvae are preserved in-situ (alcohol) and will be identified in the lab using morphological keys and newly developed molecular techniques. The larval trapping equipment is combined with a sediment trap to sample the rain of algal detritus and with sensors monitoring the key environmental variables (temperature, fluorescence, turbidity, salinity, current speed). Video imaging will be used to check proper functioning and seabed properties. Sensor data can be downloaded by a wireless link. The sampling regime of the larval traps and the recording frequency of the sensors checked and even adapted accordingly. Samples collected with the sediment trap will be analyzed with HPLC and Chemtax software to determine the types of algae collected. We will establish the fecundity of adults using classic histology techniques and the condition of the larvae by comparing size with nucleic acid ratios.

Implementation. Relationships between recruitment and environmental variables will be inferred from the between-habitat differences. Any year-to-year variation that occurs within the habitats in the period of investigation will be used to verify hypothesis derived from between-habitat comparisons. The generality of

inferences derived from the field measurements will be tested using data obtained by others in feeding experiments with cultured larvae and algae under controlled conditions in the lab. Growth and development of bivalve larvae are for instance being studied at the NIOZ for various aspects of the reproductive output (e.g. high and low reserve levels in eggs) and the resource levels (e.g. high vs. low; increasing vs. decreasing; constant supply vs. multiple shifts) during larval development.

Question 4. Long-term variability in North Sea benthic communities
Approach. Based on available historic datasets from ongoing monitoring programmes carried out by NIOZ over the last decades, the effect of changes in ocean climate on the population dynamics (emphasis on changes in abundance, and if data allow a more detailed analysis of reproductive success, mortality, and migration as well) of a selection of benthic species will be examined. Part of the data for the last decades are obtained within the routine national monitoring programme of Rijkswaterstaat, carried out in co-operation with NIOZ. The programme is designed to give a description of the actual situation, and to detect long term trends, for a large range of abiotic and biotic variables. These data provide information on a large number of physical parameters, but also on the distribution of nutrients, phytoplankton, benthos, etc. The NIOZ has started a long-term monitoring study of benthic animals in the mid 1980s, and preliminary analyses of these data showed major shifts in the benthic fauna within specific areas. Many older data (the first surveys started at the end of the 19th century) are still hidden in the files of the various marine and fishery institutes across north-west Europe, and we aim for a comprehensive analysis of all historical records of the benthic fauna of the southern North Sea, which at the moment is still lacking.
Methodologies. Archive studies will be conducted to get a complete overview of historical data on the benthic fauna of the North Sea. Stochastic population process models will be used to analyze these historic datasets on population abundance and environmental variables. Basic methodology is to use both linear and non-linear higher-order models in discrete time. Dynamic properties will be studied by estimating the stochastic component of the Lyapunov exponent using a Jacobian-based method, which may shed light on the internal dynamics of the system. Various alternative deterministic skeletons will be compared both in terms of goodness of fit, dynamical behaviour and ecological credibility. Multivariate extensions of this approach, i.e. taking into account the interdependencies among species or the spatial aspects of population changes, will be developed. Further work will be done on quantifying the relative importance of (density dependent) internal dynamics and external forcing.
Implementation. Results of the spatially-explicit stochastic models will be used to map historic, present and future (dependent on various climate-scenario's) distribution of species abundance and other ecological properties of the benthic fauna of the North Sea. These results will be implemented in the management tool developed under question 6.

Question 5. Long-term variability in the production and consumption of North Sea benthic fish assemblages
Approach. Ongoing monitoring programmes of the demersal fish assemblage revealed long-term changes in the species- and size-composition of the North Sea fish assemblage as well as in the productivity. Some of the observed changes, such as the decrease in large-sized predatory fish and the increase in smaller sized prey species, can be ascribed to the effects of fishing, whereas the increase in southern species can be directly related to a change in temperature. The decrease in the North Sea cod stock can be explained as a combined effect of overexploitation and climate change.
The Dutch coastal zone is an important nursery area for commercial fish species such as plaice and sole. As the population abundance of flatfish species appears to be determined by the availability of suitable nursery areas, changes in the quality or quantity of the nursery habitat is expected to have an effect on the overall productivity of the species. Habitat quality may be affected by the productivity of suitable benthic food, the abundance of inter- and intra-specific competitors and the occurrence of predators. Competitive and predatory interactions will change throughout the season because of the seasonal migration patterns and will be affected by temperature on all levels.
This research question will focus on a quantitative study of the relationship between benthic fish, their prey and their predators. The study will build on the results of earlier monitoring programmes on the seasonal dynamics in the abundance of the major benthic fish species.
Methodologies. The food consumption of the species will be estimated from the observed growth rate, literature estimates of the relationship between food intake and growth and the effect of temperature on this relationship. Feeding studies will be conducted to determine the seasonal variation in feeding rate and prey choice of those benthic fish species that dominate the assemblage. The feeding data will be used to allocate the consumption estimates over the different prey types. As size is the most important factor structuring inter-specific relationships, all the analysis will be size-structured. In order to quantify the predation mortality on benthic fish, we will use the stomach content data available for a large number of predatory fish from the ICES stomach sampling project, supplemented by stomach samples collected during the cause of this project.

Implementation. The study is aimed to provide the basis for a benthic module to be incorporated in ERSEM II (see question 1) and which allows the evaluation of the effect of climate change on benthic fish through the effect on benthic productivity (see question 6).

Question 6. Towards a reliable tool for spatial management of a changing North Sea
Approach. In a recent project on the possible creation of Marine Protected Areas in the Dutch part of the North Sea, the data on the distribution of benthic fauna, fishes, birds and marine mammals were combined in one GIS matrix, allowing the determination of areas with high biodiversity and biomass. This analysis indicated that, for example, the coastal zone, the Frisian Front and the Oystergrounds are areas of special interest. Present and historic sampling could provide information on density and spatial distribution of hundreds of individual species. The spatial distributions of these individual species do not arise in isolation, but are strongly dependent on biotic (other species) and abiotic variables (such as sediment composition, depth, bottom shear stress, etc.). Existing GIS techniques allow the spatial coupling of all static user functions to any of the geographical data or results. Also, a GIS-approach adds spatial information to the time series analyses and the study on population dynamics (questions 4 and 5). The first task will be to bring all the available information together in this GIS. Specifically, we will try to get a detailed spatial and temporal overview of different ecosystem features (plankton, benthic invertebrates, fishes, birds and marine mammals) in relationship to abiotic features and the intensities of the different user functions like fisheries, oil-, gas- and sand extraction, etc.. Emerging patterns appear to be governed by a complex combination of manageable (e.g. fisheries) and non-manageable (e.g. climate) drivers. Unravelling the interactions between the temporal and spatial dynamics of natural resources, their forcing functions, and their usage by an ever growing human population will form an important challenge. The recently developed Effect Modelling of Indicators, usaGe and MAnagement (EMIGMA) offers a method to integrate information on indicators, ecosystem driving forces, and management scenarios.
Methodologies. Through, among others, weighted kriging methods, more reliable inter- and extrapolations of sampling data will be achieved. The patterns will be analysed in relationship to environmental factors and the distribution of the different animal groups. Habitat suitability characteristics will be derived. Changing climate is an important forcing factor and therefore, climate information for the period of analysis, depending on the data availability for the biota, for the whole North Sea area and surrounding countries will be included. Also a GIS coupled to small impact models will be developed that allows assessment of effects of various human exploitation. Since the human exploitation of the North Sea is part of the analysis, altered human exploitation of the area is part of the GIS-related simulations, and will yield information on the effect of management measures on the functioning of those aspects of the ecosystem that are studied in the process studies. As a final result, an information system will be developed to aid in the management of the North Sea ecosystem.
Implementation. The environmental information management system (proposed name NSEIMS: North Sea Environmental Information Management System) will store, manage, and deliver descriptive information (metadata) for data sets, databases, documents, models, multimedia, projects, and spatial information and will be easily accessible by standard Web browsers. The user community will include environmental scientists, resource managers, and other stakeholders. One of the main goals will be to visualize interactions between user functions (e.g. fishery), ecosystem indicators and management options using the EMIGMA approach. Underlying data and available models that offer simulation/prediction capabilities are easily accessible either within the NSEIMS database structure or through links to other databases.

6 A. Output and/or Products (maximum 1 page):
Scientific output will consist of PhD theses and peer–reviewed papers in international scientific journals. The collected data will provide insight in relationships between key environmental variables and ecological indicators. These relationships will be used to verify a number of climate scenario's in order to envisage the impacts of future climate shifts on spatial patterns in benthic production and biodiversity. These scenario's will contribute to the development of necessary adaptive management strategies to reduce these impacts.
The following deliverables are foreseen (numbers in agreement with questions)
D1.1. Observational time series database of CO_2 and plankton distributions and CO_2 air/sea exchange fluxes
D1.2. Observational database of CO_2 datasets collected during dedicated cruises
D1.3. Integrated modeling of North Sea carbon cycle (ERSEM II) including air/sea CO_2 fluxes, estuarine exchanges, and exchanges with the Atlantic Ocean
D.1.4. Annual air/sea CO_2 flux estimates to be fed into project ME-2 for greenhouse budgets at national level in The Netherlands
D2.1 Database of satellite-based validated water quality maps (e.g. chlorophyll-a pigments, total suspended matter, coloured dissolved organic matter and vertical diffuse attenuation coefficient over PAR) that will cover the whole North Sea
D2.2 Methodology to analyze and convert the products from D2.1 to products related to the net CO_2 uptake in the North Sea, i.e. maps of photosynthetic available radiation and a primary productivity index.

D2.3 Definition of standardized indicators that will be suitable to track climate change.
D2.4 GIS containing all maps generated in Deliverables D2.1-D2.3. These maps will be made available to the public through the environmental information management system (see also D6.1-D6.3 for implementation).
D3.1 Database with high frequency records of relevant environmental variables, measured in a coastal and an off-shore station: temperature, fluorescence, vertical flux phytoplankton, sediment community respiration, turbidity, salinity, current regime.
D3.2 Database with records of condition, reproductive cycle and growth of selected adult macrozoobenthos, seasonality of pelagic and settling larvae abundance, and recruitment strength, measured in a coastal and an off-shore station.
D3.3 Overall synthesis paper relating environmental variables to reproduction, recruitment, larval growth and development.
D4.1 Paper on changes in the macrozoobenthic communities of the southern North Sea in relation to environmental factors.
D4.2 Paper on a multivariate stochastic time series analysis of macrozoobenthos abundance.
D4.3 Maps of past, present and future distribution of macrozoobenthos communities in the Southern North Sea.
D5.1. Paper on diet and food choice of dominant benthic fish species in relation to (changes in) benthic food chain.
D5.2. Paper on changes in the benthic fish community, especially with regard to the character of regime shifts in terms of foodweb-based mechanisms
D5.3. Benthic fish consumption and production estimates as input for benthic fish production module in the ERSEM model
D6.1. A set of spatial GISs filled with information on abiotic and biotic (including habitat suitability) parameters and the distribution of the user functions for the Dutch part of the North Sea for different time periods
D6.2 An Environmental Information management System, easily accessible for scientist, resource managers and other stakeholders
D6.3. Publications on the modelling techniques and outcomes that will be developed to be linked to the spatial and temporal GIS, to analyse the effect of climate change and changing user functions on the spatial distribution of the fauna

6 B. Milestones Knowledge Transfer and Dissemination (maximum 1 page):

Dissemination is ensured by the engagement of a panel of end-users (stake holders) that will meet at least two times in dedicated workshops during the life span of the project. The panel is composed of representatives from governmental organisations and NGO's. Stakeholder consultation will be held at the start op the project to ensure timely input on the spatial planning and adaptation issues in these organisations. Both governmental partners (national, local, regional water boards) and public partners will be invited. Several partners already expressed their interes, e.g. RIKZ (Dr. H. Baretta and Dr. J. Mulder, also PI of project A5), Directie Noordzee, Stichting De Noordzee (Dr. Groenewegen) and EUCC The Coastal Union (Dr. I. Lucius)
The datasets as in deliverables D1.1, D1.2 and D1.4 will routinely be forwarded to the international CO2 datacentre CDIAC (CO2 Data Integration and Analyses Centre, Oak Ridge).
The work related to question 2 is embedded in a European context. IVM is coordinating the REVAMP (Regional Validation of Meris Chlorophyll Products in North Sea Coastal Waters) FP5 project (2002-2005). REVAMP aims at supporting the monitoring of the eutrophication state of the North Sea by measuring and validating a key bio-geo-physical parameter (Chlorophyll or CHL concentration) using MERIS observations. The end product will be a North Sea atlas for the year 2003, containing CHL maps, accuracy products and Added Value Products (e.g. monthly mean values).
In the course of the project the EMIGMA system will be filled with data and trends of abiotic parameters and species abundance (benthos, birds, fish and sea mammals) in different sub-areas in the North Sea. These data will be made available to potential users like "Milieu en Natuur Planbureau", and relevant Departments of the ministries of LNV, V&W en VROM. Several participating Institutes are involved in National research programmes on North Sea related topics like Implementation of the Bird and Habitat Directives, Environmental Quality Objectives, Sustainable Fisheries, Effects of Windparks, and Marine Protected Areas. The progress and outcome of these projects will be communicated to this BSIK project and vice versa. At the end of the project, the Environmental Information Management System (NSEIMS) will be easily accessible by standard Web browsers.
Results are regularly presented at open scientific conferences as well as in workshops in BSIK context. Articles will be submitted for publication in peer-reviewed scientific journals. Findings of relevance for the public and policy-makers will be presented in custom-made format suitable for outreach to the target audience. An external web site dedicated to this project will be frequently updated with outstanding results and other scientific achievements.
Relevant datasets as well as interpretations will routinely be delivered to the IGBP-LOICZ international Core Project Office. Implications for society will be reported to wider audiences through the publications and outreach

activities of the IGBP-LOICZ project.

6 C. Milestones Translation into Application (maximum 1 page):

In conjunction with the approved EU FP 6 CARBOOCEAN Integrated Project we will provide further scientific support to international organisations and programs aiming at the assessment of carbon sources and sinks on global and regional scale. Additionally, we will provide information on the impact of elevated CO2 levels and other environmental changes on the functioning of phytoplankton species, and on the functioning of both plankton and benthic ecosystems. Our work is therefore at the heart of the new IGBP initiative program "Integrated Marine Biogeochemistry and Ecosystem Research" (IMBER). The IMBER program not only has strong emphasis on the role of biota in the marine carbon cycle and CO2 budgets, but also pays much attention to the impact of elevated CO2 levels on the functioning of the entire marine ecosystem. For further information on IMBER and downloading the IMBER Draft Science Plan pdf file see the following website of the IGBP (http://www.igbp.kva.se/cgi-bin/php/frameset.php).

Through the work of organisations as the IGBP our results will contribute to international conventions and agreements on reduction of carbon input to the atmosphere, as well as its transport and deposition/ other input to the sea. Among the most important conventions and agreements are the UN FCCC (the Kyoto agreement), the European marine conventions (OSPARCOM, HELCOM, MEDPOL), the EU directives and the ELOISE program, and various IGBP programs, particularly LOICZ and the IGBP/IHDP/WCRP co-sponsored program Global Carbon project (GCP).

By means of the recently developed Effect Modelling of Indicators, usaGe and MAnagement (EMIGMA) we will integrate information on indicators, ecosystem driving forces, and management scenarios. At the end of the project the results will be presented in an environmental information management system (proposed name NSEIMS: North Sea Environmental Information Management System). This system will be available on the Web and will be easily accessible by standard Web browsers. The user community will include environmental scientists, resource managers, and other stakeholders. One of the main goals will be to visualize interactions between user functions (e.g. fishery), ecosystem indicators and management options using the EMIGMA approach.

7 Consortium

7 A. What are the involved Core-partners (science, public, private)? Please, give name institute and name contactperson.

	Name	**Contact person**	**Science/ Public/ Private**
Coordinating Institute/ Partner 1	Royal NIOZ, Marine Ecology and Evolution	Dr. J. van der Meer	Science
Partner 2	Free University-IVM	Dr. J. van der Woerd	Science
Partner 3	Royal NIOZ, Marine Chemistry and Geology	Prof. Dr. H.J.W. de Baar	Science
Partner 4	Alterra	Dr. H.J. Lindeboom	Science
Partner 5	RIVO	Dr. J.J. de Leeuw	Science
Partner 6			Science
Partner 7			Science
Partner 8			Science
Partner 9			Science
Partner 10			Science
Partner 11			Science
Partner 12			Science
Partner 13			Science
Partner 14			Science
Partner 15			Science
Partner 16			Science

7 B. Which other organisations are involved in the project?

Privat Partners (enterprises, consultancy)

-

Public Partners (NGO's, interest groups)

-

Governmental Partners (national, local, regional, water boards)

-

7 C. What is the organisation/management structure and how is participation with non-consortium partners arranged?

The project will be coordinated by the Royal NIOZ (Dr. J. van der Meer). The six principal investigators responsible for the key questions will form a steering group that will maintain close contact and will annually evaluate the progress. Three of the PI's are from Royal NIOZ (for question 1 Prof. Dr. H.J.W. de Baar in cooperation with Dr H. Thomas, for question 3 Drs. G.C.A. Duineveld in cooperation with Drs. M. Bergman, and for question 4 Dr. J. van der Meer); one from Free University-IVM for question 2 (Dr. J. van der Woerd), one from RIVO for question 5 (Dr. J.J. de Leeuw, in cooperation with Prof. Dr. A.D. Rijnsdorp), and one from Alterra for question 6 (Dr. H.J. Lindeboom). Based on the current results and progress, the steering group will decide whether any adjustments in research plans are needed and what direction they should take. The main task of the steering group is the integration and synthesis of the work of all partners, during steering group meetings and in the write-up phase of the project.

The project will be reported annually on its development and results. An external web page, frequently updated with a project description, outstanding results and other scientific achievements, will be used for reporting.

8 A. Team-members Project Team who will carry out the research
(Please fill in TEAM_COST template)

8 B. Please attach CV or other documents of all involved researchers to illustrate scientific excellence.
(Please use CV template)

9. Time schedule, including delivery of products, responsibilities/tasks by partner

Start date 1/1/2005

End-date 30/06/2009

Product	**By Partner nr.**	**2004**		**2005**		**2006**		**2007**		**2008**		**2009**	
D1.1, D1.3, D1.4	3					x		x		x		x	
D1.2	3							x				x	
D2.1-D2.4	2											x	
D3.1	1						x				x		
D3.2-D3.3	1										x		
D4.1	1							x					
D4.2-D4.3	1											x	
D5.1-D5.2	5										x		
D5.3	5											x	
D6.1-D6.3	4											x	
Midterm/final review	all						X (mid)						

10 A. Knowledge: distribution and transfer (maximum 3 pages)

Knowledge will be distributed and transferred by making the relevant data available through the NIOZ data management system and international data centres. Results from scientific analyses will be disseminated through scientific publications, oral presentations at international scientific meeting, workshops, etc. An external web site dedicated to this project will be frequently updated with outstanding results and other scientific achievements.

The EMIGMA tool and Environmental Information Management System will be made available to relevant Dutch Governmental Organizations like MNP, LNV, V&W and VROM. Alterra and RIVO are involved in many management related projects in the North Sea and participate in several (inter)departmental Marine Management committees. The outcome of this project will be transferred through these connections.

(See also the answers on 6B and 6C).

10 B. Potential risks and solutions

Observations at sea always have the intrinsic risk of failure due to a variety of reasons (failing sensors, damage by fisheries, bad weather). However, Royal NIOZ has ample experience with these kinds of observations reducing the risk of a low data return. We therefore foresee that sufficient data will become available to achieve our objectives.

Furthermore, the participating institutes are involved in many other North Sea projects that produce relevant background information for this project. The tools and data from these other projects will be made available for this BSIK project, also reducing the potential risks.

11. What are the links and how are these capitalized upon (maximum 3 pages):

11 A. With other themes / projects within the Climate changes Spatial Planning programme?

Input from/output to:

Project nr	Project title	Details (description, timing, etc.)
CS1	North Atlantic Ocean Monitoring, by Dr. Ir. H. Ridderinkhof, NIOZ	Information on oceanic forcing (input from)
CS7	Tailoring climate information for impact assessment applications, by Dr. Ir. B.J.J.M. van den Hurk, KNMI	Information on climate scenario's and climatic forcing (input from)
ME2	Integrated observations and modelling of greenhouse gas budgets at the national level in The Netherlands, by Dr R. Hutjes, WUR	Information exchange on CO2 budgets (input from and output to)
A5	Spatial planning and coastal zones (FRICZ), by Dr. J.P. Mulder, RIKZ	Exchange of information on spatial planning tools and strategies(input from and output to)
A7	Adaptations to extreme events in transboundary river basins, by Dr. J. Aerts (VU) and Prof. Dr. Peter	Information on river discharge (input from)

	Troch (WUR)	

11 B. With other BSIK programmes (including so-called bridge-projects)?
We@Sea

11 C. With international programmes (e.g. FP6, etc)?
The work related to question 1 is fully integrated with the CarboOcean Integrated Project (2005-2009) of the EU FP 6, the CarboEurope Integrated Project (2004-2008) of the EU FP 6, and the EurOceans Network of Excellence for the functioning of pelagic ecosystems (2005-2009) of the EU FP 6
For the work related to question 2 regular scientific feedback is given by the key expert dr. G. Tilstone from Plymouth Marine Laboratory (PML) in the United Kingdom. PML is the UK Earth Observation Centre of Excellence for the study on Air-Sea Interactions and Fluxes (CASIX) (see also http://www.nerc.ac.uk/aboutus/researchcentres/sites-casix.shtml)
For the work related to questions 3 and 4 is closely related to the ICES 'North Sea Benthos 2000' Project and the MARBEF Network of Excellence for marine biodiversity (2005-2009) of the EU FP 6, and in particular the MARBEF programme "Pan-European gradients in marine settlement events" which is coordinated by Royal NIOZ
The work related to question 5 is embedded in many ICES programmes.

11 D. How is tuning and/or co-operation arranged?
The PI's of the other projects and programmes will be invited to the dedicated workshop that will be held at the start of the project in order to inititate protocols for data and infromation exchange. International cooperation will take place through invitation of guest scientists and, of course, through cooperation in international programmes mentioned above.

12. How is this project contributing to (maximum 2 pages):

12 A. New (Inter)national policies in relation to climate and spatial planning, sustainability and environment?
The project adheres directly to the Netherlands and EU policies with regards to dissemination of knowledge and CO2 management (e.g. Treaty of the European Union, Article 164 and 174 and various directives of the EU, e.g. 2002/358/EC and 2003/87/EC).
Through the development of an environmental information management system (proposed name NSEIMS: North Sea Environmental Information Management System), the project directly contributes to an integrated spatial policy of the Dutch sector of the North Sea, highly relevant in the light of plans for establishing marine reserves.
In the near future a Near Shore and an Offshore Windpark will be established, each with about 60 windmills. According to Dutch plans, before 2015 more than 1500 windmills will be build in the North Sea. The impact of these windmills and the best building sites will be studied in another BSIK project (we@sea). In this project the outcome of we@sea will be combined with the possible consequences of climate change on the North Sea ecology, especially in relationship with the fact that windparks act as refuge for benthos and fishes, but might have a disturbing effect upon birds.
Sand extraction for building and beach nourishment will increase in the near future and there are plans to allow sandmining, which is now limited to -2m below the sediment surface, to a depth of -20m. On the one hand this could create deep holes in the seafloor that may be vulnerable to anoxia, but on the other hand these holes could be attractive for fish communities. Temperature will have an influence on the physical features of such holes, and this project will deliver more information to determine the ecological possibilities and problems of future deep sandmining.
More important, around 2010, the Netherlands will have to establish Marine Protected Areas (MPAs) in relation with the EU-Bird and Habitat Directives or the OSPAR agreement. At this moment five areas have been identified in the Dutch part of the North Sea and managerial measures are being discussed. These five areas include the Doggerbank, the Klaverbank, The Coastal Zone, The Oystergrounds, and The Frisian Front. The first two are mainly determined by depth and sediment type and their boundaries are unlikely to change at shorter timescales. But the latter two are the result of short term physical processes like sedimentation and resuspension, which may be vulnerable to climate change. For example, after establishing an area with special drilling regulations at the Frisian Front, it was discovered that the typical feature for this area, namely a high benthic silt content, had shifted approximately 15 miles to the east. Also the deep silty centre of the Oystergrounds may be vulnerable to changes in windfields or storm frequencies.
For the establishment of boundaries for these MPAs it is important to be able to predict the possible impact of

climate change on both the physical features and the occurrence of benthos and fishes and their predators. This project will create a tool to predict possible impacts of climate change upon benthos and fishes in order to establish long lasting outer boundaries of the MPAs at the Frisian Front and Central Oystergrounds.
The Coastal Zone is even a more complex case. A recent study has shown that the most vulnerable area for birds lies within the NAP-20m depth contour. However, the most vulnerable area for fish lies within the –20m in relation to the mean low water spring contour. Especially in front of the coast of North- and South-Holland there is a considerable difference between the location of these depth contours, which could have a significant impact upon the qualification as Habitat or Bird Directive area. It is very likely that the distribution patterns of fish and birds will be impacted by climate change and in this project we intend to quantify this effect. Again this is important when establishing long lasting boundaries of the Coastal MPAs. The establishment of windparks, deep sandholes and MPAs will be accompanied by extensive monitoring programmes to determine trends in the development of the fauna. However, these trends are not only the result of the human activities but also of other variable drivers like climate change. To be able to interpret observed trends information on the effect of climate change in both the human impact area and the surrounding North Sea is indispensable. This project intends to provide that information.

12 B. Innovations?

The new EMIGMA tool will bring together information on the development of benthic and fish communities, the development of different user functions and the possible impact of climate change. By combining the spatial and temporal development of both ecological parameters, impacts of human uses and changes in temperature, currents, wind and fresh water input, insight into the possible effects of managerial measures will be obtained. In this project we will pay special attention to the impact of climate change upon the distribution of ecological features that are important for nature values and for human uses, especially fisheries. In the past, attention has been paid to the trends in numbers of specific species, but a direct combination with human uses has been lacking. The integral innovative approach in this project combines both the observed trends in species distribution with the natural and human induced drivers. Extrapolation of the past, in combination with new information on driving processes like recruitment and food availability, will gain insight into the possible future.

12 C. Economy?

The North Sea is one of the world's most productive fishing grounds and the establishment of MPAs or windparks will have an impact on the fishable area. On the other hand, it is well know that size and distribution of fish stocks and recruitment, also of benthic animals, are vulnerable to climate change. If the areas with rich stocks shift, this may have an impact on fisheries but also on the ecological parameters that are being protected within the MPAs.
To obtain an ecological and economical optimum for both marine nature preservation and fisheries it is important to predict possible shifts in habitats and stocks as a result of climate change. This project intends to develop tools to predict these shifts.
Also the support that this programme will give to interpret the outcome of monitoring programmes within and outside windparks and MPAs is important for the future development and planning of such areas.

13. Budget

13 A. Specification of total project budget (please fill in TEAM_COST-template)

13 B. Motivation of budget items (personnel, equipment, consumables, travel, fieldwork, other)

Personnel:
Permanently employed, senior research scientists are involved with
• planning and coordination of the North Sea cruises
• participation in international panels and working groups
• guidance of PostDoc's
• scientific data analysis
• reporting

Equipement and consumables:
Most materials are required for shipboard measuring devices (valves, current meter, sediment traps, frames) and chemical analyses (HPLC columns etc.). Small amount is needed for GIS hardware, PC's and software

Travel:
Travel costs are used for dissemination of results and partly for inviting guest scientists and organizing workshops

13 C. Specification of matching

Matching is obtained by
-input of permanent personnel in the programme (all partners)
-EC funding to a related project (VU-IVM)

-use of funding made available by NWO for matching of BSIK projects (NIOZ, VU-IVM)
-funding of shiptime (NIOZ)