

climate changes spatial planning

Adaptation

Climate related shifts in the NCP ecosystem, and consequences for future spatial planning

prof.dr. J. van der Meer
prof.dr. H.J. Lindeboom
and others

KvR 021/11

Climate related shifts in the NCP ecosystem, and consequences for future spatial planning

Authors

prof.dr. J. van der Meer[1], prof.dr. H.J. Lindeboom[2], dr. H.J. van der Woerd[3], dr. M.A. Eleveld[3], dr. A.J. Gilbert[3], dr. S.W.M. Peters[3], dr. L. Peperzak[3], G.C.A. Duineveld MSc.[1], M.J.N. Bergman[1], M.S.S Lavaleye MSc.[1], dr. R. Daan[1], A.S. Saraiva[1], ir. R. van Hal[2], dr. I.Y.M. Tulp[2], dr. J.A.M. Craeymeersch[2], dr. N. Daan[2], R. Labberton[2], F. Stuke[2], L.R.T. Teal[2], dr. A. D. Rijnsdorp[2], dr. R. Witbaard[1, 2], P. Ruardij[1], dr. H.W.G. Meesters[2], prof.dr.ir. H.J.W. de Baar[1, 4], prof.dr. H.A.J. Meijer[4], prof.dr. H. Thomas[1], prof. T. Johannesen[5], dr. H.J. Zemmelink[1], dr. A.M. Omar[5], dr. H.J. van der Strate[4], M. Klunder[1], L. Salt[1], I.T. van der Laan-Luijkx[4]

1 Royal Netherlands institute for Sea Research (NIOZ)
2 IMARES, Wageningen UR
3 Institute for Environmental Studies IVM-VU
4 University of Groningen
5 University of Bergen, Norway

NIOZ

IMARES WAGENINGEN UR

IVM Institute for Environmental Studies

KvR report number KvR 021/11
ISBN ISBN/EAN 978-90-8815-018-0

This project (A06 'Climate related shifts in the NCP ecosystem, and consequences for future spatial planning) was carried out in the framework of the Dutch National Research Programme Climate *changes* Spatial Planning.

Contents

Summary

1. Summary in Dutch

Een uitgebreide meetinspanning op de Noordzee, in combinatie met wiskundige en statistische modellering, laat zien dat de klimaatveranderingen in de vorm van een verandering in de overheersende windrichting, een toename van de windsnelheid, een toename van de zeewatertemperatuur, als wel als een toenemende CO_2 concentratie van de atmosfeer, niet alleen leidt tot een verandering van de samenstelling van het zeewater in de vorm van bijvoorbeeld opgelost anorganisch koolstof en zuurgraad, maar ook tot een, zei het beperkte, verlaging van de productiviteit van op en in de zeebodem levende filterende organismen, die op hun beurt het voedsel zijn van bodembewonende vissen.

2. Summary

An extensive measurement programme, in combination with coupled physical-biogeochemical modelling, ecosystem modelling and statistical time series analysis, was carried out on the North Sea . Results showed that climate change in the form of a change in the prevailing wind direction, an increase of wind speed, an increase of seawater temperatures, as well as increasing atmospheric CO_2 concentrations, not only changes basic seawater properties such as dissolved inorganic carbon and pH, but may also lead to somewhat lower productivity of filter-feeders, such as shellfish, at the seafloor.

3. Extended summary

The North Sea is one of the best studied shelf seas in the world, but hitherto ecosystem effects of climate change were not very well known. In view of the increasing spatial demands on the marine environment, such as wind farms or marine protected areas, knowledge gaps on the impact of climate change on the spatial structure of the North Sea ecosystem have to be bridged.

Climate scenarios predict a change in the prevailing wind direction and an increase of wind speed, as well as an increase of seawater temperatures. Increasing atmospheric CO_2 concentrations will change the basic seawater properties. These changes may lead to alterations in the food-web, in primary productivity, and via cascading effects also in other parts of the ecosystem. For example, secondary production of the benthic ecosystem and with that the exploitation of important North Sea fish resources may be drastically altered. No doubt that such changes, if they occur, will have direct societal implications.

In order to be able to better predict climate change impact, several approaches have been followed within the project. First of all relatively simple coupled physical-biogeochemical models of the water column allow simulation of system characteristics such as dissolved inorganic carbon, CO_2 partial pressure and pH. Second, more advanced ecosystem models like ERSEM that include benthic-pelagic coupling, allow predictions of, for example, benthic productivity. Yet, such ecosystem models do not yet describe changes at the species level. As ample data at the species level were available, a third approach used statistical models to relate temporal and spatial changes in population abundance or community characteristics such as biodiversity.

Such applied approaches require high resolution datasets on important parameters, such as near-bottom suspended matter, chlorophyll-a, and secondary production by benthic organisms, to enable a better insight into climate effects on the NCP ecosystem. The project therefore has put a lot of emphasis on historical and newly obtained data gathering, interpretation, and the building of observational databases. An existing database application has been extended to integrate and summarize time-series dealing with the marine environment and its forcing factors, including anthropogenic influences.
Extensive field measurements on CO_2 uptake and release have been obtained during several cruises and integrated in both physical-biogeochemical and ecosystem models. Two regions, one in the northern and one in the southern North Sea, have been comprehensively modelled. The northern region was a CO_2 sink, whereas the southern region appeared to be a CO_2 source. The models predicted a decrease in pH with about 0.2 units.

Basic to the productivity at sea is the production of plant material in the surface water layers. Up to date estimates of this primary production or even time series of productivity are unavailable. IVM developed and refined a state-of-the art algorithm to generate algal pigment maps from satellite remote sensing. They showed how this in combination with maps reflecting concentrations of suspended sediment (SPM), (coloured) dissolved organic mater (CDOM) together with satellite estimates of the solar photosynthetic active radiation (PAR) and Sea Surface Temperature can be used to estimate the phytoplankton growth in the North Sea.

Organic material produced in the surface layers sinks to the sea floor and forms the main food (energy) supply for benthic organisms which in their turn form the food source for commercial demersal fish such as plaice and sole. Productivity estimates derived from transplantation experiments of mussels, created by the NIOZ, showed distinct spatial differences which are in line with model estimates made in ERSEM. In situ monitoring with NIOZ landers at two contrasting sites (off shore stratified and well mixed coastal) generated the insight that in the deep summer stratified Oyster Grounds repeated fluorescence peaks near the bottom occur in June and in mid-July long after the spring bloom. These seem to be related to wind events temporarily disturbing the stratification. In the coastal zone wind has a large impact on mixing and resuspension of bottom material. Therefore, alterations in wind based mixing as a result of climate change could potentially have large consequences for the productivity of the ecosystem, which so far have not been estimated

Statistical analyses of existing data sets on macrofauna (BIOMON) showed that there was no trendwise change in univariate community parameters such as diversity or number of individuals. For most species an apparent trend in overall abundance was also lacking. Predictions based on non-linear time-series analysis of an almost 30-year time series (1969-1998) could not be validated by observations over the last decade. This sheds some doubt on the use of statistical non-mechanistic models. Yet, multivariate analyses suggested that the various communities undergo simultaneous change. Regarding the vastness of the area and the different ecological communities a climate control seems the most likely forcing factor. Apart from the observed relationship with the NAO index, winter temperature seems to be an important factor in explaining these inter-annual variations.

Stomach analyses was performed to decipher to what extent the above changes led to substantial alterations in the species- and size-composition of the fish assemblage and its productivity. This showed that the demersal fish community has a large overlap in their choice of benthic food resources. At the same time the diet studies showed that the new invasive *Ensis directus* became an important prey species for a wide variety of fish and bird species in the coastal zone. This implies that the increase in *E. directus* must have caused a huge change in the food relations in the entire food web of the coastal ecosystem

The northward shift and population increase of solenette and scaldfish is attributed to a temperature mediated increase in habitat quality. Like the invasion of *Ensis* the increase and range expansion of these two flatfish species have affected the North Sea food web, especially when seen in the light of the overlap in choice of prey items. Analyses of the trophic interactions between the small bodied, non-commercial, solenette and scaldfish and the commercially exploited plaice, dab and sole suggests that the decrease in growth rate is linked to decreasing benthic productivity.

The more direct effect of increasing winter temperatures has led to a significantly increased growing period of sole, but not of plaice Comparison of experimentally derived and in-situ growth rates suggests that the habitat quality of our coastal areas is deteriorating for plaice owing to the increased temperatures in summer.

The various datasets which have been collected and collated have been inserted into the management database system developed by IMARES. Part of the data sets have been used to validate and calibrate the existing ecosystem model ERSEM. This resulted in model estimates of benthic filter-feeder distributions which are close to those measured at sea. To estimate the consequences of climate change for the North Sea ecosystem, the ERSEM model was run with altered weather forcing i.e. a two degrees temperature increase, 10% wind increase and increasing CO_2 levels. Compared with the present day ecosystem performance based on ambient conditions the updated and extended ERSEM model, showed that effects of increasing winds and air temperatures lead to somewhat lower secondary production at the seafloor.

4. Uptake of CO_2 by the North Sea in interaction with plankton blooms

Prof.dr.ir. H.J.W. de Baar, Prof.dr. H.A.J. Meijer, Prof.dr. H. Thomas, Prof. T. Johannesen, Dr. H.J. Zemmelink, Dr. A.M. Omar, P. Ruardij, M. Klunder, I.T. van der Laan-Luijkx, L. Salt
Royal Netherlands institute for Sea Research (NIOZ)

4.1 Objectives

The overall aim is to quantify changes in CO_2 uptake by the North Sea via plankton blooms by means of field measurements, and quantify the role of climate change by ecosystem modelling. This research program on the North Sea carbon cycle is in the fortunate situation to rely on a previously collected comprehensive carbon and nutrient data set obtained by the NIOZ [Thomas et al., 2005].

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 pCO_2 and occupying each time 97 stations for sampling the complete water column for the CO_2 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.

4.2 Deliverables

The work package has produced the following deliverables:

- 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 modelling of North Sea carbon cycle including air/sea CO_2 fluxes, estuarine exchanges, and exchanges with the Atlantic Ocean.
- D1.4 Annual air/sea CO_2 flux estimates to be fed into project ME-2 for greenhouse budgets at national level in The Netherlands.

4.3 General Methodology

From this advanced knowledge of previous 2001-2002 cruises we designed a program comprising of repeat observations along a North-South section in the North Sea. A further two basin wide cruises in the summers of 2005 and 2008 were conducted. All data integrated simulation modelling of the carbon cycle of the North Sea, and time series observations of atmospheric CO_2 at a fixed position, resulting in a suite of estimates of the air/sea CO_2 gas exchange rate.
Complementary to the subsidy of the 'Klimaat voor Ruimte' program, there has been significant and necessary support from other sources as follows:

- the EU CARBOCEAN Integrated Project (www.carbocean.org) with subsidy support to Royal NIOZ and to University of Groningen;
- the grant entitled 'CO_2 Buffering Capacity of the North Sea' (ALW/NWO project number 817.01.004);
- the company SeaTrans AS for availability of the commercial vessel Transcarrier as a Voluntary Observing Ship platform;
- the NAM and afterwards GdF Suez for allowing access and supporting time series observations at the F3 platform in the central North Sea.

4.4 General Results

Observational time series database

The research on the carbon cycle and CO_2 dynamics of the North Sea benefits greatly from a suite of four basin wide cruises. Cruises were conducted in all four seasons in academic year 2001-2002, with an additional summer cruise in 2005. All five cruises were aboard RV Pelagia of Royal NIOZ. In all four seasons it was found that there is a strong North-South transition in the entire North Sea coinciding with the transition at the Frisian Front from shallow waters (<50 m depth) in the southern part of the North Sea to deeper waters in the northern North Sea. This distinct transition at the Frisian Front is also comprised in the Netherlands Continental Platform (NCP) jurisdictional part of the North Sea.

The strong North-South trends led us to design a long term multi-year observational program through all seasons along the North-South transect from Bergen (Norway) to IJmuiden (The Netherlands) in a collaborative program between the universities of Bergen (Norway) and Groningen and the Royal NIOZ, with additional subsidy support in context of the EU Integrated project CARBOOCEAN (2005-2009). During several years data was collected of pCO_2 in sea surface and air by a Voluntary Observing Ship (VOS) the TransCarrier sailing between Bergen (Norway) and IJmuiden (The Netherlands). At the start of the project the TransCarrier had a weekly track with triangular shape from Bergen to IJmuiden to Immingham (England), and returning to Bergen. However sometimes the track was changed and as a result the most continuous long term set of observations is in the North-South direction from Bergen to IJmuiden and back again.

Towards the first interpretation [Omar et al., 2010] of the first three years 2005-2007 this Bergen-IJmuiden transect database of TransCarrier has been combined with data of an East-West VOS line aboard the Nuka Arctica of Royal Arctic Lines with the scientific program of pCO_2 and ancillary measurements by A. Olsen of the University of Bergen. Moreover the pCO_2 and ancillary data of the above mentioned five Pelagia cruises were included, as well as pCO_2 data calculated from some 'ancient' NIOZ cruises in 1987 aboard the vessels Aurelia and Holland.
By normalization of the pCO_2 as function of the atmospheric pCO_2 in anyone given year, a composite of the pCO_2 trends during every month of the annual cycle was constructed. From this one clearly observes a strong pCO_2 minimum in the spring time due to intensive CO_2 uptake by photosynthesis of phytoplankton. Budget assessments of this biological CO_2 sink term are consistent with the abundance of phytoplankton biomass derived from SEAWIFS satellite observations of Chlorophyll colour of the sea surface.
Alternatively when looking at the increasing trend of pCO_2 over the years, here also including some very 'ancient' data of 1970, one finds that the pCO_2 in surface waters of the northern North Sea increases with 61+33 10^{-6} atm over 40 years, more or less tracking the atmospheric CO_2 increase (~1.6 10^{-6} atm/yr observed at Mauna Loa) in agreement with our recently published community estimate of pCO_2 growth rate in North Atlantic surface waters [Takahashi et al., 2009]. This emphasizes that waters originating of the North Atlantic are compatible with the northern North Sea [Thomas et al., 2007]. However this consistency with open Atlantic Ocean trends should not be extrapolated to the shallow southern North Sea where the Alkalinity effect [Thomas et al., 2009a,b] due to interaction with sediments also of the WaddenSea, and eutrophication, tend to cause perturbations.

Observational database of CO_2 datasets collected during cruises

The very large and comprehensive database collected during cruise 64PE294 aboard PELAGIA from 19 August to 11 September 2008 is completed and stored at the central Data Management Group (DMG) of NIOZ. This latest basin wide North Sea dataset continues from previously collected datasets of a similar size in the summer of 2001 and the summer of 2005, as well as the similar datasets for three other seasons autumn, winter and spring in 2001-2002. When comparing the consecutive summers of 2001, 2005 and 2008 in Fig. 4.1 one notices differences between years but also the distinct North-South gradients. When comparing the corresponding pH values in surface waters over these same years, there is an observed decrease of pH in the 2001-2005-2008 intervals. This is consistent with but stronger than the predicted world ocean trend of increasing ocean acidification due to uptake of anthropogenic CO_2 in seawater. The larger pH decrease of 0.06 unit between 2005 and 2008 as compared with 0.01 unit between 2001 and 2005 is in the expected direction because the increasing CO_2 content is known to cause a decreasing general buffer capacity of seawater. Otherwise the pH trend is stronger than predicted for the open oceans, where the more intense dynamics of biological production and decomposition in coastal seas [Thomas et al., 2005], as well as interactions with estuaries and underlying sediments also play a role.

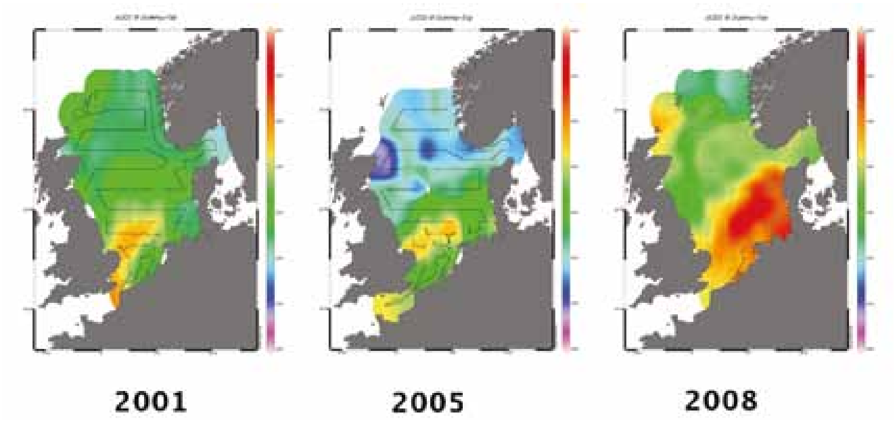

Figure 4.1 Summer values of delta-pCO_2 in surface waters of the North Sea in years 2001, 2005 and 2008.

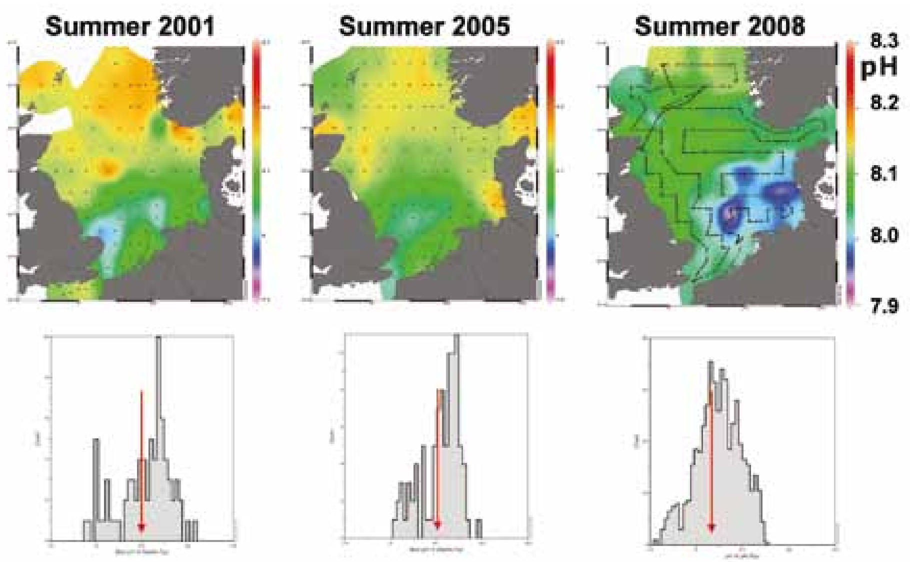

Figure 4.2 Summer values of pH in surface waters during consecutive summer cruises in 2001, 2005 and 2008. The lower graphs show the ranges of pH values for these same years. The average values of pH are indicated by the red arrows, with a decreasing trend of 0.01 pH unit between 2001 and 2005 and 0.06 pH unit between 2005 and 2008. Given the wide range of pH values in every of the three years, the average decreasing trend is of only modest significance thus far.

The latest summer cruise in 2008 was an improvement over the previous cruises in the sense that all four measurable parameters pCO_2, DIC, pH and Alkalinity of the CO_2 system in seawater were measured directly. Given the fact that in natural oceanic waters one needs to measure only two distinct parameters and then can calculate the others, one is able to verify internal consistency of the dataset. For example from measured DIC and Alkalinity one may calculate the pCO_2 value and compare this with the actual measured pCO_2 value. Having done such systematic intercomparisons of internal consistency Lesley Salt found some intriguing trends. Briefly in the central northern North Sea there is excellent internal consistency between all 4 parameters. Quite remarkably when approaching either Britain to the west or Wadden Sea and Kattegat to the east, deviations become apparent. This may partly be due to the Alkalinity effect emanating from shallow sediments [Thomas et al., 2009a,b]. Alternatively or complementary the Dissolved Organic Carbon moieties in near shore waters may also interfere with the inorganic CO_2 system, notably the determination of the measured Alkalinity values. Finally river inflows with variable compositions of dissolved salt content of the river water, may interfere with the general law of constant proportionality of sea salt in the oceans. In other words deviations of this Law of Dittmar in coastal waters may affect the calculations of the CO_2 system variables which rely on the measured salinity of the seawater sample as one of the input variables. The findings of the summer 2008 cruise have been worked out into three different draft manuscripts by Lesley Salt in context of the preparation of her PhD thesis.

Integrated modelling of North Sea carbon cycle

The datasets as mentioned above have been utilized as reference framework for basin wide computer simulation modelling of the carbon cycle within the North Sea [Prowe et al., 2009]. The modelling integrates the key physical, chemical and biological processes and interactions in the water column extending from the shallow ~50m vertically well-mixed deep southern North Sea and the deeper vertically layered northern North Sea. The mechanisms driving the air–sea exchange of carbon dioxide (CO_2) in the North Sea are investigated using the three-dimensional coupled physical–biogeochemical model. We validate our simulations using field data and identify the controls of the air–sea CO_2 flux for two locations representative for the North Sea's biogeochemical provinces. In the seasonally stratified northern region, net CO_2 uptake is high (2.06 mol m^{-2} a^{-1}) due to high net community production (NCP) in the surface water. Overflow production releasing semi-labile dissolved organic carbon needs to be considered for a realistic simulation of the low dissolved inorganic carbon (DIC) concentrations observed during summer. This biologically driven carbon drawdown outcompetes the temperature-driven rise in CO_2 partial pressure (pCO_2) during the productive season. In contrast, the permanently mixed southern region is a weak net CO_2 source (0.78 mol m^{-2} a^{-1}). NCP is generally low except for the spring bloom because remineralisation parallels primary production. Here, the pCO_2 appears to be controlled by temperature.

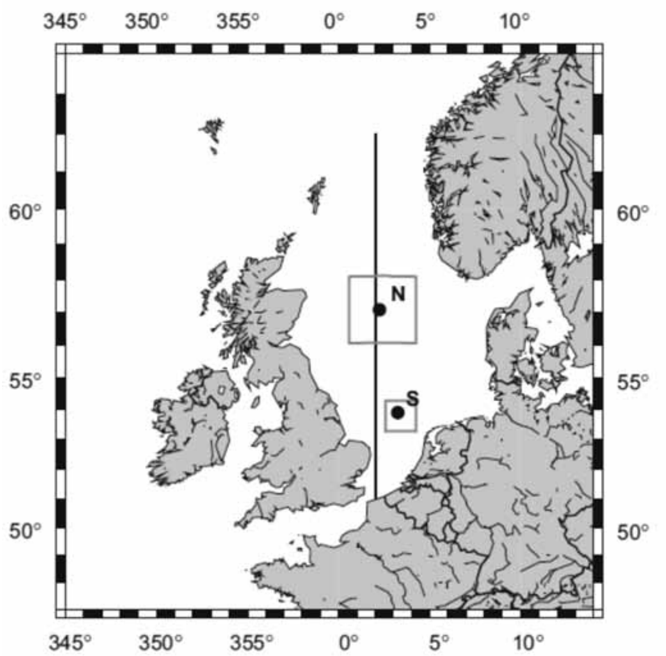

Figure 4.3 Chart of the model domain including the North Sea. Within the model [Prowe et al., 2009] the section along 20E is used to illustrate the strong north-south trends largely coinciding with the transition from deep northern North Sea to shallow southern North Sea. The regions N and S are used as representative examples of these two regimes in the below Fig. 4.4.

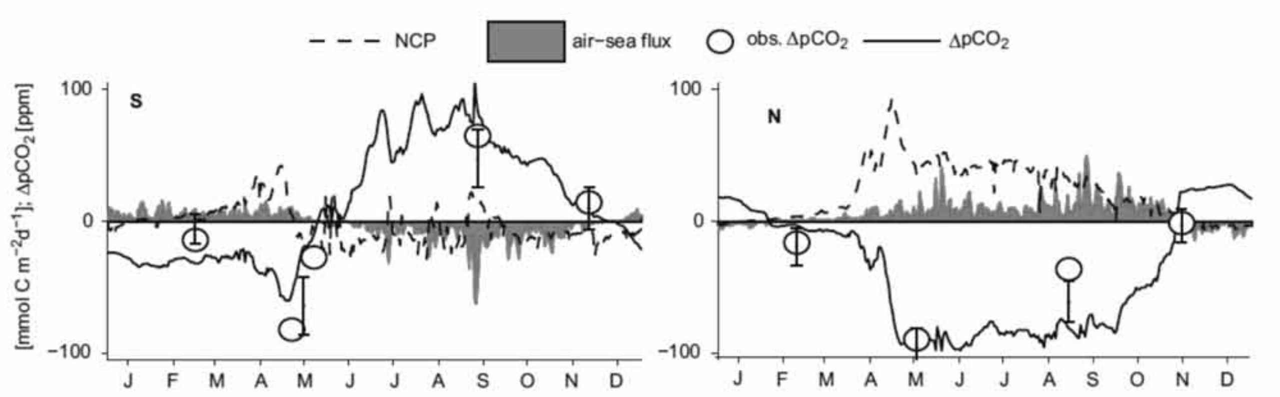

Figure 4.4 The annual cycle of model-derived air-sea flux of CO_2 based on model-derived delta pCO_2 and Net Community Production (NCP). Also shown is the observed delta pCO_2 throughout the seasons of the year. Left graph is for southern region S in above Fig. 4.3 in the shallow southern North Sea which is vertically mixed throughout almost the whole year. Right graph is for the northern region in the above Fig. 4.3 in the deep northern North Sea where in large part of spring-summer-autumn there is strong vertical stratification of surface waters well distinct from deep waters.

Modelling Climate Change: doubling of the pCO_2 concentration in the atmosphere.

The ERSEM-model is applied to forecast the effect of doubling the pCO_2 concentration of the atmosphere on the pH of the North-Sea ecosystem.

For the possibility to apply the GETM-ERSEM to model changes with respect to the dynamics of dissolved inorganic carbon (DIC) the following additions are implemented:

- Routine which describes the DIC-speciation (CO_2, HCO_3^-, CO_3^{2-}) as controlled by Alkalinity, salinity, temperature, nutrients and pH. This routine is public-domain available.
- Separate Routines for the pelagic and benthic systems which describe processes which modify alkalinity such as nitrification, de-nitrification and anaerobic mineralization, re-oxidation of anoxic constituents (e.g. sulphide).
- Separate routines for the pelagic and benthic system which describe processes which modify the DIC-dynamics such as light induced primary production, oxic respiration, chemical induced primary production (nitrification) and anoxic respiration.

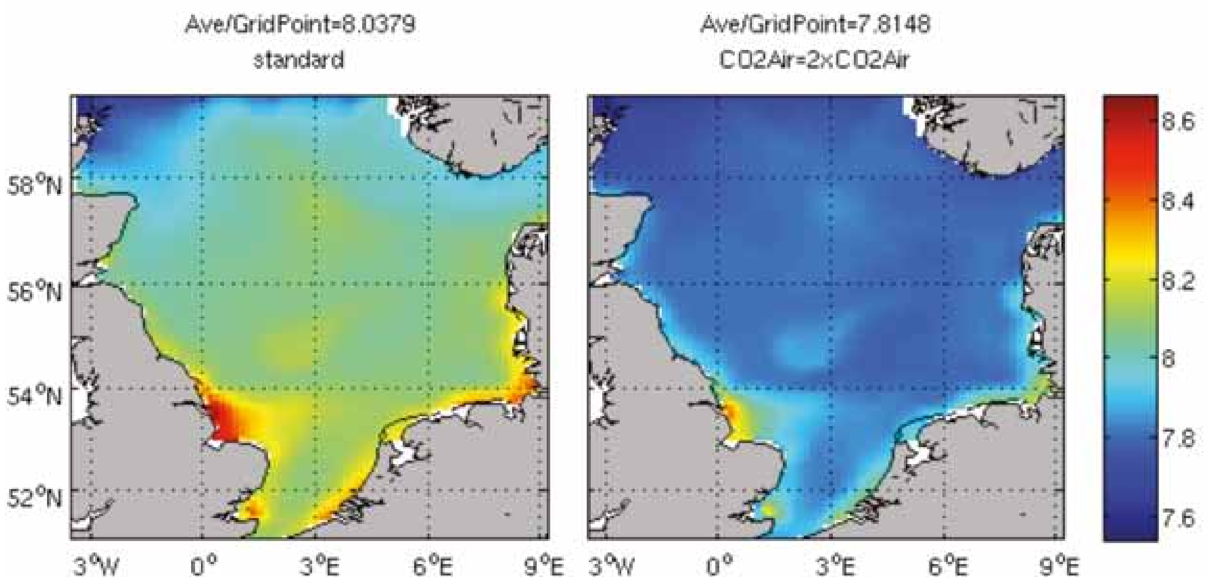

Figure 4.5 A comparison of yearly average pH for the standard run (left panel) and a run with increased pCO_2 (right panel).

A two-year run was made to check the consequences of a change of CO_2 in the atmosphere. In this run only this forcing is changed. It is assumed that a higher CO_2 concentration in the water has no direct effect on the primary production. This assumption is based on the fact that the most limiting process in a cell is the transfer of inorganic carbon to organic carbon. The uptake capacity of a cell to take up CO_2 and/or HCO3- by the prevailing pH's is such that it will not be a controlling factor for the primary production.

If we look to the whole North Sea and to the average pH averaged over the whole year we see a difference of maximally of 0.2 on the pH-scale (Fig. 4.5).

Annual air/sea CO_2 flux estimates

This objective and deliverable has been addressed in several ways. Firstly for all the basin wide cruises in four seasons of 2001-2002 and summers of 2005 and 2008 (Fig. 4.6) large datasets of air/sea CO_2 gas exchange fluxes have been produced. Along the cruise track (Fig. 4.6, right hand graph) there were semi-continuous measurements of pCO_2 in surface waters plus ancillary data (S, T, wind velocity). With the addition of atmospheric pCO_2 values (taken once every two hours) this provides approximately 20,000 data points of delta pCO_2. In combination with the air-sea gas exchange coefficient as function of the measured wind velocity this yields about 20,000 estimates of air/sea CO_2 gas exchange rates. Similarly datasets of about 20,000 values of air/sea gas exchange rates are available for the previous five cruises in four seasons of 2001-2002 and summer 2005.

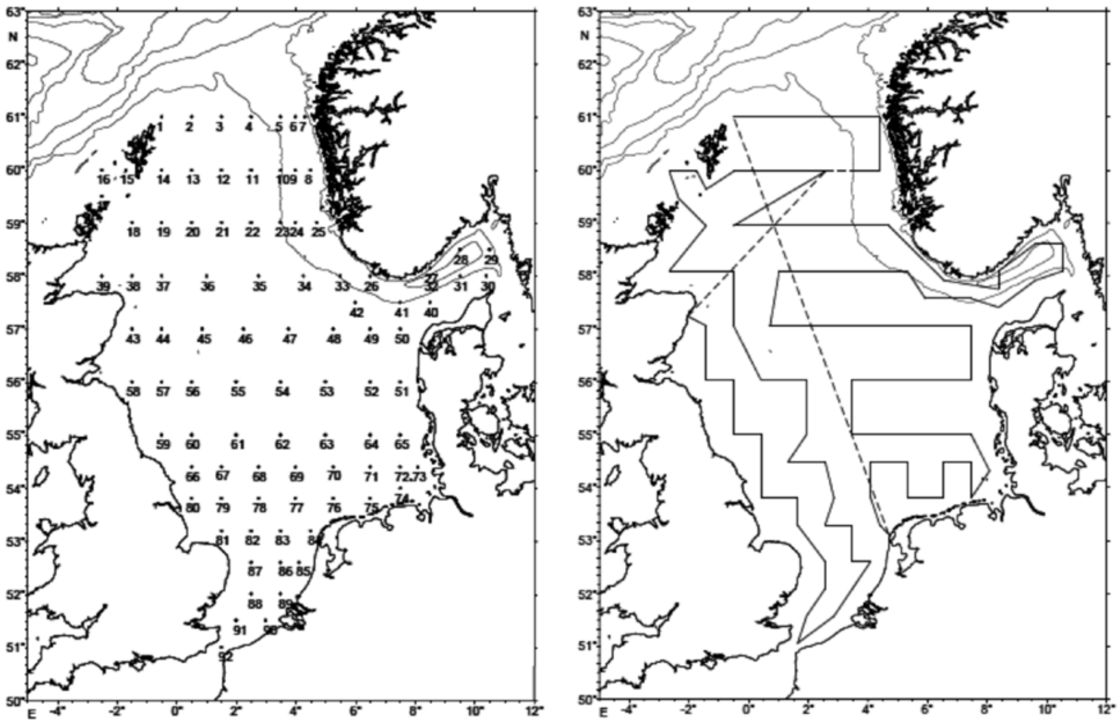

Figure 4.6 Left is station grid of the summer 2008 cruise, identical to station grids of the preceding cruises in 2001-2002 and 2005. At each station all four variables pCO_2, DIC, Alkalinity and pH were determined at 12 depths. Right is the cruise track from station to station in 2008, underway there was semi-continuous measurements of pCO_2 in surface waters plus ancillary data (S, T, wind velocity). In combination with once every two hours pCO_2 values in the air provides an overall about 20,000 data points of delta pCO_2. In combination with the air-sea gas exchange coefficient as function of wind velocity this yields about 20,000 estimates of air/sea CO_2 gas exchange rates. Similarly datasets of about 20,000 values of air/sea gas exchange rates are available for the previous five cruises in four seasons of 2001-2002 and summer 2005.

Secondly we obtained atmospheric time series observations at the F3 Platform [Luijkx et al., 2009; Van der Laan-Luijkx, 2010]. This atmospheric measurement site F3 (Fig. 4.7) is situated (54°51'N, 4° 44'E) in the central North Sea, close to cruise station 63 (Fig. 4.6 left graph). The closest land (the Netherlands) is located 200 km away from the measurement station. It is therefore an ideal location for measuring atmospheric background concentrations and studying air-sea interaction of CO_2 and partitioning of CO_2 emissions between the land biosphere and oceans. The data from this measurement station are a valuable contribution to the existing European data sets of atmospheric O_2 and CO_2, since only few atmospheric measurements stations which can record continuously exist. Moreover, this station is the first sea based atmospheric measurement station with on-site continuous recording of O_2 and CO_2.
The F3-FB-1 (short: F3) platform produces both oil and gas. Until 2008 it was owned by the Dutch oil company NAM and after that it was transferred to GdF Suez. The platform consists of two parts connected by a bridge. One part is the production platform, the other is the accommodation platform. The positioning of the production platform was intentionally north of the accommodation platform, for safety purposes.

Figure 4.7 The F3 platform (left graph) consisting of the larger actual production platform and the smaller accommodation platform, and its location (right graph) in the central North Sea.

As the prevailing wind direction is south-west, potential leakages or fires are blown away from the accommodation platform. The ideal situation for atmospheric measurements is therefore on the south-west corner of the accommodation platform. This is where the air-inlet of the measurement system is situated. The air inlet is on the topmost deck, approximately 50 meters above sea level.

Next to the atmospheric pCO_2 values, the additional data of atmospheric O_2/N_2 ratio values and trends does provide fundamental constraints to discriminate the CO_2 exchange between the air and on the one hand the sea and on the other hand the land [Van der Laan-Luijkx, 2010]. The continuous measurements for delta O_2/N_2 and CO_2 were started at the end of August 2008. Flask samples were collected on a weekly basis, generally during well-mixed atmospheric conditions and preferred wind direction, i.e. between south and west. Fig. 4.8 shows the combined first data from the F3 platform for continuous and flask measurements between August 2008 and June 2009. Although the measurements do not yet cover an entire year, the amplitude of the seasonal cycle can be estimated. In this section only the peak-trough difference will be discussed, defined as amplitude hereafter. The seasonal amplitude for CO_2 is about 16 ppm. For delta O_2/N_2 a single harmonic fit of the data yields an amplitude of about 110 per meg. When looking at the data however, this is likely to be too small, and an estimate by the eye would produce about 150 per meg. For CO_2 the seasonal amplitude compares well to the marine boundary layer reference from the same latitude from the GLOBALVIEW-CO_2 (2008) database with an amplitude of 15 ppm. Both O_2 and CO_2 amplitudes can be compared to the observations at other stations at similar latitudes. For station Lutjewad (53°24'N, 6°21'E) in the Netherlands the seasonal amplitude of CO_2 is 14 ppm. This value is based on continuous measurements. For both Lutjewad and Mace Head, Ireland (53°20'N, 9°54'W), flask data showed a seasonal amplitude of 153 and 102 per meg for delta O_2/N_2 and 16 and 14 ppm for CO_2 respectively.

Finally, in the simulation model by [Prowe et al., 2009] as illustrated in the above Fig. 4.4 we estimated the annual cycle of the air/sea CO_2 gas exchange in the North Sea. As shown the validity of the modelling simulation derived delta pCO_2 is verified versus the observed delta pCO_2 in the cruises.

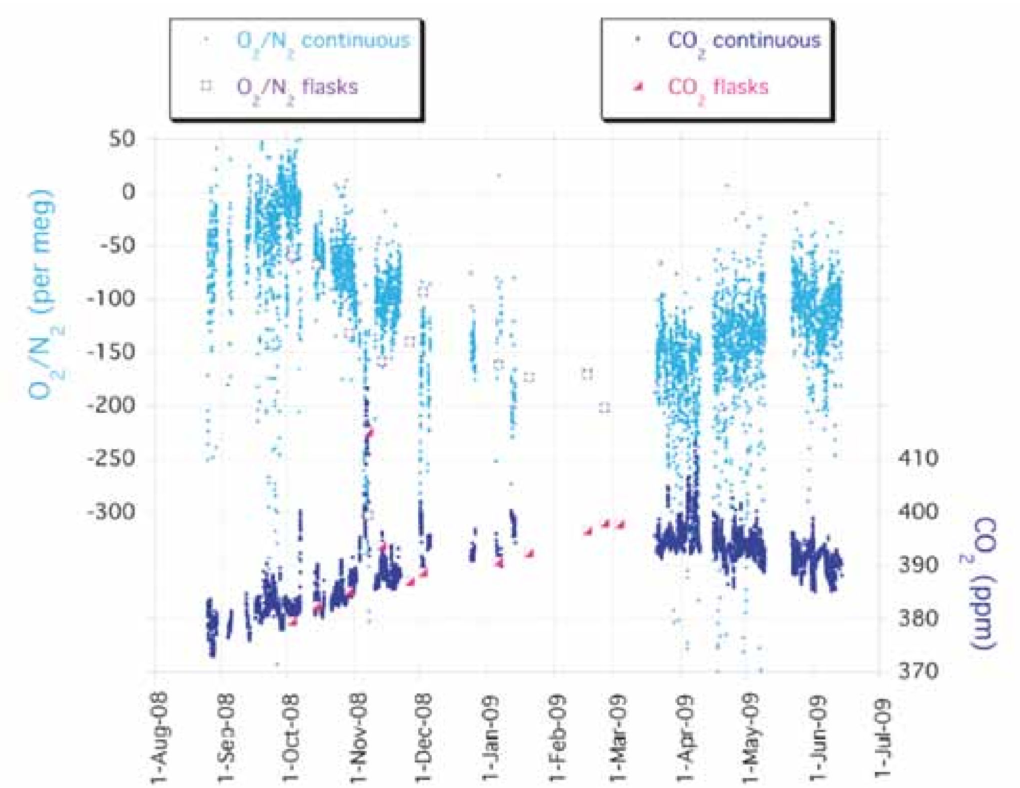

Figure 4.8 Observations at the F3 platform for the period August 2008 through June 2009. The continuous measurements of delta O_2/N_2 (small light circles) and CO_2 (small dark squares) were performed with the Oxzilla/CarboCap setup as described by [Van der Laan-Luijkx 2010]. The data points are half-hourly averages and include all measurements. Also shown are measurements of flask samples (open symbols). Both y-axes have been adjusted so that their ranges are nearly the same on a molar basis. Although the measurements do not yet cover an entire year, the amplitude of the seasonal cycle of delta O_2/N_2 can be estimated. The seasonal amplitudes are about 150 per meg for delta O_2/N_2 and 16 ppm for CO_2.

In summary there is the combination of three distinct approaches to assess air/sea gas exchange of CO_2 in the North Sea:

(i) large datasets of gas exchange rates obtained from shipboard measurements of delta pCO_2 and wind velocity in the context of thus far six basinwide cruises;
(ii) annual cycle dataset of atmospheric CO_2 and delta O_2/N_2 at F3 platform from which the CO_2 exchange between air and sea or land respectively, is assessed;
(iii) integrated simulation modelling of the carbon cycle in the North Sea including estimates of the air/sea exchange rate in the seasons.

4.5 Publications and other products

Bozec Y., H. Thomas, L.-S. Schiettecatte, A.V. Borges, K. Elkalay & H.J.W. de Baar 2006. Assessment of the processes controlling the seasonal variations of dissolved inorganic carbon in the North Sea. Limnol. Oceanogr., 51:2746–2762.

Iglesias-Rodriguez M.D., E.T. Buitenhuis, J.A. Raven, O. Schofield, A.J. Poulton, S. Gibbs, P.R. Halloran & H.J.W. de Baar . Response to Comment on "Phytoplankton Calcification in a High-CO_2 World". Science 322.

Laan-Luijkx I.T. van der 2010. Atmospheric oxygen and the global carbon cycle. Observations from the new F3 North Sea platform monitoring station and 6 additional locations in Europe and Siberia. PhD thesis, University of Groningen, 154p. (promotores profs. H. Meijer and H. de Baar).

Luijkx I.T., N. Neubert, S. van der Laan & H. Meijer 2009. Continuous measurements of atmospheric oxygen and carbon dioxide on a North Sea gas platform Atmos. Meas. Tech. Discuss 2:1693-1724.

Omar A.M., A. Olsen, T. Johannessen, M. Hoppema, H. Thomas & A.V. Borges 2010. Spatio temporal variations of CO_2 in the North Sea. Ocean Science 6:77-89.

Prowe A.E.F., Helmuth Thomas, Johannes Pätsch, Wilfried Kühn, Yann Bozec, Laure-Sophie Schiettecatte, Alberto V. Borges & Hein J.W. de Baar 2009. Mechanisms controlling the air–sea CO_2 flux in the North Sea. Continental Shelf Research 29:1801-1808.

Schiettecatte L-S, H. Thomas, Y. Bozec & A.V. Borges 2007. High temporal coverage of carbon dioxide measurements in the Southern Bight of the North Sea Marine Chemistry 106:161-173.

Takahashi T., S.C. Sutherland, R. Wanninkhof, C. Sweeney, R.A. Feely, D.W. Chipman, B. Hales, G. Friederich, F. Chavez, C. Sabine, A. Watson, D.C.E. Bakker, U. Schuster, N. Metzl H. Yoshikawa-Inoue, M. Ishii, T. Midorikawa, Y. Nojiri, A. Kortzinger, T. Steinhoff, M. Hoppema, J. Olafsson, T.S. Arnarson, B. Tilbrook, T. Johannessen, A. Olsen, R. Bellerby, C.S. Wong, B. Delille, N.R. Bates & H.J.W. de Baar 2009. Climatological mean and decadal change in surface ocean pCO_2, and net sea–air CO_2 flux over the global oceans. Deep-Sea Research II, 56:554-577.

Thomas H., Y. Bozec, H.J.W. de Baar, K. Elkalay, M. Frankignoulle, L.-S. Schiettecatte & A.V. Borges 2005. The Carbon budget of the North Sea. Biogeosciences 2:82-96.

Thomas H., F. Prowe, S. van Heuven, Y. Bozec, H.J.W. de Baar, L.S. Schiettecatte, K. Suykens, M. Koné, A.V. Borges, I.D. Lima & S.C. Doney 2007. Rapid decline of the CO_2 buffering capacity in the North Sea and implications for the North Atlantic Ocean, Global Biogeochemical Cycles, 21, GB4001, doi:10.1029/2006GB002825, 2007.

Thomas H., F. Prowe, I.D. Lima, S.C. Doney, R. Wanninkhof, R.J. Greatbatch, U. Schuster & A. Corbière 2008. Changes in the North Atlantic Oscillation influence CO_2 uptake in the North Atlantic over the past 2 decades Global Biogeochemical Cycles 113 GB4027.

Thomas H., L.-S. Schiettecatte, K. Suykens, Y.J.M. Koné, E.H. Shadwick, A.E.F. Prowe, Y. Bozec, H.J.W. de Baar, & A.V. Borges 2009a. Enhanced ocean carbon storage from anaerobic alkalinity generation in coastal sediments. Biogeosciences 6:267–274.

Thomas H., Y. Bozec, H. Lenhart, A. Moll, J. Pätsch, H.J.W. de Baar, K. Elkalay, L.-S. Schiettecatte, M. Frankignoulle & A.V. Borges 2009b. Carbon and nutrient budgets of the North Sea. In: Liu, K-K; Atkinson, L; Quiones, R and Talaue-McManus, L (eds.): Carbon and Nutrient Fluxes in Continental Margins: A Global Synthesis, Springer, New York.

Zemmelink H.J., H.A. Slagter, C. van Slooten, J. Snoek, B. Heusinkveld, J. Elbers, N.J. Bink, W. Klaassen, C.J.M. Philippart & H.J.W. de Baar 2009. Primary production and eddy correlation measurements of CO_2 exchange over an intertidal estuary. Geophys. Res. Lett., 36, L19606, doi:10.1029/2009GL039285, 2009.

Outreach beyond the scientific community:

Baar H.J.W. de 2008. Ocean Acidification. Meteorological Information Bulletin Maritime (for voluntary meteorological observation ships and platforms), KNMI (Royal Netherlands Meteorological Institute), 21(78):16-20.

Santen H. van 2007. De Zure Zee; door uitstoot van CO_2 wordt de zee zuurder en lost kalk op. NRC Handelsblad, Wetenschapsbijlage, 7 April, p.45-46.

5 Seasonal and spatial variations in plankton blooms

dr. H.J. van der Woerd, dr. M.A. Eleveld, dr. A.J. Gilbert, dr. S.W.M. Peters, dr. L. Peperzak
Institute for Environmental Studies IVM-VU.

5.1 Objectives

The mapping of environmental parameters of the highly dynamic North Sea requires information with a high spatial and temporal resolution. Remote Sensing data in particular does complement cruise-based observations and provide maps for the complete North Sea. Satellites like MERIS (ESA) observe the North Sea almost every day and are especially designed for the study of coastal waters since they can cope with more complex optical signals. In this work package a state-of-the art algorithm has been tested and improved to deliver algae pigment maps with validated accuracy. In addition relevant products like the distribution of concentrations of suspended sediment (SPM) and (coloured) dissolved organic mater (CDOM) are available. It is demonstrated how these concentrations can be combined with satellite estimates of the solar photosynthetic active radiation (PAR) and Sea Surface Temperature to estimate the phytoplankton growth in the North Sea. The outlook is to use this satellite-based information for the detection of climate-related signals. This can be done either via derived indicators or by estimating export production and vertical carbon fluxes by a biogeochemical model.

5.2 Deliverables

The work package has produced the following deliverables:

- 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 that 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 GeoTif GIS-compatible data containing all maps generated. These maps have been made available to the environmental information management system in WP6.

5.3 General methodology

All relevant satellite imagery from the MERIS, MODIS and SeaWiFS instruments were collected. This database was maintained on a dedicated server that is needed to store and process over 1 Terabyte of data. In the shallow Southern North Sea, the satellite signal is strongly influenced by suspended sediment particles that 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). Therefore standard satellite products could not be used. Instead this project elaborated on the experience gained in the EC FP5 project REVAMP. In the REVAMP project (2002-2005) a methodology was developed to retrieve the Chlorophyll-a pigment concentration from the European MERIS instrument. This A6 project has enabled the further development and fine-tuning of the HYDROPT algorithm. The data have been processed and integrated with the routine monitoring of the Dutch continental shelf, carried out by Rijkswaterstaat (end user) as part of the national monitoring programme. The feasibility of calculating North Sea net primary production using the generated maps of chlorophyll in the Vertically Generalized Production Model (VGPM) was examined. The extraction of satellite-based indicators for the DPSIR indicator framework to structure current knowledge of climate change and eutrophication the North Sea has been reviewed.

5.4 General results

Water-Quality maps

The methodology to extract the water-quality information from the reflection spectra measured by SeaWiFS, MERIS and MODIS has been tested and documented extensively in this project. In [Van der Woerd and Pasterkamp, 2008] the mathematical formulation, parameterisation of HYDROPT and validation with in-situ data is described. In [Eleveld et al., 2008] it is shown how all the individual observations can be combined to look for yearly changes. In [Peters et al., 2008] the in-situ measurements were tied in with the satellite data to derive an optimum retrieval for the Dutch Exclusive Economic Zone. Tools to test the quality of the retrieval were developed to eliminate bad products. In this way the highest quality products are derived for the Dutch part of the continental shelf. These products are the basis of all the maps that have been generated and provided in the deliverables. Finally, in order to couple this area to the whole North Sea area, we have analysed all the in-situ measurements that were collected in the REVAMP project and suggest a new approach to link the various biochemical regions of the North Sea [Tilstone et al., 2010] in one product.

Primary Production

[Eleveld et al., 2007] reported on the feasibility of calculating North Sea net primary production (NPP) using the Vertically Generalized Production Model (VGPM). This model is developed for Ocean and was adapted to our highly productive coastal waters. The first step involved making an assessment of the quality of the satellite data products to be used as input for the VGPM. The second step involved calculating net primary production maps from images of autumn 2002 to winter 2006. This work demonstrates that it is a promising new tool to study NPP and potential relations with climate change (SST, clouds and PAR).

Indicators

A review article, which is in preparation, uses the DPSIR framework to structure current knowledge of climate change and the North Sea. The review builds upon the knowledge of state indicators of eutrophication in [McQuatters-Gollop et al., 2009]. Whereas [McQuatters-Gollop et al., 2009] discussed trends in indicators for four European regional seas, the second will focus more on policy aspects, notably the Marine Strategy Directive and its requirements for indicators to capture Good Ecological Status.

Environmental Management

Validation is a quantitative comparison between satellite measurements and in-situ measurements. We collected all in-situ measurements of the North Sea that have been measured by Rijkswaterstaat. In [Peters et al., 2008] is reported in detail how for the Dutch EEZ the in-situ measurements compare to the HYDROPT results. Although small deviations do occur at certain stations, the overall match is excellent, allowing these satellite maps (available since 2002) to be tied-in with routine monitoring activities by the most prominent end-user.

In Van der Woerd et al. [2010] we report on the use of secondary products; in this case the detection and monitoring (Harmful) Algal Blooms (e.g massive blooms of Phaeocystis Globossa). These blooms have adverse effects on the marine ecosystem and is connected to the climate by NOA, SST and runoff events. The article proposes a combined satellite, in-situ, model system to detect and track these blooms.

Finally, all images (.jpg) and georeferenced (.tif + .twf) of seasonally averaged chlorophyll and related parameters (SPM, CDOM, Kd) plus indicators extracted at MWTL-stations in the North Sea are made available to the management system. An example is provided in Fig. 5.1 below.

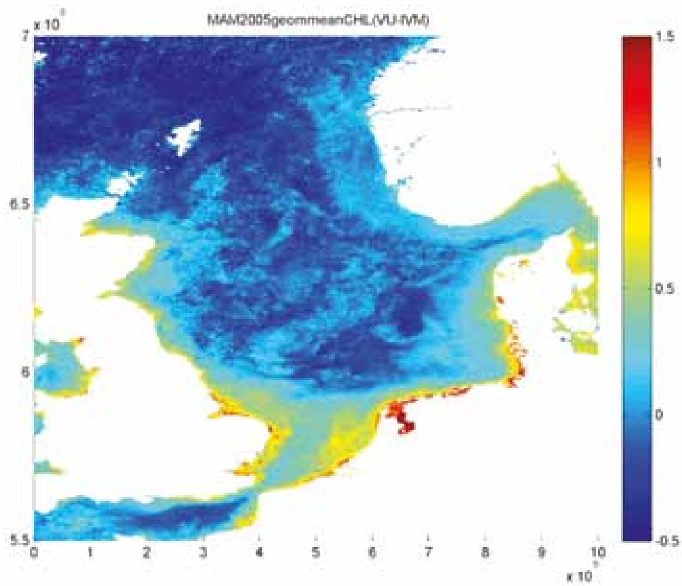

Figure 5.1 The geometric mean concentration of chlorophyll-a in the North Sea in the Spring bloom season (March, April, May) of 2005.

5.5 Publications and other products

Eleveld M.A., H.J. van der Woerd, & H. Beck 2007. Improving the Estimation of North Sea Primary Production: MERIS CHL and KD in VGPM. Proc. of ENVISAT Symp. 2007. ESA Special Publication SP-636 (462067me). Noordwijk: ESA. ISBN 92-9291-200-1.

Eleveld M.A., R. Pasterkamp, H.J. van der Woerd & J. Pietrzak 2008. Remotely sensed seasonality in the spatial distribution of sea-surface suspended particulate matter in the southern North Sea. Estuarine, Coastal and Shelf Science 80:103–113.

McQuatters-Gollop A., A.J. Gilbert, L.D. Mee, J.E. Vermaat, Y. Artioli, C. Humborg & F. Wulff 2009. How well do ecosystem indicators communicate the effects of anthropogenic eutrophication? Estuarine, Coastal and Shelf Science 82:583-596.

Peters S., H.J. van der Woerd & M.A. Eleveld 2008. The OVATIE-2 final report. Retrieval and validation of satellite water-quality products in the Dutch Coastal Zone. IVM Report R08/xx. Amsterdam, The Netherlands

Tilstone G., H.J. van der Woerd, H. Krasemann, V. Martinez-Vicente, S. Peters, M. Eleveld & et al. 2010. Novel ways of parameterising remote sensing algorithms for European Coastal Waters using trends in absorption properties. J. Geophys. Res. Oceans. Under Review.

Woerd H.J. van der & R. Pasterkamp 2008. HYDROPT: A fast and flexible method to retrieve chlorophyll-a from multispectral satellite observations of optically complex coastal waters. Remote Sensing of Environment 112:1795–1807.

Woerd H.J. van der, A. Blauw, L. Peperzak, R. Pasterkamp & S. Peters. 2010. Analysis of the spatial evolution of the 2003 algal bloom in the Voordelta (North Sea). Netherlands J. Sea Res. Under Review.

6. Secondary production of benthos and in-situ measurements of near bottom processes

G.C.A. Duineveld, Dr. R. Witbaard, M.J.N. Bergman, M.S.S Lavaleye.
Royal Netherlands institute for Sea Research (NIOZ)

6.1 Objectives

For the understanding how climate change translates into North Sea ecosystem effects, knowledge is needed on near-bottom processes that affect the benthic food supply and the distribution of benthic fauna. Latter are principal consumers of the annual primary production in the shallow NCP and form the food source for commercial demersal fish such as plaice and sole.

Climate scenarios predict a change in the prevailing wind direction and an increase of wind speed as well as seawater temperatures. This will have direct effects on the coastal ecosystem where waves presently stir the seabed and its inhabitants during strong wind. In deeper water, stronger winds will enhance mixing which could promote primary productivity especially in stratified areas.

Previous surveys of the distribution of benthos on the NCP have undersampled large bivalves and other common but sparsely distributed filter-feeders due to methodological limitations. Large filter-feeders form an important route along which climate effects on primary production in the surface waters are transmitted to the benthic ecosystem. Hence distribution patterns of filter-feeders will help to identify areas on the NCP potentially sensitive to changes in pelagic-benthic coupling.

Better insight into how climate (weather) operates on the food supply of the benthic ecosystem and ultimately benthic productivity on the NCP requires high resolution datasets on important parameters such as near-bottom suspended matter and chlorophyll-a in conjunction with measurements on the performance of benthic species. Such datasets should be obtained by in-situ measurements to ensure realistic ambient conditions. The process oriented data obtained by such measurements, in combination with the fauna distribution, form important input for the validation and improvement of existing ecological models such as ERSEM.

6.2 Deliverables

The work package has produced the following deliverables in accordance with those discussed in the kick off meeting at the start of this project

- D3.1 Long term and high frequency measurements (database) of (a)biotic environmental conditions in two contrasting North Sea habitat sites, i.e the coastal zone and the Oyster Grounds.
- D3.2 A Data base and Atlas of the distribution of large macrofaunal species from the NCP.
- D3.3 A dataset for synthesis and callibration of environmental variables within the existing ERSEM model.
- D3.4 A dataset on spatial differences in secondary production of Mytilus edulis from in situ lander experiments as well as a dataset on the spatial growth differences of the bivalve Chamelea striatula.

6.3 General methodology

In 2007 and 2008 bottom landers were deployed at two contrasting sites in the North Sea. By means of these landers we collected high resolution temporal data of environmental conditions, such as turbidity, fluoresence, currentspeed and direction and water temperature. In addition to these lander deployments and in cooperation with CEFAS (UK) mussel transplantation experiments were transformed in five contrasting North Sea bottom environement. Benthic standing stock assessments were made of the larger macrofauna by means of the triple D dredge. Samples from this collection were used for the estimation of spatial differences of shell growth rates.

With this, a data set has been collected by which the functional and spatially different response of the benthic environment to environment can be assessed. The distribution maps generated not only form a base line to assess future effects of climate change but also acted as validation and callibration data of model outcomes of ERSEM.

6.4 General results

Lander deployments

In the coastal zone during periods of calm weather turbidity levels were relatively low with a clear tidal periodicity. Significantly higher peaks in the near bottom silt concentration even surpassing 300 mg/L occurred in conjunction with stirring by waves caused by wind. Wave height and turbidity appear to have a highly significant coupling.

Lander deployment observations in the deep summer stratified Oyster Grounds are in line with observations of primary production by CEFAS. Long after the cessation of the spring bloom prominent fluorescence peaks near the bottom were recorded in June and in mid-July which match those of the spring bloom. Near-bottom fluorescence showed a distinct tidal signal. Because of anticipated higher temperatures and a longer isolation of the Bottom Mixed Layer in combination with enhanced surface productivity the area is likely to become susceptible to more extreme hypoxic conditions.

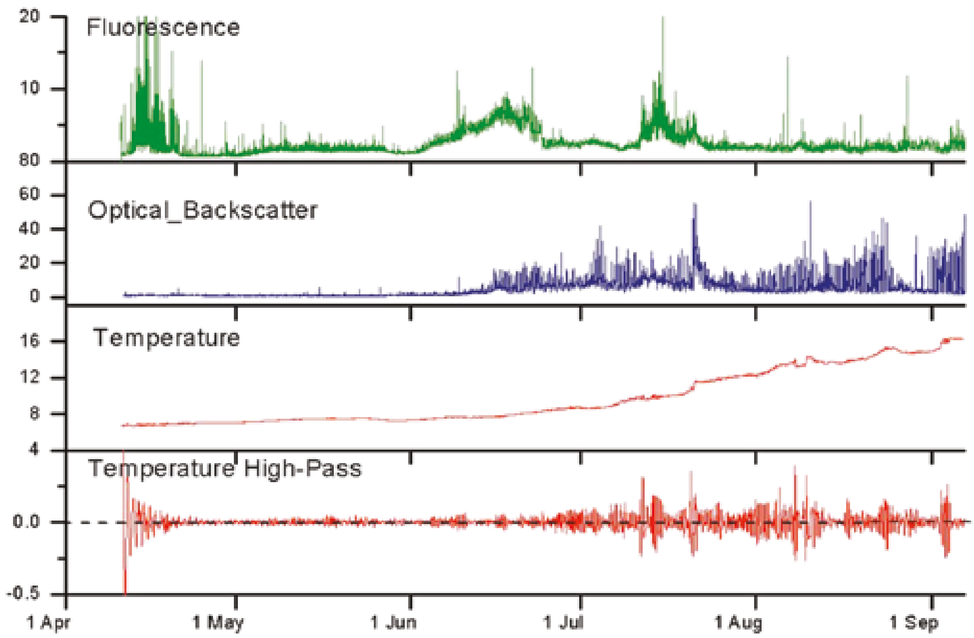

Figure 6.1 Seasonal variations in fluorescence (in Uranine units ppb), optical backscatter (ppm), temperature (oC) and filtered temperature data showing periods of high-frequency variation at the lander position in the central Oyster Grounds from April to September 2008. The peaks with increased fluorescence in midsummer coincide with a short term temperature change, suggesting that they are related to events of wind mixing.

Fauna maps

On basis of the dredge inventory distribution maps of macrofauna on the NCP have been constructed. These maps form an important baseline in the study of climate related range expansion/shrinkage as well as data against which the ERSEM model can be improved and calibrated. Comparison of model estimates and field data show a reasonable well overlap.

Secondary production

The transplantation experiments with *Mytilus* in cooperation with CEFAS (UK) as well as the growth inventory of *Chamelea striatula* demonstrates large geographical differences in growth and productivity. Calibration of the isotope temperature signals within the carbonate of this species has been made. Dutch coastal waters have the highest rates of secondary production. All areas show a distinct temporal differences in shell and tissue growth organism. Growth experiments with the long lived bivalve *Arctica islandica* further contributed to the development of this species as proxy for the reconstruction of Holocene bottom water temperatures.

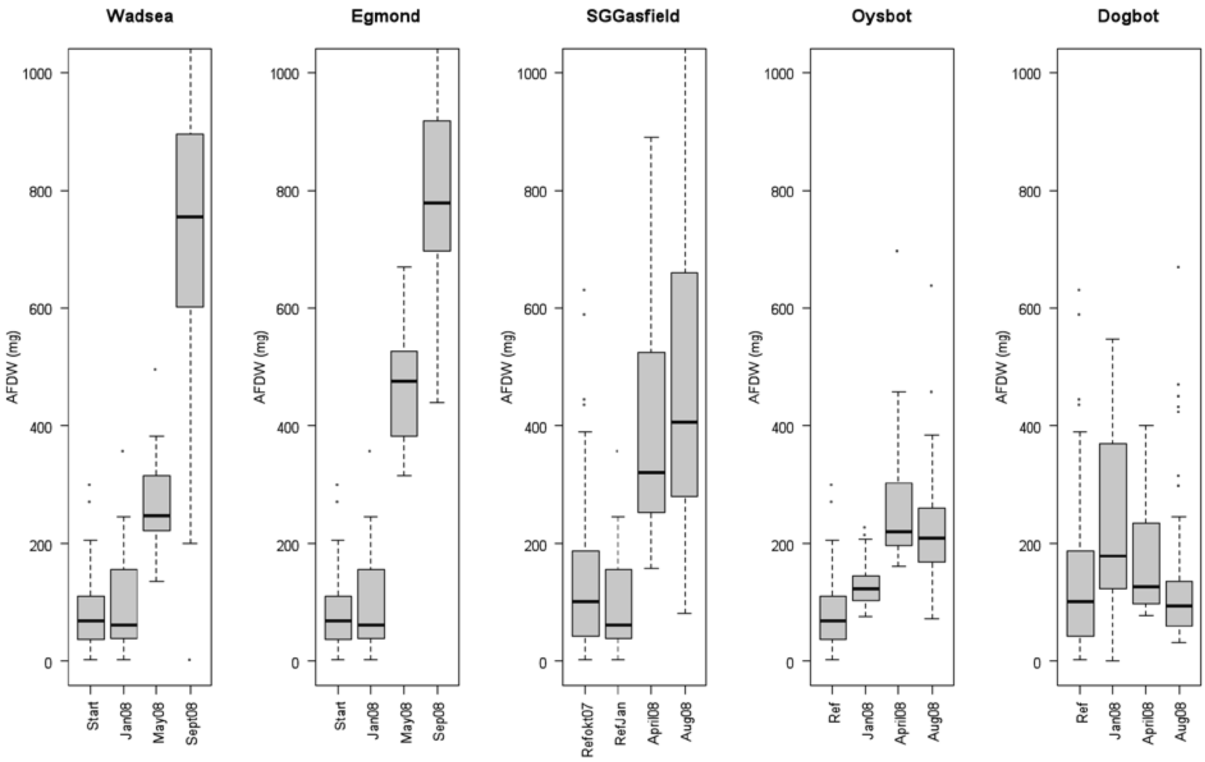

Figure 6.2 Weights of mussels (mg AFDW) at five bottom locations in the North Sea at 3 dates in 2008. Weights of the reference samples taken at the start of the experiment are indicated. The results illustrate the enormous differences in tissue growth of mussels. The ERSEM model estimates of net bivalve filter feeder production are in line with these observations.

6.5 Publications and other products

Bergman M.J.N. 2007. Cruise Report 64PE260. Coastal transport of silt and pelagic larvae; spatial distribution of benthos populations at the Dutch continental sector. 5-8 February 2007, NIOZ, Texel.

Bergman M.J.N. 2007. Cruise Report 64PE261. 19 February -2 March 2007. COSTRA. Coastal transport of silt and pelagic larvae; spatial distribution of benthos populations at the Dutch continental sector & NZW Noordzeewind project: effects of the OWEZ wind park on benthos recruitment, NIOZ, Texel.

Bergman M.J.N. Cruise Report 64PE288. 14 -18 April 2008. COSTRA Coastal transport of silt and pelagic larvae; spatial distribution of benthos populations at the Dutch continental sector.
Bergman M.J.N. 2008 Cruise Report 64PE289. 21-26 April 2008. COSTRA, Coastal transport of silt and pelagic larvae; spatial distribution of benthos populations at the Dutch continental sector. NIOZ, Texel.

Boender, A. 2010. BSc. Report. The reconstruction of ambient seawater temperature using *Cerastoderma edule* and *Chamelea striatula* (Wadden Sea, the Netherlands. VU, Amsterdam, NIOZ, Texel, 33pp.

Duineveld G.C.A. Cruise Report 64PE266. March – April 2007. BSIK Klimaat voor Ruimte programme -Distribution and growth of bivalve populations in the Dutch continental Sector of the North Sea. NIOZ, Texel.

Duineveld G.C.A., R. Witbaard, M.J.N. Bergman & M.S.S. Lavaleye 2010. Spatial distribution and production of larger sized bottom fauna in the North Sea and in-situ measurements of near bottom processes.

Held M. den 2008. *Chamelea striatula* as bioindicator in the Dutch part of the North Sea. Internship report, Hogeschool vanHall Larenstein - NIOZ. 28pp.

Watmough T., R, Witbaard, G.C.A. Duineveld, M.J.N. Bergman, M.S.S. Lavaleye. Dredge fauna of the NCP. NIOZ report in prep.

Witbaard R. & D. Hippler 2010. Seasonal shell growth record of Arctica islandica: Results from a field experiment. In Bivalve mineralization archival potential and proxy incorporation. 4-5 may 2009. eds. André et al, Koninklijke Vlaamse Academie van Belgie voor wetenschappen en kunsten.

Witbaard R. 2010. Mussel transplantation experiments as source of validation data for model estimates of benthic secondary production. In: Marine Ecosystem Connections: essential indicators of healthy, productive and biologically diverse seas (contract ME3205) Report: Results of field work to quantify key processes affecting the flow of C, N, O and Si at study sites Commissioned by The Department for Environment, Food and Rural Affairs (Defra). Editor: Suzanne Painting Cefas, Pakefield Road, Lowestoft, NR33 0HT , 62 pp.

Witbaard R., Cruise Report 64PE287, 5 -13 April 2008, Coastal transport of silt and pelagic larvae; spatial distribution of benthos populations in the North Sea. NIOZ, Texel.

7 Long-term variability in North Sea benthic communities

Prof. Dr. J. van der Meer, Dr. R. Daan & A.S. Saraiva

7.1 Objectives

This project aims to explore possible effects of changes in ocean climate on the population dynamics of a selected set of macrozoobenthos species, which are relatively large invertebrates (that is larger than 1 mm) living in the seafloor. Stochastic population process models and more mechanistic and individual based models that are linked to ecosystem models such as ERSEM, were developed and confronted to long-term datasets from the North Sea and Wadden Sea to examine the predictive capacity of these models.

7.2 Deliverables

The work package *Long-term variability in North Sea benthic communities* revealed the following deliverables:

D4.1 Paper in which changes in the macrozoobenthic community of the Southern North Sea are described in relation to environmental factors.

D4.2 Paper in which the ability of stochastic time-series analysis to predict the effects of climate change on of macrozoobenthic abundance is explored.

D4.3 Paper describing a mechanistic modeling approach of predicting the impact of changing temperature, food levels and silt levels on bivalve population dynamics.

Originally, deliverable D4.3 aimed at producing maps of the past, present and future distribution of macrozoobenthos communities in the Southern North Sea. However, due to the lack of significant results of the time series analysis exercise, deliverable D4.3 was reformulated. Maps are now based on the runs of the ecosystem model ERSEM. See further chapters 4 and 9.

7.3 General methodology

During the period 1991-2005 NIOZ carried out the macrozoobenthos monitoring programme (BIOMON) funded by Rijkswaterstaat. The monitoring is based on a boxcore sampling program in which 100 stations on the Dutch Continental Shelf are visited each spring. A cluster analysis revealed distinct communities, and a general description of trends in community characteristics (such as species diversity, total density, and total biomass density) is presented. Next, trends at the species level are described. Additionally, these BIOMON data are, as far as possible, compared to unpublished data collected by the late dr. F. Creutzberg and by dr. G.C. Cadée between 1976 and 1981.

As a next step the relevance and usefulness of non-linear time series analyses was examined. A previously published time series model for two polychaete species was validated. Temperature changes had a strong effect on the population dynamics of these species. The original model was based on data from the western Wadden Sea obtained in the period 1969-1998, and was validated using data from the period 1999-2010. Wadden Sea data are used as they comprise a much longer period than the BIOMON data.

Because the results of this statistical approach were not entirely satisfying, a start was made with the development of a mechanistic and individual-based approach to population dynamics of bivalve species, which in a next phase can be incorporated in an ecosystem model. Many bivalves species inhabit coastal waters where climate change may induce changes in temperature and in both quantity and quality of suspended particulate matter. The study of interactions between the organism and its environment requires a certain level of detail concerning the feeding process, not only from the bivalve point of view (which material can they actually use as food) but also from the ecosystem point of view (to what extent are bivalves able to clear the water column and change ecosystem dynamics?). However such detail is commonly neglected in ecosystem modelling and a mechanistic description of the feeding process is still lacking. In this study, the Synthesizing Units concept, part of the Dynamic Energy Budget (DEB) theory, is used to describe the main feeding processes in bivalves.

7.4 General results

From the very beginning it became clear that, on the basis of fauna composition, four spatially well defined regions could be discerned within the monitoring area on the Dutch Continental Shelf (DCS). An earlier statistical analysis has shown that the Dogger Bank, the Oyster Ground, the southern offshore area and the coastal area each had their own characteristic fauna composition. The different regions are roughly separated from each other by isobaths. The Oyster Ground is the deepest region and is separated by the 30-m depth contour from the Dogger Bank and the southern offshore area. The border between the latter and the coastal area is roughly marked by the 20-m depth contour. At the community level there were no trendwise changes over the period of monitoring. Species diversity was consistently highest at the Dogger Bank and in the Oyster Ground, on average twice as high as in the southern offshore and coastal areas. Faunal densities were generally the highest in the Oyster Ground. The highest biomass values were found in the coastal area, due to the presence of banks of bivalves (*Spisula subtruncata* and *Ensis americanus*). At the species level a few trends were observed: the disappearance of the polychaete *Aricidea minuta* from the DCS around 2000 and a dip in the densities of the brittle star *Amphiura filiformis* in the Oyster Ground during the second half of the nineties. A rather strong decrease of silt contents of the sediment in the latter area after 2001 was not reflected in a change in the abundance of one or more common species. A comparison of the monitoring data with data collected in the period 1975 – 1981 appeared to be possible for only a few (mainly mollusc) species in the Oyster Ground, but indicated that the gastropod *Turritella communis* has strongly decreased since those years whereas there was a significant increase in the abundance of several small bivalve species.

7.5 Statistical model

Ten years ago, several linear and non-linear stochastic population process models were fitted on 29-years time series (1970-1998) of the abundance of two polychaete species in the western Wadden Sea. The predatory species *Nephthys hombergii,* a generalist predator, was strongly influenced by winter temperature. The correlation between the one-year ahead forecasts, using the observed winter temperature, and the true observations equalled 0.90. During the last 10 years, that is after the model results were published, winter sea surface temperature increased by 1 degree Celsius in the western Wadden Sea, reflecting not so much a change in the zonal winter winds over the North Atlantic Ocean as indicated by North Atlantic Oscillation (NAO) index, but merely a real large-scale warming trend. It seems that climate has run out the domain as occurring during the period 1970-1998. We used the data from this relatively warm period 1999-2010 to test the stochastic population process models that were fitted on the 1970-1998 data. The model forecasts a *N. hombergii* population increase for most of the years within the testing period. The actual population change was, however, in most of these cases considerably lower than the forecast. Similarly, the predicted population trajectory for *N. hombergii* was consequently above the observed series (Fig. 7.1). Despite the promising results using the training set, one-year ahead forecasts and long-term predictions using the testing set were significantly different from the observed trajectory. The predicted increase in predator abundance and decrease in prey abundance did not take place. This poor predictability may have been caused by interactions with other factors, whose levels have changed over the last decade. One example is the rise of several other predatory polychaetes, such as *Alitta* (previously *Nereis*) *virens* and *A. succinea* whose biomass density has considerably increased since the beginning of this century. Yet this all remains speculation and a more complete understanding of the complex interactions within the benthic community will only be achieved when knowledge of the species' physiology and ecology allows the building of mechanistic and individual-based models. This will take some time and for the time being predictions on the impact of climate change on population dynamics on the basis of time series models should be treated with some scepticism.

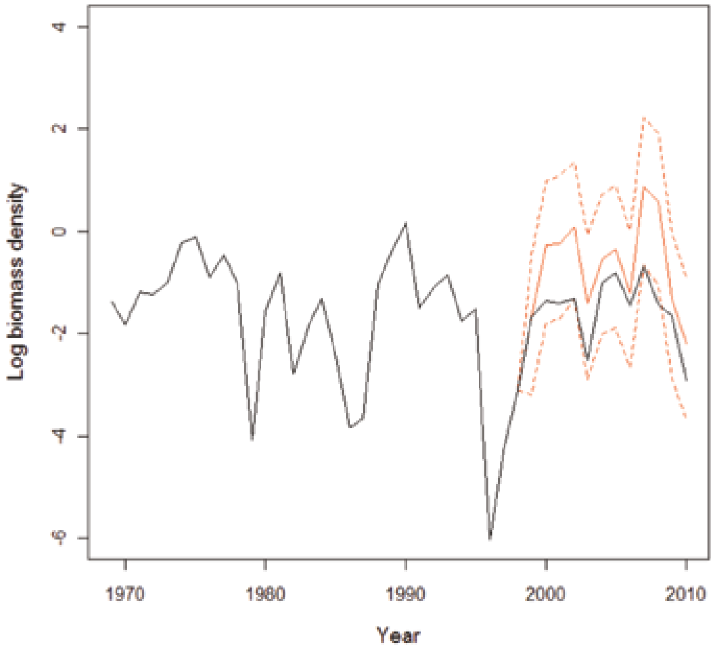

Figure 7.1 Predicted (red solid line) and observed (black solid line) changes in log biomass density for the predator *N. hombergii* versus time. Red dashed lines refer to the 95% bootstrap interval.

7.6 Mechanistic model

Filtration, ingestion and assimilation were assumed as three different steps and pseudofaeces production computed as the difference between filtered and ingested fluxes. To describe each process included in bivalve feeding, the model makes use of the Synthesizing Units (SU) concept. Such units transform arrival fluxes of substrates into a production flux of products. It is assumed that the substrate molecules arrive according to a Poisson process and that the binding occurs with a fixed probability. During the production (handling time), no substrate particles are accepted by the SU, and the binding probability for each arriving substrate will be null. The process of transformation is classified according to: (i) the relative role of substrates in product formation (substitutable when any substrate can be separately transformed into the product; complementary when all substrates are required to produce the product) and (ii) their interaction at the binding/production level (parallel if there is no interaction between the substrates; sequential if the binding of one substrate interferes with the binding of the others. Temperature influence on the feeding processes is described by the Arrhenius relation, with the additional idea that each rate is controlled by SUs having an inactive configuration at low and high temperatures. As an approximation, we assume that all physiological rates are affected by temperature in the same way. Parameters of the model were estimated using literature data on filtration, ingestion and pseudofaeces production. Model predictions were then compared with data from other sources using the set of parameters obtained before and the results reveal a satisfactory agreement (Fig. 7.2).

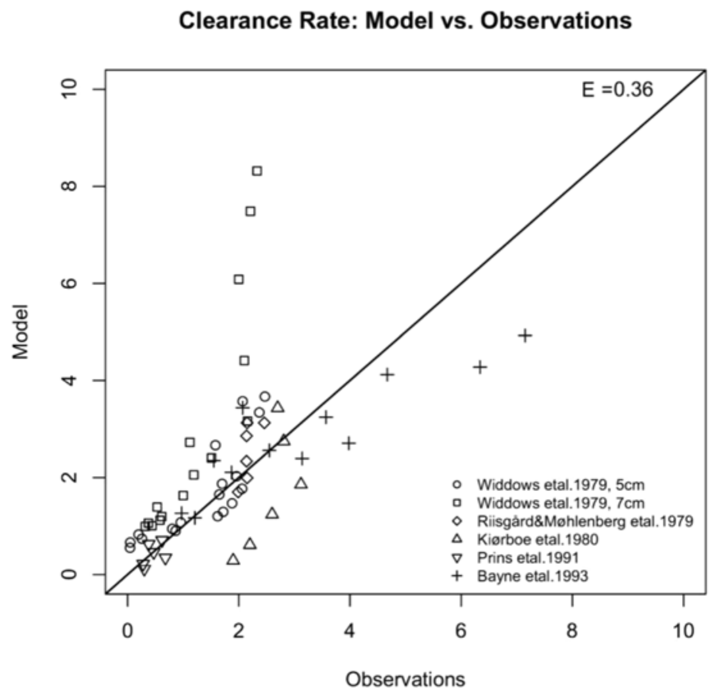

Figure 7.2 Model results versus observations on clearance rate. E value reflects the variance of the error. Data from different sources.

The model was able to reproduce the main patterns found in the observations and the results were also usually quantitatively accurate. This holds in particular for clearance and filtration rate and to a lesser extent for ingestion and pseudofaeces production. The main uncertainty related to ingestion concerned the apparent existence of a pseudofaeces production threshold as observed in laboratory experiments. These observations may, however, be explained by a temporary pseudofaeces accumulation inside the bivalve before rejection. Besides, the topic is only important for pseudofaeces production in systems with very low total particulate matter concentration and in absolute amounts no significant effects on the bivalve growth are expected. We conclude that the model has the desired flexibility to be implemented as an extension to the standard DEB model, in order to simulate bivalve growth in ecosystems with varying food quantity and quality and temperature.

7.7 Publications and other products

Daan R. & M. Mulder 2009. Monitoring the invertebrate benthic fauna in the Dutch sector of the North Sea 1991-2005: an overview. Texel, NIOZ. Rapport 2009-5.

Meer J. van der & R. Dekker 2011. Using stochastic population process models to predict the impact of climate change. J. Sea Research (to be submitted).

Saraiva S., J. van der Meer, S.A.L.M. Kooijman & T. Sousa 2010. Modelling feeding processes in bivalves: a mechanistic approach. Ecological Modelling (conditionally accepted)

8 Long-term variability in the production and consumption of North Sea benthic fish assemblages

Ir. R. van Hal, Dr. I.Y.M. Tulp, Dr. J.A.M. Craeymeersch, Dr. N. Daan, R. Labberton, F. Stuke, L.R.T. Teal, Dr. A.D. Rijnsdorp
IMARES, Wageningen UR

8.1 Objectives

Substantial changes in the species- and size-composition of the fish assemblage and productivity have been reported for coastal and offshore waters of the North Sea. The observed changes can partly be related to the effects of fishing which removes between 20-50% of the biomass of the larger sized fish, but other factors such as climate change and eutrophication may have played a role as well. This project focuses on the effect of climate change on the fish-benthos interactions, and the implications for the consumption and productivity of the benthic fish. Special attention is given to nursery ground processes, since it is well established that the availability of suitable nursery grounds in the coastal waters determine the overall abundance of commercially important flatfish species. The specific objective is to quantify the relationship between environmental conditions and the consumption and production of fish assemblages over large temporal and spatial scales by modelling

8.2 Deliverables

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.

8.3 General methodology

The approach taken comprised of the statistical analysis of available long-term data sets on the distribution and abundance of bottom dwelling (demersal) fish, the analysis of growth from otolith growth patterns, field studies of trophic relationships (stomach sampling) and modelling study to estimate the energy demand and the effect of temperature and food availability on habitat quality and the scope for growth.

8.4 General results

Stomachs analysis of the demersal fish community revealed a clear overlap in the benthic food resources of the southern North Sea (Fig. 8.1). While there is some preference for specific prey items, most species consume a wide range of different prey. This creates the overlap in food resources which is a potential source of competition between the species.

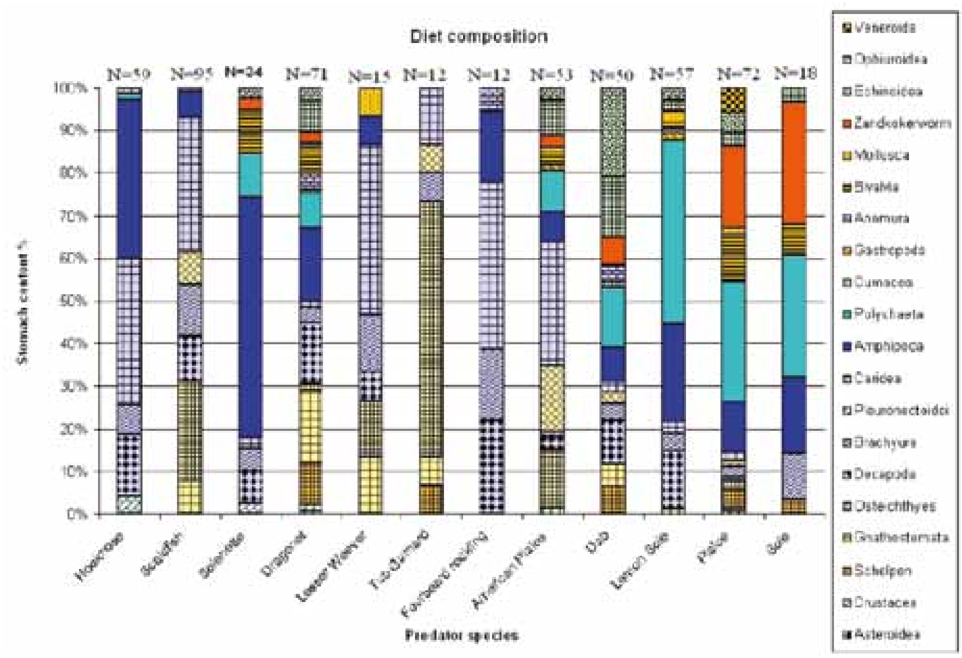

Figure 8.1 Diet composition of demersal fish community in the 3rd quarter. N= the total number of full stomachs analysed [Labberton, 2009].

A detailed study was conducted to study the importance of the razor clam *Ensis directus* an invasive species that established itself in 1978 and became the dominant filter feeder in Dutch coastal waters with densities of around 120 g/m^2 since 2002. Diet studies have shown that the species is an important prey species for a wide variety of fish and bird species. This implies that the increase in *E. directus* must have caused an enormous change in the food relations in the entire foodweb of the North-western European coastal ecosystem [Tulp et al., in press].

In order to analyse the consequences of changes in the demersal fish assemblage on the consumption and production of fish, long-term variations in fish abundance were explored in relation to environmental variables. In the International Bottom Trawl Survey covering the total North Sea and carried out in the 1st quarter, species richness showed a gradual increase in both northerly and southerly fish species over the past 25 years; a change that was most likely due to overexploitation, although climate change may have had add-on effects [Daan, 2006]. In the Dutch coastal waters, 3rd quarter total fish biomass showed a dome-shaped pattern with a peak in the early 1980s, coinciding with relatively high abundance of plaice and dab. Statistical analysis of the common patterns in the time trends in abundance revealed patterns for the three coastal areas showing a peak in the early 1980s and early 2000s (Fig. 8.2). The changes around the late 1980s coincides with regime shifts.

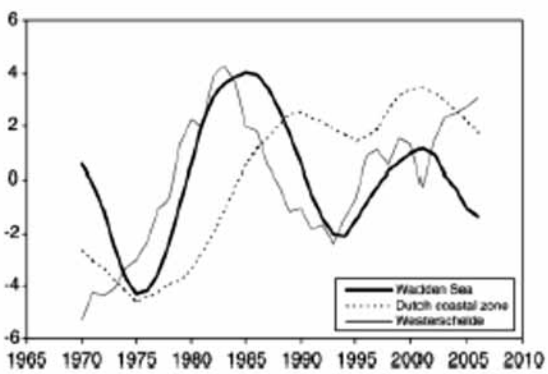

Figure 8.2 Common trends in the abundance of 34 fish species in the Westerschelde and the Wadden Sea and coastal zone of the Netherlands [Tulp et al., 2008].

Since the late 1980s, two southern flatfish species (solenette and scaldfish) substantially increased in abundance and moved northward. These changes coincided with a series of mild winters during a period where populations of predators were depressed by fishing. In 1996, following a very cold winter, the abundance of both species temporarily decreased as they retracted to the south. The likely cause of the change in abundance and distribution is the temperature mediated increase in habitat quality, which allowed them to immigrate into new areas and subsequently reproduce successfully [van Hal et al., 2010]. The observed increase in abundance of these small flatfish species has affected the North Sea food web. A preliminary assessment of the energy demands of solenette suggests that it now requires 35% of primary production in part of the central North Sea [Jennings et al., 2008]. This energy may have supported larger species in a less heavily fished ecosystem, and might explain the decline in growth rate observed in several flatfish species between the 1980s and the 2000s.

The trophic interactions between the small bodied, non-commercial, solenette and scaldfish and the commercially exploited plaice, dab and sole was explored by estimating the changes in competitive biomass. Competitive biomass is estimated as the biomass by which an individual has to share its food resources and includes the overlap in spatial distribution and overlap in diet. The results show, however, that the increase in abundance of the small bodied flatfish solenette and scaldfish has not compensated for the decrease in the biomass of the larger bodied plaice, dab and sole since the late 1980s. Hence, the overall biomass of benthivorous flatfish decreased since the peak in the 1980s, suggesting that the food requirement has also dropped. The decrease in growth rate that coincides with the decrease in flatfish biomass suggests a decrease in the benthic productivity, which may have increased the competitive interactions. .

Production and consumption of the demersal fish assemblage will also be affected by the rising seawater temperature. It is expected that northern and southern fish species will differ in their response. In order to explore this, we analysed the effect temperature on growth of 0-group sole, the southern species, and 0-group plaice, the northern species during a period when the water temperature has increased (1970 to 2004). It was shown that the increasing winter temperatures significantly increased the growing period of sole, a warm-water species that spawns in spring, but not of plaice, a temperate species that spawns in winter. Growth rate increased with higher summer temperatures in sole and to a lesser degree in plaice. Compared to experimental growth rates at ambient temperatures and unlimited food, observed growth rates were close to experimental values until mid-June but were much lower in July to September, suggesting food limitation in summer. The higher temperatures observed since 1989 positively affected the quality of the shallow coastal waters as a nursery area for sole but not for plaice. A further increase may negatively affect the nursery quality if the production rate of benthic food cannot meet the increase in energy requirements of 0-group flatfish [Teal et al., 2008].

The implications of temperature on plaice growth was analysed using Dynamic Energy Budget parameters and spatially explicit bottom temperatures. Assuming no food limitation, modelled growth of 0- and 1-group plaice was higher then observed in the field. Including benthic food available for fish (from ERSEM), lowers the high growth, as no longer optimal food conditions are considered, making the growth rates more realistic and this even further increases the area with unfavourable conditions in the warmest years. This is an indication that the habitat quality of our coastal areas is deteriorating for plaice owning to the increased temperatures in summer.
The results of the various sub-projects conducted lead to the following general conclusions on the effects of climate and fishing on the productivity and trophic relationships in the benthic ecosystem. The long-term data sets analysed in this project provided strong support for the interacting effects of climate and fishing on the trends in population abundance of fish. Since species richness increases

from the poles toward the equator, the increase in species richness is consistent with the northward shift of the more numerous Lusitanian (southern) species. Fishing will impact the size structure of the fish assemblage by removing larger sized (predatory) fish and allowing smaller sized (prey) fish to increase. The reduction in abundance of predatory fish can further enhance the immigration of the generally smaller sized southern species, as reflected in the changes within the benthic fish assemblage in the southern North Sea [van Hal et al., 2010]. The changes in the structure of the demersal fish assemblage has major consequences for the trophic processes. This project has provided the basic data on the abundance and distribution of the major benthic fish species and their diets, to quantify the trophic interactions within the benthic fish assemblage. A preliminary estimate of the food requirement of solenette, one of the species that has increased in abundance in response to climate change and fishing, suggested that this population already required 35% of the primary production in the area. The overall decrease in biomass of demersal fish is likely related to a decrease in the benthic productivity (bottom-up control), which may have increased the intra- and inter-specific competition for food.

Growth of demersal fish appears to be food limited. In 0-group, food limitation occurs from mid summer onwards and could be related to the building up of the biomass of benthic consumers. A further increase in temperature will affect the quality of the nursery grounds of plaice and sole. As the surface area of high quality nursery grounds may determine the population abundance, climate change may have a substantial impact on the productivity of these important species. How an increase in temperature may affect the productivity will depend on its effect on the benthic productivity. If the benthic productivity will keep up with the increase in food requirements of the benthic consumers, a further increase in temperature may enhance the productivity of sole, but will negatively affect the productivity of plaice because of the reduction in the habitat quality when the temperature exceeds the tolerance limits.

8.5 Publications and other products

Daan N. 2006. Spatial and temporal trends in species richness and abundance for the southerly and northerly components of the North Sea fish community separately, based on IBTS data 1977-2005. ICES C.M. 006/D:02, 11.

Hal R. van, K. Smits & A.D. Rijnsdorp 2010. How climate warming impacts the distribution and abundance of two small flatfish species in the North Sea. J. Sea Res. 64:76-84.

Jennings S., R. van Hal, J.G. Hiddink & T.A.D. Maxwell 2008. Fishing effects on energy use by North Sea fishes. J. Sea Res. 60:74-88.

Keeken O. van, M. van Hoppe, R.E. Grift & A.D. Rijnsdorp, 2007. Changes in the spatial distribution of North Sea plaice (*Pleuronectes platessa*) and implications for fisheries management. J. Sea Res. 57:187-197.

Labberton R. 2009. Study on stomach contents of demersal fish species in the North Sea. IMARES Report 09.006. pp 61.

Stuke F.E.M. 2009. Climate induced changes in competition and growth of North Sea flatfish. IMARES Report 10.019. pp 39.

Teal L.R., J.J. de Leeuw, H.W. van der Veer & A.D. Rijnsdorp 2008. Effects of climate change on growth of 0-group sole and plaice. Mar. Ecol.-Prog. Ser. 358:219-230.

Tulp I., L.J. Bolle, A.D. Rijnsdorp 2008. Signals from the shallows: In search of common patterns in long-term trends in Dutch estuarine and coastal fish. J. Sea Res. 60:54-73.

Tulp I., J. Craeymeersch, M. Leopold, C. van Damme, F. Fey & H. Verdaat 2010. The role of the invasive bivalve *Ensis directus* as food source for fish and birds in the Dutch coastal zone. Estuarine and Coastal Science. In press.

9 Knowledge transfer and dissimination

Dr. R. Witbaard, Dr. H.J. Lindeboom, P. Ruardij & Dr. H.W.G. Meesters
IMARES, Wageningen UR

9.1 Objectives

Unravelling the interactions between the temporal and spatial dynamics of natural resources, their forcing functions, and their usage by an ever growing human population is a challenge and generates the neccesity for spatial management of the North Sea and its resources. Up to now, sampling has provided us with information on density and spatial distribution of hundreds of individual species in a variety of phyla and taxa. The spatial distributions of these individual species do not arise in isolation and are strongly dependent on biotic (other species) and abiotic variables. Changing climate is regarded as one of the more important forcing factors for the North Sea ecosystem although the various antropogenic impacts play their role as well.
Essential to management of such an ecosystem is the possibility to get rapidly insight in existing data sources as well as to be able to link them. This offers the possibility to identify probable relationships between observed changes in time. Within the project we adapted the data information system (EMIGMA) to enable stakeholders to rapidly extract overviews and links to existing knowledge relevant to the management of the North Sea. A downloadable version of the EMIGMA tool can be found at: http://www.imares.wur.nl/NL/onderzoek/faciliteiten/emigma/
Data collected by the various partners have been used to improve and extend the ERSEM model. This updated model is to be used to discover how the North Sea ecosystem as a whole is likely to respond to the forcing by changing climate. For this, we ran the model with conditions of increased air temperatures and more wind and increased PCO_2.

9.2 Deliverables

The deliverables as presented in this part of the project consist of:
D6.1 A series of maps on physical and biological indicators of the North Sea environment. For as far as the maps are based on time series, the existing data can be linked and compared to other existing and incorporated datasets.

D6.2 An updated management system available to scientists and resource managers supplying data, links and internet resources to rapidly get to available sources of information on those topics incorporated in the system.

D6.3 Publications on the modeling techniques which are developed to estimate the effects of climate change on the North Sea ecosystem. One paper focussing on the anticipated effects on the bentic secondary production as this links in with the food availability to benthic fish species. The other paper with the statistical analyses on the observed parallel change of the benthic communities related to the effects of climate, such as the NAO index in special winter temperatures and wind.

9.3 General methodology

The starting point was the existing managment system which was developed and filled with data for the Wadden Sea. Relevant data for the North Sea was largely lacking. To fill this omission available data on especially the distribution of macrobenthic species from the North Sea has been added as well as derived information such as diversity indices. By the incorporation of new features and the inclusion of external links to the adopted system, important external data sources are now being made available to the users.

Multivariate analyses on the BIOMON data set for the period 1991-2005 was used to determine to what extent climate forcing (and which factor) affects the benthic communities at the NCP.

Performing and incorporation of the results of runs of the ERSEM model are included to enable the user to get visual information on the temporal and spatial scale of important controlling processes for the North Sea ecosystem such as primary production. Ongoing contacts with stake holders in discussions about spatial planning and the designation of marine protected areas at the North Sea will help to dissiminate the system and the data stored within.

9.4 General results

Based on existing data sets on the distribution of macrobenthic fauna time series on the distribution of the numerical most abundant species were made for the four main communities of the Dutch continental shelf. Both the timeseries data as well as the derived maps and summary data (averaged) have been added to the management system. Data series which are indicative for climate change, i.e. the various indices such as NAO and NAM have been incorporated and the management system has been extended with a look-up function in which links to important sources of information easily become available to the user. Links to external web sites has been added and updated. With this, the user of the system can now rapidly assess and find sources of information (Fig. 9.1).

Multivariate analyses of benthic abundance data showed that the various communities on the NCP undergo simultaneous change. A climate control is suggested from the relationship with the NAO index with winter temperature as an important factor.

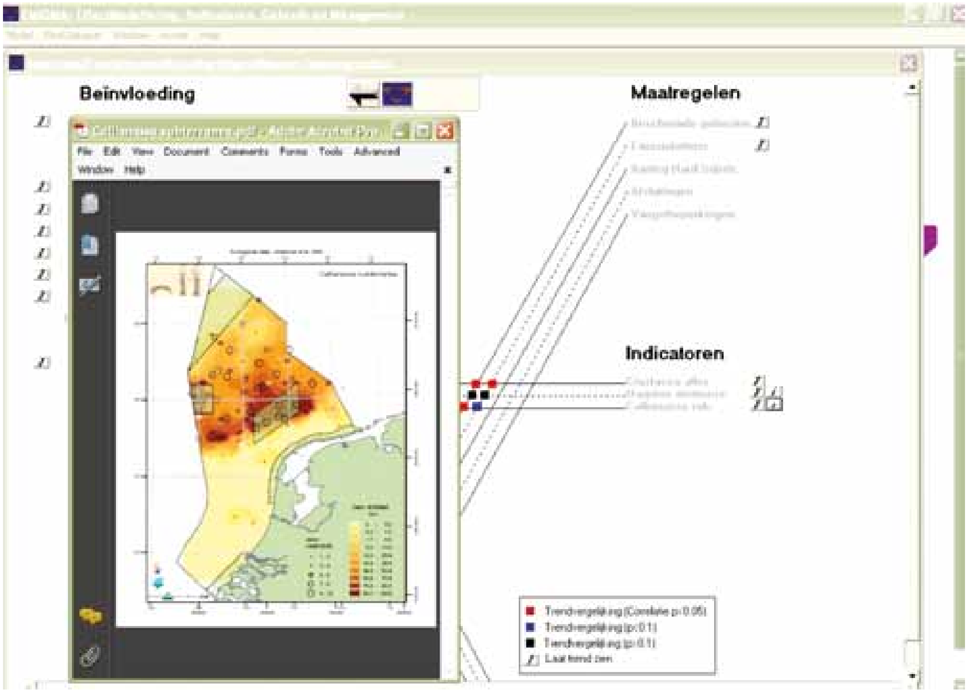

Figure 9.1 An example of the appearance of maps enclosed within the management system.

Within the new pdf lookup function an additional functionality has been added to the system by which the user directly can explore available datasources and background information. Within this function it is also possible to show results runs of the ERSEM model as pictures or avi-movies.

Climate scenario runs

The GETM-ERSEM model (www.nioz.nl/northsea_model) was used to estimate the ecosystem effects of climate change. Hereto it was essential to include the process of benthic pelagic coupling into the model. For validation, model estimates and standing stock were compared with newly collected field data. An example of such a comparison is given in Fig. 9.2.

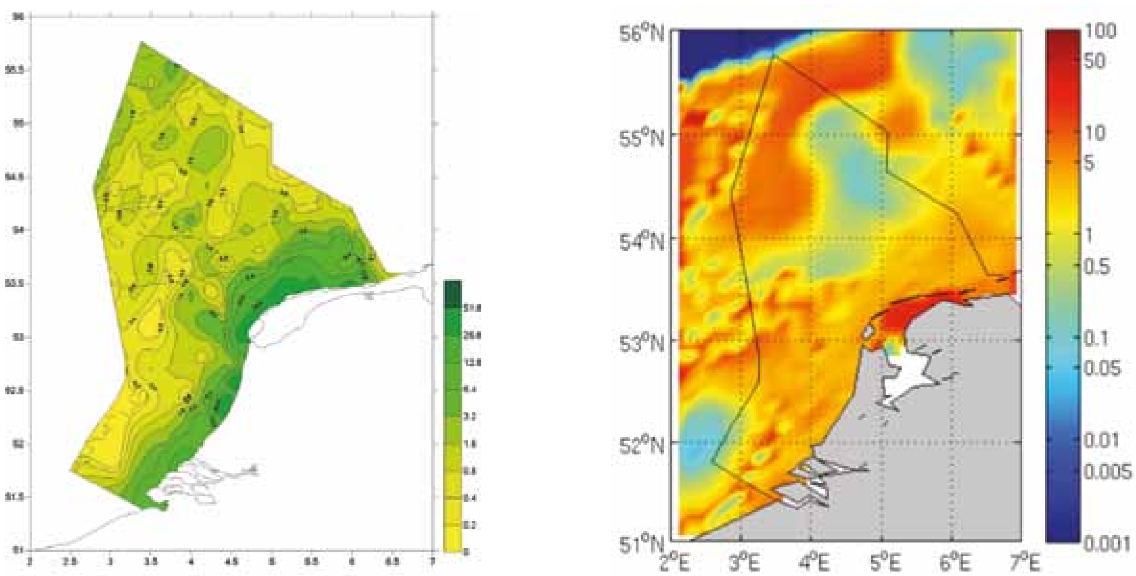

Figure 9.2 Comparison of the filterfeeder biomass (AFDW/m²) on the Dutch continental shelf based on the combination of dredge and boxcore samples (left-hand panel) and ERSEM model estimates shows a high degree of overlap.

Finally the model was run with simplified climate change scenario's i.e. an increase of either, the air-temperature, wind and the atmospheric CO_2 concentration.
To measure ecosystem effects of the applied change scenario's the model outcomes were summarized as the length of the stratification period, the net primary production, bacterial production and net filter feeder production. Comparison between the deep summer stratified North Sea and the shallow well mixed parts were made and are given in the tables below.

area:		Southern North Sea (51-54° N)			Northern North Sea (54-59.5°N)		
variable ↓	run:	standard	$T_{air} = T_{air} +2$	f	standard	$T_{air} = T_{air} +2$	f
surface temperature (°C)		11.9	12.9	1.08	10.7	10.7	1.0
bottom temperature (°C)		11.8	12.9	1.09	9.2	11.6	1.26
days with stratification (d)		27	29	1.07	153	159	1.04
net. prim prod. (gC m^{-2} y^{-1})		193.1	203.2	1.05	149.6	155.5	1.04
net. bact. Prod. (gC m^{-2} y^{-1})		156.6	164.3	1.05	70	72.6	1.05
filter-feeder prod.(gC $m^{-2}y^{-1}$)		3.43	3.3	0.96	2.1	2.0	0.95

The effects of a 10% increase in wind speed leads to 1.5 times higher silt concentration in the water column resulting in lower net primary production, a reduction of stratification and a decrease of bacterial and filterfeeder production.

area:		Southern North Sea (54-57° N)			Northern North Sea (57-59.5°N)		
variable ↓	run:	standard	wind= wind*1.1	f	standard	wind= wind*1.1	f
surface temperature (°C)		11.9	11.7	0.99	10.7	10.6	0.99
bottom temperature (°C)		11.9	11.7	0.99	8.8	8.8	1.0
days with stratification (d)		27	22	0.81	153	141	0.93
net. prim prod. (gC m^{-2} y^{-1})		193.1	181.7	0.94	149.6	135.8	0.90
net. bact. prod. (gC m^{-2} y^{-1})		156.6	148.6	0.98	70	66.4	0.94
filterfeeder prod. (gC m^{-2} y^{-1})		3.43	3.2	0.96	2.1	1.8	0.83

9.5 Publications and other products

Craeymeersch J.A., R. Witbaard, E. Dijkman & H.W.G. Meesters 2008. Ruimtelijke en temporele patronen in de diversiteit van de macrobenthische infauna op het Nederlands Continentaal Plat. IMARES Rapport C070/08 40 pp.

Lindeboom H.J. (Ed) 2008. Ecologische Atlas Noordzee ten behoeve van gebiedsbescherming. Wageningen IMARES, 289pp.

Lindeboom H. 2010. Emigma, (NSEIMS) A data management and information system. Available upon request.

Meesters H.W.G., R. Witbaard, F.E. Fey, E. Dijkman & J. Cremer 2010. EMIGMA Effect modellering indicatoren Gebruik en Management. Beschrijving en handleiding bij Emigma (revisie). IMARES rapport 2010. in prep.

Witbaard R., H.W.G. Meesters, G. Duineveld & R. Daan 2010. A 15 year time-trend of the macrobenthic fauna on the Dutch continental Shelf. in prep.

Climate changes Spatial Planning

Climate change is one of the major environmental issues of this century. The Netherlands are expected to face climate change impacts on all land- and water related sectors. Therefore water management and spatial planning have to take climate change into account. The research programme 'Climate changes Spatial Planning', that ran from 2004 to 2011, aimed to create applied knowledge to support society to take the right decisions and measures to reduce the adverse impacts of climate change. It focused on enhancing joint learning between scientists and practitioners in the fields of spatial planning, nature, agriculture, and water- and flood risk management. Under the programme five themes were developed: climate scenarios; mitigation; adaptation; integration and communication. Of all scientific research projects synthesis reports were produced. This report is part of the Adaptation series.

Adaptation

Dutch climate research uses a 'climate proofing' approach for adaptation. Climate proofing does not mean reducing climate based risks to zero; that would be an unrealistic goal for any country. The idea is to use a combination of infrastructural, institutional, social and financial adaptation strategies to reduce risk and optimalise opportunities for large scale innovations. Climate changes Spatial Planning realised projects in a multidisciplinary network that jointly assessed impacts and developed adaptation strategies and measures. The following themes were central to the programme: water safety, extreme precipitation, nature and biodiversity, agriculture, urban areas, transport (inland and road transport) and the North Sea ecosystem. In special projects, the so called hotspots, location-specific measures were developed that focused on combining 'blue', 'green' and 'red' functions.

Programme Office Climate changes Spatial Planning

c/o VU University Amsterdam, FALW
De Boelelaan 1085
1081 HV Amsterdam
The Netherlands
T +31 20 598 7318

c/o Alterra, Wageningen UR
P.O. Box 47
6700 AA Wageningen
The Netherlands
T +31 317 48 6540
info@klimaatvoorruimte.nl

www.climatechangesspatialplanning.nl