WADDEN SEA ECOSYSTEM No. 25

Quality Status Report 2009
Thematic Report No. 4.2

Climate Change and Ecology

Katja Philippart

Eric Epping

2009
Common Wadden Sea Secretariat
Trilateral Monitoring and Assessment Group

Colophon

Publisher
Common Wadden Sea Secretariat (CWSS), Wilhelmshaven, Germany;
Trilateral Monitoring and Assessment Group (TMAG).

Editors
Harald Marencic, Common Wadden Sea Secretariat (CWSS)
Virchowstr. 1, D - 26382 Wilhelmshaven, Germany

Jaap de Vlas, Rijkswaterstaat, Waterdienst
Lelystad, The Netherlands

Language support
Seabury Salmon

Lay-out and technical editing
Common Wadden Sea Secretariat

Graphic support
Gerold Lüerßen

Published
2009

ISSN 0946-896X

This publication should be cited as:
Katja Philippart and Eric Epping, 2009. Climate change and ecology. Thematic Report No. 4.2. In: Marencic, H. & Vlas, J. de (Eds), 2009. Quality Status Report 2009. Wadden Sea Ecosystem No. 25. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Wilhelmshaven, Germany.

4.2 Climate change and ecology

4.2.1 Observed and expected changes

The Northern Hemisphere has been warmer since 1980 than for any period during the last 2,000 years, and has experienced a stronger temperature increase for northern than for southern latitudes. Observations of the Sea Surface Temperature (SST) from the western Wadden Sea have shown a cooling trend in the late 19th Century, as well as a steady warming trend between ~1980 and the early 21st Century (Figure 4.2.1; Van Aken, 2008). Ongoing research and analyses shows that the year-to-year variations in SST as well as the long-term trends correlate well with changing atmospheric circulation and with changes in cloudiness (Van Aken, 2010).

Climate models predict an increase for global mean air temperature of 1°C up to 6°C for the year 2100 relative to 1990 (IPCC 2007). In Europe, the average temperature increase will probably be slightly faster than the world average. Based on the most recent results from climate research, KNMI (Royal Netherlands Meteorological Institute) has developed four climate scenarios for The Netherlands (see Table 4.2.1). Although the rate of change varies between these scenarios, a number of key characteristics of climate change in The Netherlands and bordering areas are common across all of them, viz. a continuation of the rise in temperature, an increased frequency of mild winters and hot summers, an increase in precipitation during winters, an increase in extremes in precipitation, and a further rise of the sea level (http://www.knmi.nl/climatescenarios/knmi06/).

4.2.2 Synergistic effects

Throughout the history of Wadden Sea observations, several drivers (*e.g.*, large infrastructural works, eutrophication, fisheries, pollutants, and invasive species) have been identified that changed the functioning of the Wadden Sea ecosystem. Some have been effective for a restricted period of time and have been countered by effective measures and policies, whereas others continue to affect the functioning. Most of these drivers have often been treated as isolated actors for change. More likely, several drivers have been acting in concert which may have amplified or suppressed responses to individual drivers. The reduction in nutrient supply, for example, has not been followed by a decrease in productivity and biomass of phytoplankton. This lack of response may be due to concurrent ecosystem changes (*e.g.*, lower stocks of filter-feeding bivalves) that prevent a restoration according to the original nutrient-primary production relationships (see Figure 4.2.2).

In a similar way, the response of marine systems to climate change will also depend on other human-induced changes in the marine environment (such as fisheries, nutrient enrichment of many coastal regions, ocean acidification, contamination and the introduction of non-native species). These changes are likely to result in more fragile marine ecosystems, which will challenge the effectiveness of the management strategies to reduce the impacts of climate change. Future effects of climate change should, therefore, always be considered with regard to synergistic effects of other drivers on the Wadden Sea ecosystem.

4.2.3 Possible consequences

Climate change may stress the present structure and functioning of the food web and may result in a cascade of yet unknown effects. For example, the response of organisms and of the ecosystem as a whole may not only depend on these absolute shifts in temperature, but on the phasing of the new temperature regimen (tidally, daily

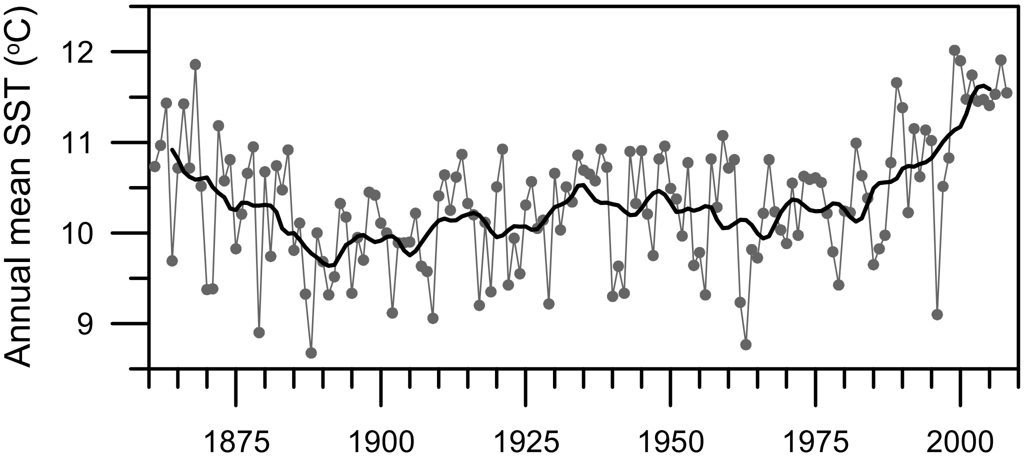

Figure 4.2.1: Long-term field observations on water temperature (annual means) in the Marsdiep tidal inlet between 1861 and 2008. The thick line indicates the 10-year running average (Van Aken, 2008).

Table 4.2.1: Climate change in The Netherlands around 2100 compared to the baseline year 1990, according to the four KNMI'06 climate scenarios (http://www.knmi.nl/climatescenarios/knmi06/). The climate in the baseline year 1990 is described with data from the period 1976 to 2005. The seasons are defined as follows: 'winter' stands for December, January and February, and 'summer' stands for June, July and August.

2100		Moderate	Moderate+	Warm	Warm+
Global temperature rise		+2°C	+2°C	+4°C	+4°C
Change in air circulation patterns		no	yes	no	yes
Winter	Average temperature	+1,8°C	+2,3°C	+3,6°C	+4,6°C
	Coldest winter day per year	+2,1°C	+2,9°C	+4,2°C	+5,8°C
	Average precipitation amount	+7%	+14%	+14%	+28%
	Number of wet days (≥0,1 mm)	0%	+2%	0%	+4%
	10-day precipitation sum exceeded once in 10 years	+8%	+12%	+16%	+24%
	Maximum average daily wind speed per year	-1%	+4%	-2%	+8%
Summer	Average temperature	+1,7°C	+2,8°C	+3,4°C	+5,6°C
	Warmest summer day per year	+2,1°C	+3,8°C	+4,2°C	+7,6°C
	Average precipitation amount	+6%	-19%	+12%	-38%
	Number of wet days (≥0,1 mm)	-3%	-19%	-6%	-38%
	Daily precipitation sum exceeded once in 10 years	+27%	+10%	+54%	+20%
	Potential evaporation	+7%	+15%	+14%	+30%
Sea level	Absolute increase	35-60 cm	35-60 cm	40-85 cm	40-85 cm

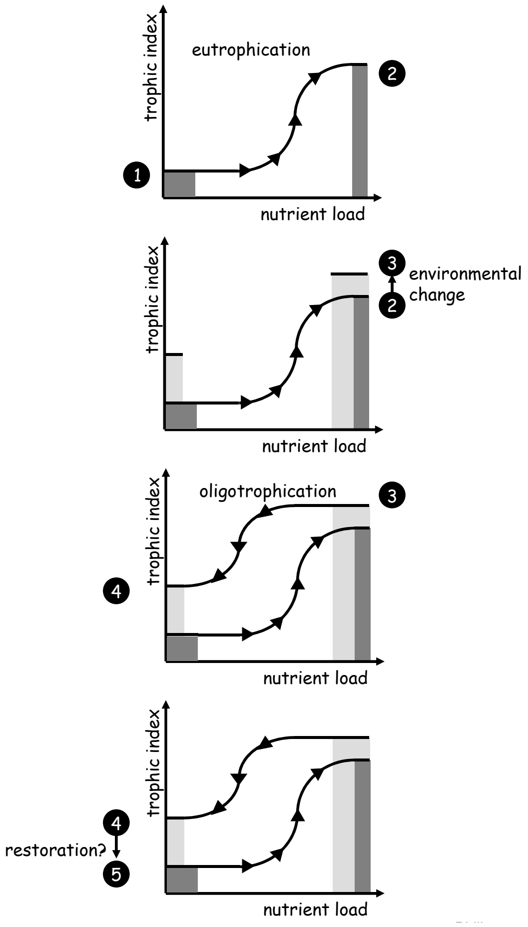

Figure 4.2.2: Conceptual model of environmental changes in the Wadden Sea. An increase in nutrient loads ("eutrophication") causes a change in a trophic index (e.g., primary productivity) from a low to a higher value. During this period of eutrophication, however, other environmental conditions may alter as well (e.g., a decline in stocks of filter-feeding bivalves as the result of overfishing or climate change) preventing a relaxation to initial conditions.

and seasonally) with other key variables as well. Extreme scenarios involve major changes in the present balance between the surface of tidal and subtidal areas, between autotrophy and heterotrophy, between pelagic and benthic production, and between import and export of energy and matter. These shifts in ecosystem functioning will inevitably have consequences for possibilities and limits of sustainable use and for the protection of natural ecosystems and their services. For the Wadden Sea, we envision the following possible developments.

4.2.3.1 Sediments

With increasing temperature, the kinematic viscosity of water decreases. As a result, the mobility potential of non-cohesive sediments decreases, whereas the particle settling velocities increase (Krögel and Flemming, 1998). The effect of an increase in water temperatures on settling and resuspension rates of sediment may lead to a shift in the timing of sediment redistribution and of stabilization, which may have consequences for the pelagic (via effects on turbidity) and benthic (via effects on habitats) biomass and production.

Rising sea level not only inundates the lower coastal regions but also contributes to the redistribution of sediment along sandy coasts. Long-term beach erosion may increase due to accelerated sea-level rise (SLR) and may eventually lead to the deterioration of barrier chains such as the Wadden Sea (Fitzgerald *et al.*, 2008). If SLR is not compensated by sedimentation, tidal exchange through inlets increases, which leads to sand sequestration in ebb-tidal deltas and (further) erosion of adjacent barrier shorelines.

4.2.3.2 Nutrients

The combination of a decrease in oxygen solubility and an increase in sulfate reduction rate with increasing temperatures, may promote low redox conditions, or even the formation of sulfureta in sediments. This transition may induce major shifts in the geochemistry of sediments and in the biogeochemical cycles of essential elements.

A higher annual river runoff will inevitably result in relatively higher TN and TP outputs from the IJsselmeer to the Wadden Sea, thereby counteracting ongoing de-eutrophication measures and stimulating coastal eutrophication (Van Raaphorst and De Jonge, 2004). It will also result in an increased input of sediment by means of river runoff, which will lower the transparency of the Wadden Sea, affecting the absolute and relative production by phytoplankton and microphytobenthos.

4.2.3.3 Primary producers

Enzymatic process rates, like respiration, on average increase by a factor of 2-3 with a rise in temperature of 10°C. Photosynthesis, however, is temperature sensitive only at light saturating conditions, when the carboxylation rate is limited by RuBisCO activity. At non-saturating conditions, photosynthesis is far less sensitive to changes in temperature. The temperature-induced increase in respiration without a concomitant increase in gross photosynthesis will reduce the rate of photosynthesis and alter the fitness of individual phototrophic species. As a consequence, the species composition of the phototrophic community may change. On an ecosystem level, the differential effect of temperature on photosynthesis and respiration may also result in a more heterotrophic nature of the Wadden Sea, with a concomitant reduction in net productivity and food availability.

A change from a rather constant to a strongly pulsed supply of riverine nutrients may drastically change the microalgal competition for nutrients and favour large phytoplankton species (Stolte and Riegman, 1995). Because of their larger storage capacity, these species are better competitors under high and fluctuating nutrient regimes than smaller algae (Sommer, 1984; Stolte *et al.*, 1994; Grover, 1997). Reduced grazing pressures and enhanced rates of sedimentation may result in an enhanced carbon and energy flux to benthic communities (Thingstad and Sakshaug, 1990; Riegman *et al.*, 1993).

An earlier seasonal onset of zooplankton grazing due to increased spring temperatures (Wiltshire and Manly, 2004) may restrain the peak in microalgal biomass during the spring phytoplankton bloom, and promote regenerative production by flagellates at the expense of diatoms.

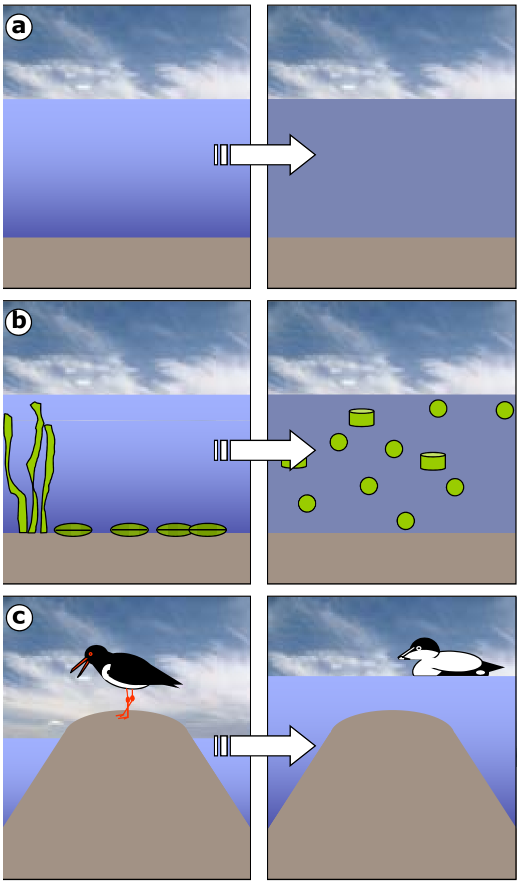

Figure 4.2.3: Some examples of possible developments within the Wadden Sea under various scenarios of climate change. (a) An increase in rainfall and storminess may result in higher concentrations of total suspended matter and subsequently to increased turbidity of the waters of the Wadden Sea. (b) Increased turbidity and riverine nutrient loads may result in a shift within primary producers from benthic (seagrass and microphytobenthos) to pelagic (phytoplankton) species. (c) If sea level rise is not compensated by an increase in sedimentation, the subsequent drowning of the tidal flats may reduce species that feed on tidal flats during emergence and favour those that mainly rely on subtidal food sources (Drawings by KP).

An increase in river runoff and subsequent lowering in salinity may lead to shifts from marine to more brackish species such as a shift within macrophytes from seagrasses (*Zostera noltii*) to widgeon grass (*Ruppia maritima*) (Van Katwijk *et al.*, 2005).

4.2.3.4 Secondary producers

On the level of higher organisms, the demand for oxygen may exceed the capacity of oxygen supply to tissues at elevated temperatures, restricting whole-animal tolerance to thermal extremes (Portner and Knust, 2007). Mismatches in metabolic balances, food availability and relationships between predators and preys affect mortality and reproduction rates, and have resulted in shifts from Arctic to Atlantic species in the more northern seas and from temperate to more subtropical species in southern waters (Philippart *et al.*, 2007). With increasing temperatures, more shifts and the establishment of new trophic relationships are to be expected.

For the Wadden Sea, an increased frequency of mild winters will favour macrobenthic species which are sensitive to cold winters, and result

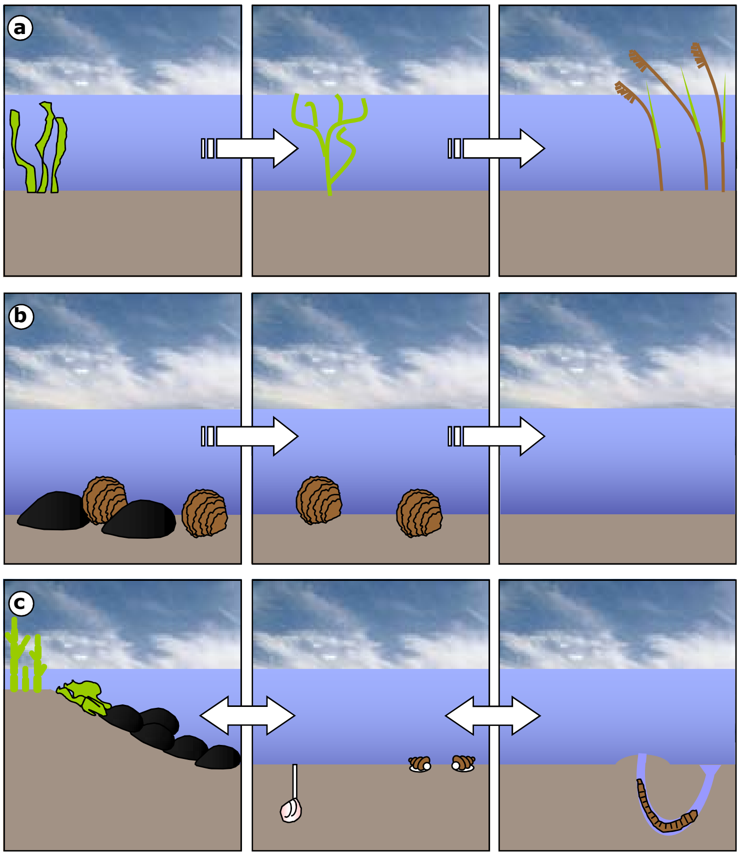

Figure 4.2.4: Some examples of possible developments within the Wadden Sea under various scenarios of climate change. (a) An increase in river runoff and subsequent lowering in salinity may lead to shifts from marine to more brackish species near the freshwater sources, e.g., a shift from *Zostera* to *Ruppia* and *Phragmites*. (b) A decrease in pH values may affect calcifying species with *Mytilus* being more vulnerable than Crassostrea. (c) Climate-induced changes in macrozoobenthos communities will change the effects of this fauna on the sediment, e.g., by means of stabilisation, de-stabilisation and bioturbation (Drawings by KP).

in greater weight loss in all bivalves during the winter and low reproductive success in the subsequent summer for various important (bivalve) species (*e.g.*, *Mya arenaria*, *Mytilus edulis* and *Cerastoderma edule*) (Beukema, 2002), possibly as a consequence of enhanced predation on bivalve spat by juvenile shrimps (Beukema, 1992; Philippart *et al.*, 2003). The reproductive success of warm-water species, such as *Crassostrea gigas*, may be favoured by higher temperatures in (late) summer (Diederich *et al.*, 2005).

An increase in river runoff and subsequent lowering in salinity may lead to shifts from marine to more brackish species such as a shift within polychaetes from lugworms (*Arenicola marina*) to nereid polychaetes (*Nereis diversicolor* and *N. virens*) (Zipperle and Reise, 2007).

4.2.3.5 Ecosystem functioning and feedbacks

Changes in the balance between production by phytoplankton and microphytobenthos may affect the cycling of energy and matter (*e.g.*, via pelagic zooplankton versus filter-feeding macrozoobenthos), the food availability for macrozoobenthos (*e.g.*, filter-feeding bivalves versus deposit-feeding polychaetes), and the fate of energy and matter (*e.g.*, export through pelagic communities versus local retention in benthic communities).

For example, changes in standing stocks of filter-feeding bivalves may affect algal stocks due to changes in grazing pressure, affect growth of other benthic species due to reduced or enhanced competition for food, and change the food availability for shellfish-eating fish and birds (Beukema, 2002; Cadée, 2008). In addition, changes in reef-building bivalves (such as *Mytilus edulis* and *Crassostrea gigas*) as the result of acidification (Gazeau *et al.*, 2007) will affect the balance between erosion and sedimentation and, as the result of supplying specific habitats for marine flora and fauna, the local biodiversity (Cadée, 2007; Kochman *et al.*. 2008).

In addition, changes in macrozoobenthos communities will change the effects of this fauna on the sediment (*e.g.*, by means of stabilisation, de-stabilisation and bioturbation), subsequently affecting bio-irrigation of oxygen and nutrients, survival of resting stages of planktonic organisms such as copepods, diatoms and dinoflagellates, and the burial rates of 'solid particles' such as clay, organic matter, eggs and shells (Reise, 2002; Widdows and Brinsley, 2002; Meysman *et al.*, 2006).

4.2.4 Next steps

Coastal waters are most likely to change as the result of past and current activities and changes in climate settings. The potential climate scenarios provided here are highly speculative and are based on still limited knowledge of isolated processes. Understanding the functioning of the Wadden Sea ecosystem as a composite, including positive and negative feedback mechanisms, is urgently needed to develop prognostic models and to construct reliable future scenarios. A European and integrated coastal monitoring network is required to keep close track of variations and trends in the coastal environment.

National and European policies tend to focus on state variables (such as phytoplankton biomass), which may signal environmental changes, but are of limited use for identifying the causes of change. There is, therefore, a need to extend conventional monitoring programs with a parallel assaying of key processes. Since ecosystem functioning often comes down to species, we should encourage the painstaking work of monitoring marine organisms to species level, including their larval and postlarval stages (early warning system approach). In order to project the consequences of environmental changes for biodiversity, we have to assess the plasticity of (key) species towards environmental conditions.

This knowledge should be integrated in mechanistic ecosystem models as a tool for managing the marine environment (*e.g.*, examining scenarios of nutrient reduction, protected areas and exploitation of marine resources). Effort should focus on ensuring that the level of detail (complexity) of the models matches what can and will be measured, including species-specific data. The latter will enable appropriate parameter values to be obtained and ensure that the models are fit-for-purpose and not unnecessarily complicated.

As a summary of strategic research topics to adequately understand and project the consequences of climate change for biodiversity and ecosystem functioning of the sea, we therefore need to (1) extend our coastal monitoring efforts; (2) extend our knowledge on sensitivities and adaptation capabilities of key species in the marine environment; and (3) develop fit-for-purpose models to manage our marine environment.

More explicitly, we advocate including measurements of process rates to present monitoring efforts on state variables at several specific locations, reflecting the various habitats and large-scale variation throughout the Wadden Sea. These sites should not only be used for monitoring, but also be the focus points for experiments and teaching and learning about the ongoing changes in ecosystem functioning and the factors that are underlying these changes.

Acknowledgements

This work was based upon two invited lectures (by Eric Epping and Katja Philippart) during the Wadden Sea Symposium in 2007, and supported by the National Programme Sea and Coastal Research funded by The Netherlands Organisation for Scientific Research (NWO).

References

Beukema, J.J., 1992. Dynamics of juvenile shrimp *Crangon crangon* in a tidal-flat nursery of the Wadden Sea after mild and cold winters. Marine Ecology Progress Series 83:157-165.

Beukema, J.J., 2002. Expected changes in the Wadden Sea benthos in a warmer world: lessons from periods with mild winters. Journal of Sea Research 30:73-79.

Cadée, G.C., 2007. Will the recent *Crassostrea gigas* reefs replace the former *Ostrea edulis* beds in the Wadden Sea? [Vervangen de recente Japanse oesterriffen de vroegere oesterbanken?]. De Levende Natuur 108: 62-65.

Cadée, G.C., 2008. Scholeksters en Japanse oesters. Natura 105:6-7.

Diederich, S., G. Nehls, J.E.E. van Beusekom, and K. Reise. 2005. Introduced Pacific oysters (*Crassostrea gigas*) in the northern Wadden Sea: invasion accelerated by warm summers? Helgoland Marine Research 59:97-106.

FitzGerald, D.M., Fenster, M.S., Argow, B.A. and Buynevich, I.V., 2008. Coastal Impacts Due to Sea-Level Rise. Annual Review of Earth and Planetary Sciences 36:601-647

Gazeau, F., Quiblier, C., Jansen, J., Gattuso, J.P., Middelburg, J. and Heip, C.H.R., 2007. Impact of elevated CO2 on shellfish calcification. Geophysical Research Letters 34: L07603, doi:10.1029/2006GL028554.

Grover, J. P., 1997. Resource competition. Chapman & Hall.

International Panel on Climate Change – IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K Pachauri, and A.Reisinger (Eds)]. IPCC, Geneva, Switzerland. 104 pp.

Kochmann, J., Buschbaum, C., Volkenborn, N. and Reise, K., 2008. Shift from native mussels to alien oysters: Differential effects of ecosystem engineers. Journal of Experimental Marine Biology and Ecology 364:1-10.

Krögel, F. and Flemming, B.W., 1998. Evidence for temperature-adjusted sediment distributions in the backbarrier tidal flats of the East Frisian Wadden Sea (southern North Sea). In: Alexander, C.R., Davis, R.A. and Henry, V.J. (Eds) Tidalites: Processes and Products. SEPM Spec Publ 61:31-41

Meysman, F.J.R., Middelburg, J.J. and Heip, C.H.R., 2006. Bioturbation: a fresh look at Darwin's last idea. Trends in Ecology and Evolution 21:688-695.

Philippart, C.J.M., van Aken, H.M., Beukema, J.J., Bos, O.G., Cadée, G.C. and Dekker, R., 2003. Climate-related changes in recruitment of the bivalve *Macoma balthica.* Limnology and Oceanography 48:2171-2185.

Philippart, C.J.M., Anadón, R., Danovaro, R., Dippner, J.W., Drinkwater, K.F., Hawkins, S.J., Oguz, T., O'Sullivan, G. and Reid, P.C., 2007. Impacts of climate change on the European marine and coastal environment: ecosystems approach. ESF Marine Board Position Paper, 9. European Science Foundation, Marine Board: Strasbourg, France. ISBN 2-912049-63-6. 82 pp.

Portner, H.O. and Knust, R., 2007. Climate change affects marine fishes through the oxygen limitation of thermal tolerance. Science 315:95-97.

Reise, K., 2002. Sediment mediated species interactions in coastal waters. Journal of Sea Research 48:127-141.

Riegman, R., Kuipers, B.R., Noordeloos, A.A.M., and Witte, H., 1993. Size-differential control of phytoplankton and the structure of plankton communities. Netherlands Journal of Sea Research 31:255-265.

Sommer, U., 1984. The paradox of the plankton: fluctuations of phosphorus availability maintain diversity in flow-through cultures. Limnology and Oceanography 29:633-636.

Stolte, W., McCollin, T., Noordeloos, A.A.M. and Riegman, R., 1994. Effect of nitrogen source on the size distribution within marine phytoplankton populations. Journal of experimental marine Biology and Ecology 184:83-97.

Stolte, W. and Riegman, R., 1995. Effect of phytoplankton cell size on transient-state nitrate and ammonium uptake kinetics. Microbiology 141:1221-1229.

Thingstad, T.F. and Sakshaug, E., 1990. Control of phytoplankton growth in nutrient recycling ecosystems. Theory and terminology. Marine Ecology Progress Series 63:261-272.

Van Aken, H.M., 2008. Variability of the water temperature in the western Wadden Sea on tidal to centennial time scales. Journal of Sea Research 60: 227-234.

Van Aken, H.M., 2010. Meteorological forcing of long-term temperature variations of the Dutch coastal waters. Journal of Sea Research 63,143-15.

Van Katwijk, M.M., Bos, A.R. and Hermus, D.C.R., 2005. Klein zeegras en Snavelruppia op het Balgzand. Report Afdeling milieukunde, Radboud Universiteit Nijmegen. 34 pp. [in Dutch]

Van Raaphorst, W. and de Jonge, V.N., 2004. Reconstruction of the total N and P inputs from the IJsselmeer into the western Wadden Sea between 1935-1998. Journal of Sea Research 51:109-131.

Widdows, J. and Brinsley, M., 2002. Impact of biotic and abiotic processes on sediment dynamics and the consequences to the structure and functioning of the intertidal zone. Journal of Sea Research 48:143-156.

Wiltshire, K.H. and Manly, B.F.J., 2004. The warming trend at Helgoland Roads, North Sea: phytoplankton response. Helgoland Marine Research 58:269-273.

Zipperle, A. and Reise, K., 2005. Freshwater springs on intertidal sand flats cause a switch in dominance among polychaete worms. Journal of Sea Research 54:143-150.