Climate and Human Induced Impacts on the Coastal Zone of the Southern North Sea

Victor Smetacek[*1], Gerold Wefer[2], Jürgen Alheit[3], Frank Lamy[2], Adrian de Kraker[4], Burghard Flemming[5], Han Lindeboom[6], Hansjörg Streif[7], Tjeerd van Weering[6], Hans von Storch[9]*

[1]Alfred-Wegener-Institute for Polar and Marine Research, Am Handelshafen 12, D-27570 Bremerhaven, Germany
[2]University of Bremen, Department of Geosciences, Postfach 33 04 40, D-28334 Bremen, Germany
[3]Baltic Sea Research Institute, Seestraße 15, D-18119 Warnemünde, Germany
[4]University of Amsterdam, Department of Human Geography, Nieuwe Prinsengracht 130, NL-1018 VZ Amsterdam, The Netherlands
[5]Senckenberg Institute, Schleusenstraße. 39A, D-26382 Wilhelmshaven, Germany
[6]Netherlands Institute for Sea Research (NIOZ), P.O. Box 59, NL-1790 AB Den Burg, The Netherlands
[7] Niedersächsisches Landesamt für Bodenforschung, Stilleweg 2, 30655 Hannover, Germany
[8]Institute for Coastal Research, GKSS Research Center, Max-Planck-Strasse 1, D-21502 Geesthacht, Germany
** corresponding author (e-mail): vsmetacek@awi-bremerhaven.de*

Abstract: Ongoing changes in the morphology and ecology of the coastal zone and expected future scenarios with emphasis on the southern North Sea were discussed and research needs identified. The impact of sea level rise and the effects of resultant dyking activity need to be considered for the entire coastal zone as manipulation in one region can have unexpected effects in neighbouring areas. The extent to which the barrier islands can be maintained in their present state has also to be critically assessed. Anthropogenic impacts on coastal ecosystems can be direct (e.g. diking, fisheries) or subtle (pollutants). However, differentiating climate-induced from anthropogenic impacts is not always obvious. Long-term, integrated data sets provide the best context for evaluating observations of individual phenomena. Maintenance of monitoring programmes and introduction of new methodologies to extend coverage and detail is required for this purpose. The role of public perception was discussed at length as coastal management is not as much management of nature as it is management of human activity. Hence it is essential that social scientists be involved to a greater extent in decision-making processes.

Introduction

The coastal zone has been occupied by humans for many millennia but it is only since about the 16th century that anthropogenic impact has become a significant shaping force. Coastal plain environments such as the southern coast of the North Sea are most strongly impacted because dyke building fundamentally alters the land-sea interface, hence also the coastal sea and its ecosystems. Until recently coastal engineering was mainly concerned with protecting the land from ravages of the sea but experience gained so far has led to the realisation that the entire coastal system needs to be treated as a whole, as modifications in one area can lead to unexpected developments in adjoining regions.

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Besides, the impact on marine ecosystems is increasingly becoming a cause for concern.

This report summarises the discussion that were held by a multidisciplinary group at the Hanse-Wissenschaftskolleg. The intention of the discussions was to ascertain what has been learned so far and what can be expected in the future.

Coastline, Islands and Sediments

The southern North Sea is roughly triangular in shape. From the Rhine delta the coastline stretches in north-eastern to eastern directions as far as the Elbe estuary where it turns northward along the western coast of Schleswig-Holstein and Jutland, Denmark. A maximum water depth of the southern North Sea of about 70 m is encountered on the north-western flank of the Dogger Bank; however, the depth is generally less than 45 m in the inner part of the German Bight.

The following tidal zones can be distinguished along the southern North Sea coast. Low mesotides with an amplitude between 1 and 2 m occur between the Rhine delta and the island of Terschelling, the Netherlands. High mesotides with an amplitude of 2 to 3 m occur eastward from Terschelling as far as the island of Wangerooge. Low macrotides with an amplitude of more than 3 m occur in the innermost part of the German Bight (Siefert and Lassen 1985), between the tidal inlet of the Jade Bay and the peninsula of Eiderstedt, Schleswig-Holstein, reaching a maximum value of 4.2 m at Bremen on the Weser estuary. The tidal amplitude decreases in a northerly direction to that characteristic of high mesotides between Eiderstedt and Sylt, to that of low mesotides between Sylt and Blåvands-Huk, and to that of microtides on the north of Nymindegab, Denmark.

The present tidal conditions are partly mirrored by the coastal morphology. Continuous barrier systems partly with lagoons (Ringkøbingfjord and Nissumfjord) exist in the zone of small tidal amplitudes along the western coasts of the Netherlands and Denmark. Elongated barrier islands (West Friesian and East Friesian islands) and sheltered tidal flats occur in the zone which is affected by low to high mesotides. Characteristic for the macrotidal conditions in the innermost part of the German Bight are extended open tidal flats and rounded to sickle-shaped sandy shoals (Mellum, Scharhörn, Trischen, Tertius, and Blauort), which in part are mobile and ephemeral structures.

Additionally, the present-day morphology of the coastal landscape is strongly influenced by geological elements which were formed prior to the Weichselian late glacial and Holocene sea-level rise. Cores of Pliocene and Pleistocene sediments, surrounded by Holocene coastal deposits, crop out on the islands of Sylt, Schleswig-Holstein, as well as on Texel, in the Netherlands. Other structures were formed by the medieval storm surges which destroyed extended areas of former coastal marshlands and formed huge tidal bays like the former Zuider Zee (nowadays Ijsselmeer) and the Lauwers Zee in the Netherlands. Comparable structures are the bay flats existing along the coast of Niedersachsen, Germany, Dollart and Jade Bay. Severe destruction of former coastal marshland which occurred along the western coast of Schleswig-Holstein in the course of the storm surges of 1362 and 1634 AD created a special form of islands, the so-called Halligen. These marsh islands like Nordstrand, Pellworm and a group of smaller islands consist of Holocene tidal flat to brackisch sediments as well as of peat. Special forms of the Halligen are Föhr and Amrum which have cores of outcropping Pleistocene sediments. Additionally, Amrum is characterised by a spit-like sandy beach.

Late Holocene Sea-Level Evolution

First evidence for marine influences along the southern margin of the North Sea basin date at roughly 8000 years BP when the rising sea reached a level of about 25 m below the present and began to intrude into the lower valleys of local rivers and streams draining the more elevated Pleistocene sand bodies (e.g. Hanisch 1980; Zagwijn 1986). The postglacial sea-level rise is documented in a number of sea-level curves reconstructed for different sections of the coast. This is represented in Fig. 1 by the rise of mean high-water levels which are more relevant for coastal processes (modified after Flemming and Davis 1994). Besides having some features in common, the curves reveal quite distinct local trends. Thus, the curves rise more steeply up to about 6500 years BP (»10 mm/year), followed by a period of a more gradual rise (»1.5 mm/year) up to the onset of the "Little Ice Age" in the late Middle Ages. A distinct acceleration is again observed over the past 300 years or so, mean high-water levels currently rising by as much as 2.5 mm/year. This acceleration predates any anthropogenic influence and has evidently been overlooked in recent disputes over human impacts on climate change. The current estimates of global warming over the next century (up to 5.8°C) recently reported by the IPCC has led to a corresponding upward correction of the predicted acceleration in mean sea-level rise which is now estimated to reach as much as 8.8 mm/year over the next century. How this would affect the evolution of mean high-water levels is unknown, but a threefold increase in the current rate would not appear unrealistic.

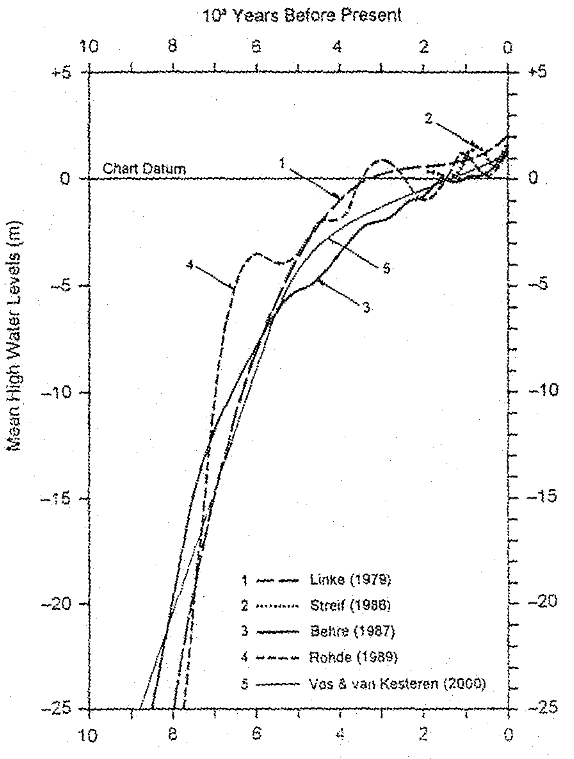

Fig. 1. Holocene evolution of mean high-water levels along different parts of the Wadden Sea coast as reported by different authors (modified after Flemming and Davis 1994). 1: Elbe Estuary near Cuxhaven, Germany (Linke 1979); 2: Island of Wangerooge, East Frisian Wadden Sea (Streif 1986); 3: East Frisian Coast (Behre 1987); 4: North Frisian Wadden Sea, Germany (Rohde1989); 5: Dutch Wadden Sea coast (Vos and van Kesteren 2000).

Of interest in the context of this article are also the departures in the trends of the individual curves. Quite evidently, and irrespective of potential errors in the individual reconstructions, the relative vertical motions of the sea and the local land masses are not synchronised along the shoreline of the southern North Sea, even over distances as little as 100 km. This means that the effects of sea-level rise will have slightly different impacts depending on the location along the coast.

Any acceleration in the rate of sea-level rise will also result in larger tidal ranges. This is intimated in the model illustrated in Fig. 2 (modified after Flemming and Davis 1994; based on data reported in Franken 1987). The individual curves apply to different locations along the coast and show similar temporal trends as the evolution of mean high-water levels (curve 1: western-most Dutch Wadden Sea and northern-most Danish Wadden Sea; curve 2: north of Ameland, central Dutch Wadden Sea; curve 3: north of Spiekeroog, central East Frisian Wadden Sea, Germany). The increasing tidal ranges reflect the tidal response to a deepening water body.

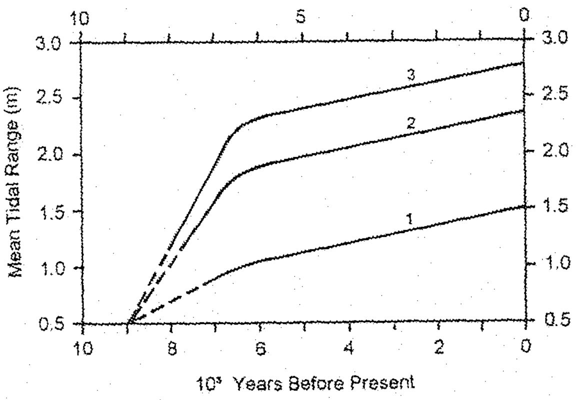

Fig. 2. Holocene evolution of mean tidal ranges at different locations along the southern North Sea coast (modified after Flemming and Davis 1994; based on numerical simulations of Franken 1987). 1: western-most and northern-most Wadden Sea; 2: central Dutch Wadden Sea; 3: central East Frisian Wadden Sea, Germany.

Although the amounts are small in the short-term (a few centimetres/century), they would nevertheless have to be added to the overall effects produced by the rising sea.

In summary, any impacts on the coast produced by an acceleration in sea-level rise will first be felt along the island shores. Beach erosion will increase at locations already experiencing erosion today, whereas currently stable shores will begin to show increasing signs of erosion in the future. Coastal management and protection will thus not only have to cope with locally increasing sand losses at increasingly shorter time intervals, but also with a rapid alongshore expansion of the affected zones.

Mean Sea Level Rise

The mean sea level has undergone an increase of the order of 100 m mainly due to growing volume of sea water in the world ocean in the past 10,000 years. This global increase of sea level is moderated by regional phenomena, mainly glacial rebound and other crustal movements (such as earthquakes).

On shorter time scales, changing circulation patterns affect sea level. On the local scale, anthropogenic effects, such as pumping gas and oil, building dykes and dredging rivers, may have a significant impact on the mean relative height of sea level and coastal land. Also the changing heat content in the ocean, reflecting atmspheric warming for natural or anthropogenic reasons, changes the volume of the ocean and thus the mean sea level. The latter effect is the only one simulated by present day atmosphere-ocean GCMs as a response to a changing composition of the atmosphere because of anthropogenic emissions.

The Intergovernmental Panel on Climate Change has found wide consensus that the global sea level has risen in the past 100 years by something of the order of 10 cm. Locally much larger increases have been found. An example is the record of Cuxhaven in the German Bight, where the mean high tide has increased by about 30 cm in the past century, reflecting probably mostly changing hydrographic conditions in the river Elbe (von Storch and Reichardt 1997). Also in Den Helder such an increase was recorded, whereas the increase in Esbjerg was much smaller (Figs. 3 and 4). In Smogen, at the Swedish coast in the Kattegat, sea level was sinking, likely due to the glacial rebound of land. In the past 40 years, mean sea level has also increased along the entire southern and eastern coast of the North Sea due to a change in the mean atmospheric circulation (Langenberg et al. 1999).

Increases in mean sea level lead to increases in levels of storm surges, even if the statistics of storms is unchanged. In fact, for Cuxhaven a significant increase in the frequency of severe storm surges was noticed, but it turned out that this increase was mostly due to the increase of the mean sea level, since the intensity of storms has not changed significantly in the past century. A similar finding resulted from a North Sea model simulation, where no significant upward trend for the intraseasonal percentiles since about 1960 was found (Langenberg et al. 1999; Kauker and Langenberg 2000). Seemingly, the increase of the intensity of storm activity since the 1960s after a decline since about 1920 (Alexandersson et al. 2000, Fig. 5) was not associated with a significant change in storm surge levels.

Changes in Tidal Range Due to Dyke Building and Channelling of Rivers

The combination of three factors influence the tidal conditions in the estuaries: the changing amount of fresh water discharge from the catchment areas, the tidal wave entering from the seaward side, and the morphology of the rivers. Whereas direct human influences on the water discharge and the tidal wave are of minor importance, anthropogenic modifications of the river morphology have a tremendous influence.

Various technical measures, aimed at different purposes, have been carried out in the estuaries of the rivers Ems, Weser, and Elbe as well as in the tidal inlet of the Jade Bay and have had strong influences on the natural tidal regimes. Of greatest importance were repeated dredging measures for the deepening of shipping channels and the construction of longitudinal training walls as well as groins. All these measures have been carried out to concentrate the natural currents in one main

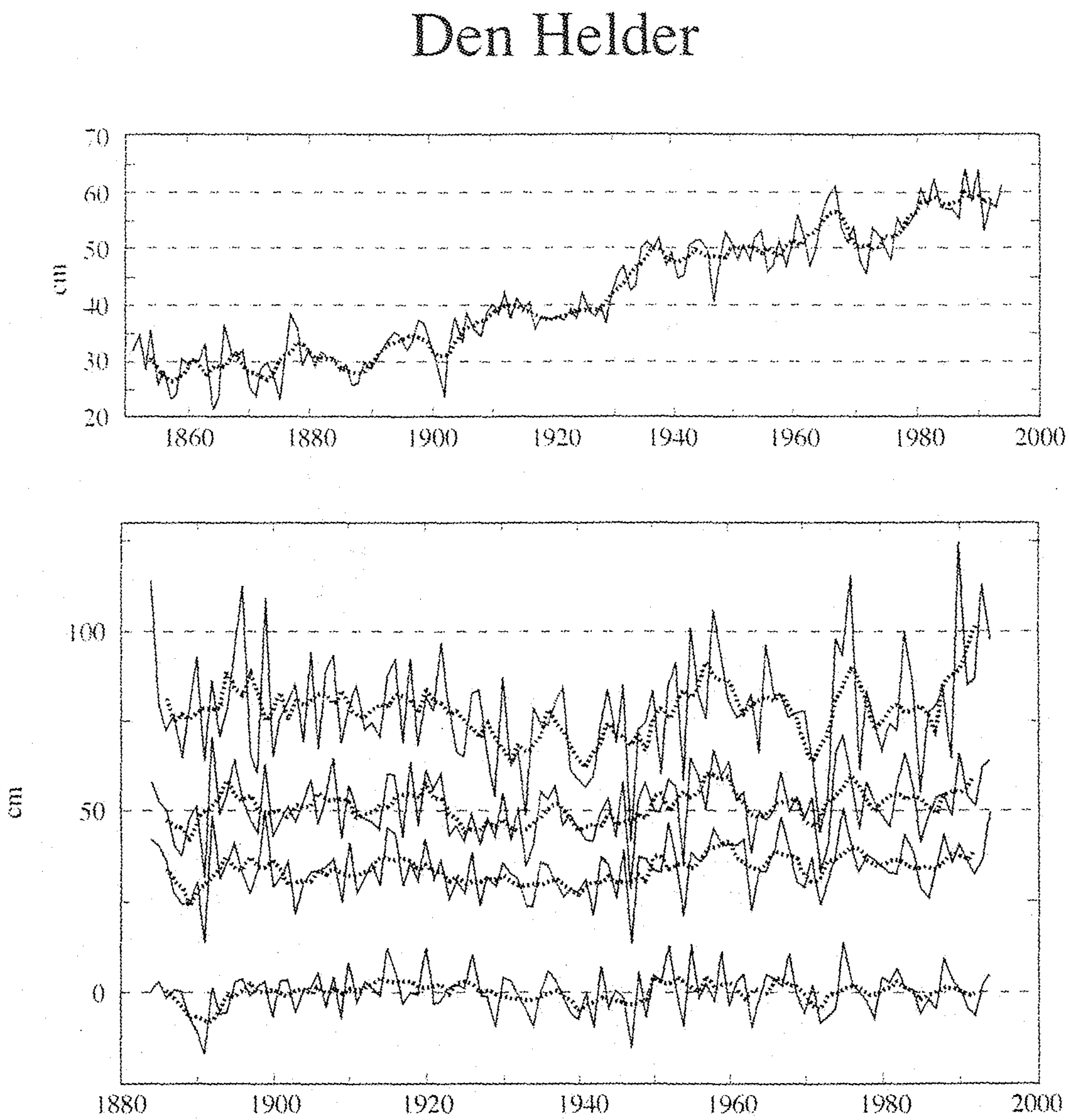

Fig. 3. Changing mean sea level (top) and of intraseasonal (DJF) percentiles after subtraction of trend in mean sea level (bottom) in Den Helder (Pfizenmayer, pers. comm.).

channel with great water depth. Additional influences have come from harbour constructions and extensive high water protection works, such as dykes and barrages against storm tides. At present artificial weirs set the upper limit of the estuaries. Such constructions exist on the river Elbe at Geesthacht, 48 km above Hamburg, on the Weser at Bremen-Hemelingen and at Herbrum on the river Ems.

The most impressive example of anthropogenic influences on the tidal regime can be observed at the lower course of the river Weser (Streif, this volume). The tidal amplitude was 13 cm at the tide gauge at Bremen in 1882. At present it reaches an amplitude of 4.18 m which is the highest tidal range along the entire German North Sea coast. This enormous change is the result of a series of technical measures which began with the first Weser

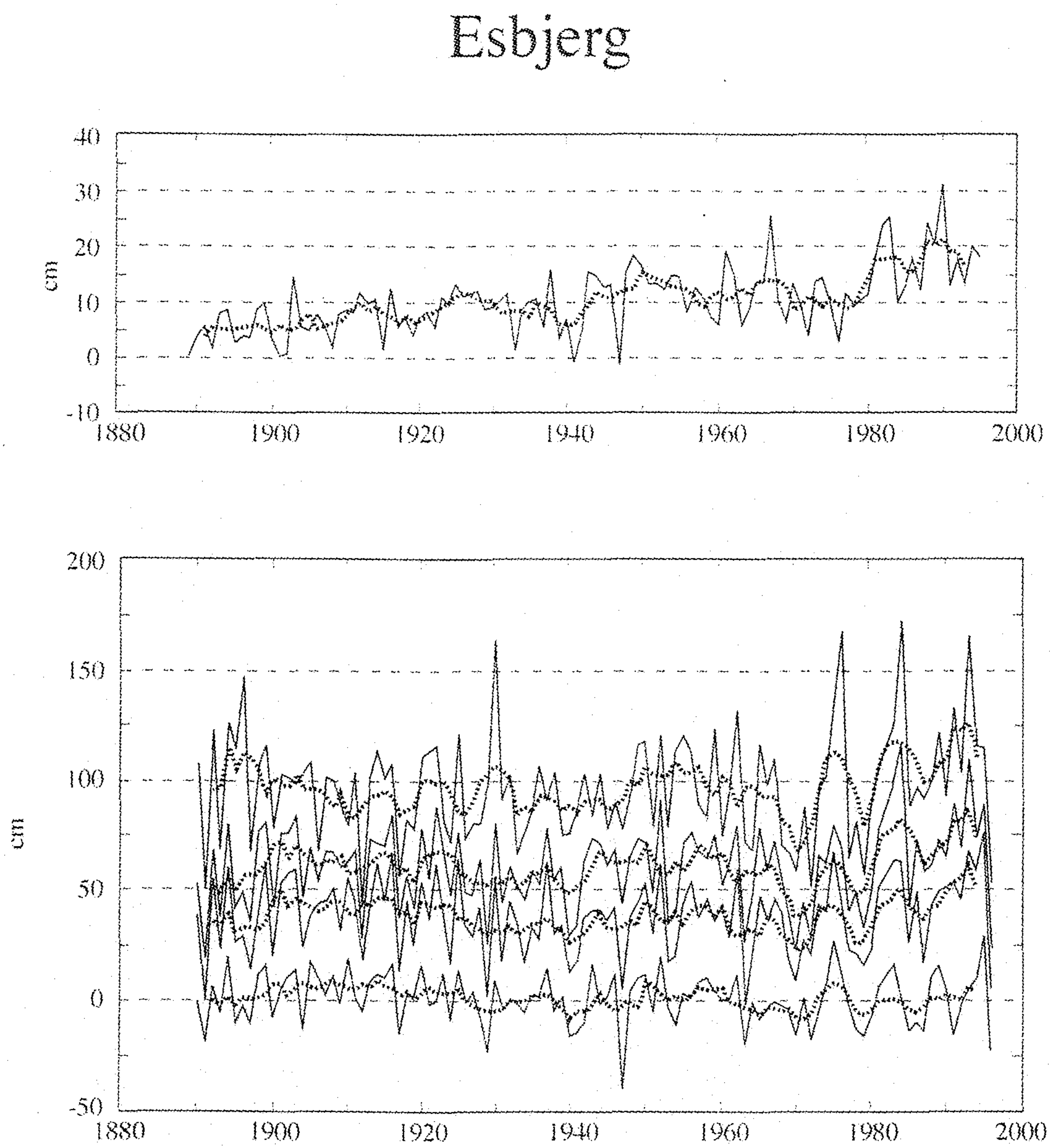

Fig. 4. Changing mean sea level (top) and of intraseasonal (DJF) percentiles after subtraction of trend in mean sea level (bottom) in Esbjerg (Pfizenmayer, pers. comm.).

correction in 1877 and led step by step to the present day conditions. The drastic increase in tidal range is mainly due to a lowering of the low water level and to a small rise of the high water level. Comparable trends, however with a lower amplitude, can be observed at the river Elbe. In the time span between 1887/96 and 1978 the tidal amplitude increased from 1.87 m to 3.35 m at Hamburg-St. Pauli and 0.07 m to 1.43 m at Geesthacht. In the period 1881/85 and 1980, the tidal amplitude of the river Ems increased from 2.18 m to 2.86 at Leer and from 0.2 m to 2.06 m at Herbrum.

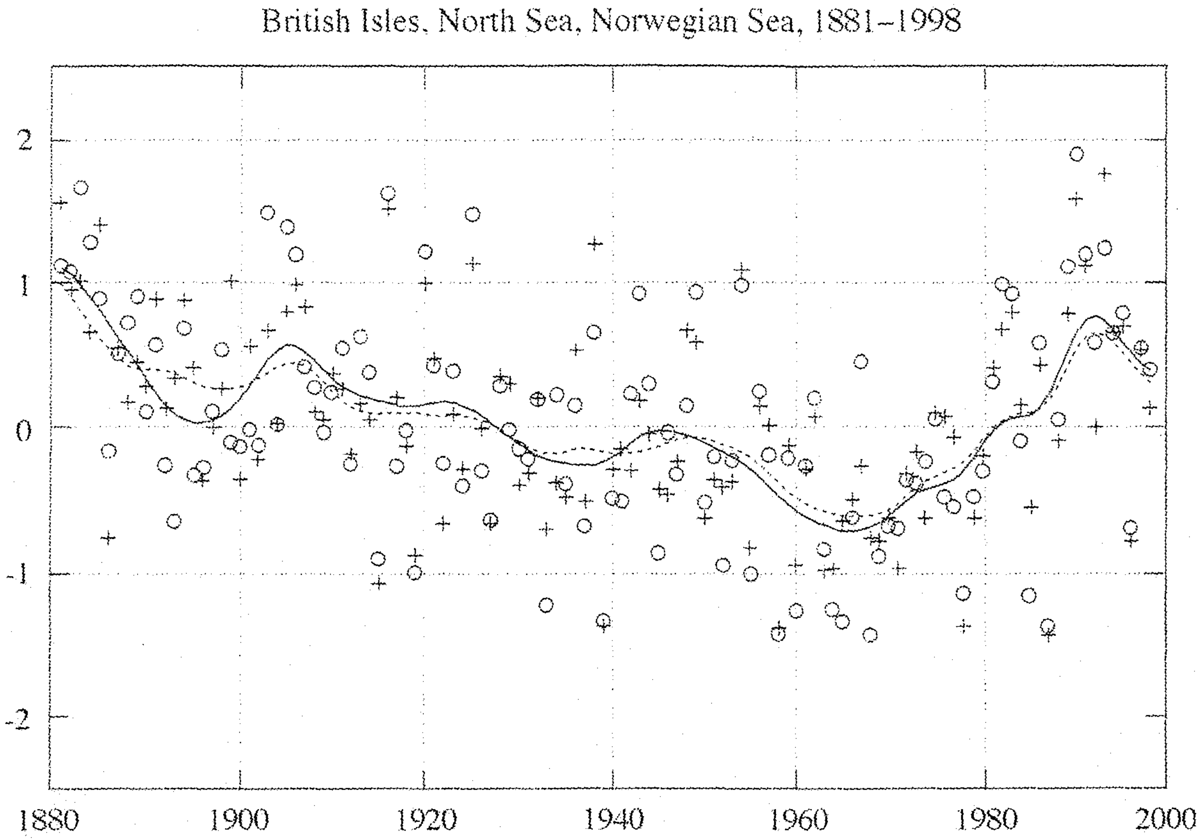

Fig. 5. WASA's index of storm intensity, derived from daily geostrophic winds calculated from various local pressure readings in the greater North Sea area. (Alexandersson et al. 2000).

Causes of Changes, Human Influence on Natural Processes

As already outlined sea level change is not a monocausal effect. Processes on geological time scales take part in changing sea level as well as processes on time scales of hours like storms and tides. Many of these processes are natural, but human impact is steadily increasing since a few centuries. Initially the human effect came about by the construction of dykes, later the dredging of rivers, the extraction of gas and oil from off-shore and on-shore deposits had a significant role in changing water levels on average and in extreme storm surge situations. Presently the main concern is related to Global Warming, i.e., the implication of global climate change due to human emissions of greenhouse gases and aerosols into the atmosphere. These emissions cause increased concentrations of the radiatively active substances in the air, which are expected to increase the amount of heat in the ocean and thus to an increase of sea level of the order of a few decimeters within the next hundred years. The ablation zones of small and large glaciers are expected to increase, changing the mass balance of these large stores of water. At the same time, global warming is also expected to intensify the global water cycle, so that more water may be deposited in the accumulation zones of the glaciers on Greenland and Antarctica. The net effect is currently unknown. Detailed research indicates that the Antarctic ice cap may actually grow, while that of Greenland is found in some analyses to shrink.

The different processes have different time scales and different forcing mechanisms. The robustness of their predictions vary accordingly. The geological processes may be considered on the managerial time scale as constant linear trends, while the prediction of changing morphodynamics and related hydrodynamics is hardly possible today. The global climate change scenarios are continuously improving, but they suffer notoriously from problems specifying regional and local features (the North Sea is a regional feature, and the Southern North Sea a local feature in this context) and precipitation statistics are needed for the assessment of the mass balance of Greenland and Antarctica.

Shifts in Perception, Polarisation of Position

The perception of the coast has seen significant changes in the past centuries and decades. Originally the coast was little more than the end of the world, the boundary to the unknown and threatening world of the ocean (Corbin 1990). People living at the coast were considered mostly backward; houses had no windows to the sea. In the late 18th century people's perception of the coast was changing. The coast (and the mountains) became the location of nature, of health and recreation. With the increasing importance of commerce and travel, the harbours became the centres of economic action – the coastal area gained an advantage over inland areas. This again changed, when shipping industry declined due to globalisation, air travel became a mass transportation system (with implications for tourism), when other means of bulk transportation (pipe lines) became available, and when the new economy emerged. Today, the coastal areas seem to have little advantages over inland areas and many coastal zones are in a depression or decay. What is left, is a potentially high environmental quality, but even this is seen as endangered by many people, because of Global Warming, pollution and over-use of resources.

Today, "the coast" is subject to various social conflicts, reflecting different uses and views of the coast (Döring et al. 2001). The perception of the coast as something natural and undistrurbed, with a healthy ecology and "soft" tourism, is in conflict with the view of a widely managed and manageable economic zone. The local population is demanding self determination (with respect to, e.g., fishery and tourism) and reject remote interference from the state government or the EU bureaucracy, whereas NGOs find further regulation needed to protect the environment against human degradation.

Recommendation for Future Research

Whereas the principles of island morphogenesis are reasonably clear, there is still considerable controversy regarding the behaviour of individual islands. Comparisons between the islands along the German Bight need to be carried out to ascertain similarities and differences. Thus, islands in front of a dyked coastline lose mud, because this material cannot be redeposited further inland. The fate of this mud is not clear and it is assumed that this material is being deposited in deeper areas of the North Sea. This needs to be verified by sediment coring.

Time series of indicators of the environmental state need to be recorded, continued and made available to the scientific community. Process based models of the ecology, the hydrodynamics, the morphodynamics and the flux and deposition of substances need to be improved. Data assimilation schemes, which combine limited dynamical knowledge (i.e. process based or empirical models) and limited observational evidence, need to be developed in order to allow for a synoptic monitoring of the coastal environment. With such data, the effect of natural variations and man-made forcing can be discriminated. The coastal module of the Global Ocean Observation Systems (GOOS) has been following goals similar to those outlined here.

Past development of environmental stress and the impact of regulation measures (e.g. related to lead in gasoline) need to be reconstructed and critically analysed, to what extent public control was efficiently exerted, or if the regulation had no significant or an unwanted impact.

Climate change scenarios need to be downscaled to the local scale of the coastal zone, and need to be combined with scenarios of future changes of other environmental factors (such as use of polders or shipping channels, emission of substances), of economy (e.g. role of agriculture and new economy) and public attitudes (e.g. with respect to flooding of polders in case of surges). The relative importance of the different factors need to be assessed, and strategies need to be defined which create conditions and options fa-vour-able for socially demanded developments.

The barrier islands need to be subjected to a cost/benefit analysis because it is not clear whether they can be maintained the way they are. The different views, and the dynamics of changing these views, need to be analysed by social scientists. In particular, the perceptions and attitudes of lay people need to be related to the process knowledge acquired by environmental scientists. To do so, case studies of past conflicts (for instance with respect to the status of the Nationalpark Nordfriesisches Wattenmeer, the reasons for the seal pandemic of 1988 or the effects of out-phasing of lead from gasoline) need to be made, and scenarios of future, changing perceptions should be attempted.

Effects of Climate and Humans on Ecosystems

Role of Climate and Natural Variability

Shifts in climate patterns occur at various scales of which the best documented are those that have the most drastic impact on the biosphere – the glacial/interglacial cycles. Climatic changes oc-curing at scales of several years, such as El Nino, are also well documented, and their impact on upwelling ecosystems reasonably well understood. However, climate regime shifts occurring at decadal and century scales also occur but they are poorly documented and the mechanisms of their impact on ecosystems the subject of much speculation. Evidence is increasing that decadal-scale changes, such as those caused by the North Atlantic Oscillation (NAO), are accompanied by characteristic responses in marine ecosystems. It is imperative to gain a better understanding of the decadal variations because these appear to have substantial effects on ecosystem structure and functioning and also occur on the same time scales as the effects of human impact. Indeed, the areas where such cycles are believed to occur, and have been observed, coincide with regions where human presence and exploitation patterns have had strong effects on ecosystems. Thus, fluctuations in commercially exploited fish stocks have the longest documentation, whereas records of changes in the structure and productivity of the supporting ecosystem are meagre and only available from a few regions.

The fishing periods of the Bohuslän herring in the Skagerrak are known for the last millenium. During these periods lasting for several decades, the herring fishery was very strong. They alternated with periods also lasting for several decades when herring stayed away from the Bohuslän coast. These decadal fluctuations seem to be governed by the NAO (Alheit and Hagen, this volume). Similar ups and downs in small pelagic fish stocks in upwelling regions of the Pacific have been documented for the twentieth century. These stocks are dominated alternately by sardines or anchovies whereby the regime shifts last about three times those of El Nino episodes and do not seem to be related to them. Indeed, the shifts occur simultaneously in all three upwelling regions – off California, Japan and Peru – suggesting that the changes are not brought about by propagation of a particular hydrographical regime which would entail lag times in the different populations. Fisheries biologists attribute these shifts to teleconnections and are still searching for the underlying causes. Sediment records from the Santa Barbara basin off California indicate that the shifts from sardine to anchovy domination go back a very long time. Unfortunately, such sedimentary records are not available from other regions.

Another potential source of information on herring fisheries along the southern North Sea coast is documentation of the salt trade. Salt has been traded as a commodity since Roman times. In coastal areas it was extracted from peat and used on a large scale to conserve fish starting in the 14th century. When the salt-containing peat layers were exhausted, salt was shipped from the Gulf of Biscaye to the Dutch coast where it was refined and used for conserving herring. A lot of documentary sources exist on this salt trade from the 14th – 17th

century which could provide interesting information on herring consumption and consequently on the issue of variability of the herring fisheries as a whole. Further, archaeological research in Belgium has provided time series of fish remains from various sites starting around 1300 and earlier in which herring and other species appear.

Other fish stocks such as cod and their relatives seem to undergo population variation at similar time scales to the pelagic fish although these large demersal fish are individually much longer lived. Their fluctuations have been explained by successful recruitment of a single year class. Thus a weather singularity which favours recruitment of a particular year class can have an impact for 20 years or more. Such an explanation cannot apply to e.g. anchovies as the periods of their domination include many generations. It is not yet clear how climatic shifts can cause fluctuations in so many different types of fish species.

Lindeboom (this volume) has presented a number of examples showing that marine ecosystems are not in steady state but undergo periodic shifts in biomass levels and abundance of species that have been difficult to explain so far. The shifts recorded from coastal systems of the North Sea have tended to be abrupt and cannot be related easily to long-term secular changes such as eutrophication or pollution. On the other hand, data collected by the Continuous Plankton Recorder surveys (CPR) from the eastern N. Atlantic and the North Sea indicate that the average phyto-plankton and zooplankton biomass fluctuated about twofold for periods of about a decade with transition periods of increasing or decreasing biomass over the entire study region. These large-scale shifts in biomass levels have been attributed to changes in the strength of westerly winds over the N. Atlantic but the mechanisms are not yet clear.

In recent years research on harmful algal blooms has intensified because of the economic effects on aquaculture, tourism and fisheries. Montresor and Smetacek (this volume) have discussed the role of these blooms on human history over the past millenium. Many toxic species belong to the dinoflagellates that tend to attain maximum population size in summer and autumn, in contrast to diatoms that appear earlier in the year when nutrients are more plentiful. The fact that dinoflagellates can build up equally high biomass levels in shelf regions in the second half of the year suggests that they have a very different strategy relative to seasonality of their environment. Thus, some species make benthic resting cysts that are preserved in sediments. Their sediment records indicate that the shifts are in the century scale and follow features such as the "medieval warm period" or the "little ice age". This could well be related to changing position of water masses bringing in populations from elsewhere that then establish themselves by means of benthic cysts. This type of periodic appearance and disappearance will apply particularly along the outer limits of the distributional range of a given species.

Can we Distinguish Human Impact from Natural Changes?

Human impacts on the coastal North Sea are considerable and range from subtle to obvious. Obvious impacts are caused by coastal engineering such as dykes, macropollutants, aquaculture, introduction of exotic species, beam trawling, cockle fishery and increasing tourism in breeding areas. Subtle changes can be due to micropollutants, shifts in nutrient ratios, the direct effects of ship traffic or the influence of local perturbation on the larger system. Some of these impacts are dealt with below.

Dyking results in the diversion of mud deposition, reduction of salt marshes, brackish water areas and muddy tidal flats. These affect the local benthos and, by divorcing the mud flat from its natural extension -the landward salt marshes - can exclude species with life-cycle stages that are dependent on the salt marsh.

The combination of excessive fertiliser use as well as the dumping of untreated sewage into coastal waters of the North Sea via the major rivers resulted in significant increases in the concentration of the macronutrients nitrate and phosphate. In addition, the ratio between nitrogen and phosphorus - the Redfield ratio of 16:1 - changed in the North Sea over time because it was technically easier to remove phosphate than nitrate. This eutrophication led to shifts in the dominant species of phytoplankton and increasing growth of green macroalgae along the shore. The latter have been held responsible for the "black spot" phenomena along some mud-flat coasts.

The silica concentration dropped with the increase in nitrogen - a trend since observed in all affected rivers - resulting in lower contribution of diatoms to total phytoplankton production. One of the shifts in phytoplankton species composition is reflected in the ratio of diatoms to non-diatoms which happen to be all flagellates. Their contribution to algal biomass is reported to have jumped at the turn of the eighties (Lindeboom, this volume). The species which increased most spectacularly is the colonial flagellate *Phaeocystis* which is often grouped with the harmful algae because its blooms lead to unsightly and odourous accumulation of foam on the beaches.

The apparent increase in flagellates in the North Sea plankton is of some concern because it encourages the incidence of toxic algal blooms during the summer months when nutrient levels used to be low. Whether toxic algae have indeed increased over the past years and, if so whether this is due to eutrophication, the spread of aquaculture or simply better monitoring is being debated (Montresor and Smetacek, this volume). It seems that the spread of toxic species is occurring at an alarming rate, partly due to transport and introduction of toxic species to formerly innocent waters.

The harmful effects of xenobiotics (man-made chemicals that are taken up by organisms) such as DDT and PCBs was a big issue in the seventies and eighties and legislation controlling their release to the environment has resulted in a significant reduction of their concentrations in natural waters. This also applies to heavy metals whose con-centrations in the rivers has gone down significantly. More recently, tributyl tin (TBT), an ingredient in antifouling paint, is reported to induce malformation and hence malfunction of the sexual organs of the whelk (*Buccinum*). Since this species has recently disappeared from the North Sea it is very likely that TBT is the sole cause. This large, carnivorous snail used to be very common and played a major role not only in the food web but its shells were occupied by other organisms and hence its presence increased biodiversity of the North Sea. If TBT is indeed the cause, then banning its use should result in return of the whelk.

From the previous section it will be clear that natural ecosystems are subject to considerable fluctuations, both in terms of total biomass as well as abundance of dominant organisms, which are very poorly understood. Hence, separating human impacts from natural variability is possible in only a few obvious cases. It should also be pointed out that both climate and human effects are external forces. Even though we have trouble separating them, it should be remembered that internal controls such as predator-prey and host-pathogen cycles also play an important role in controlling the popu-lations of wild organisms. Knowledge of these aspects is even more limited than environmental factors. In summary, much more research effort is needed before an understanding of the factors shaping structure and functioning of marine ecosystems and their major components can emerge.

Shifts in Perception of the Human Population

Before the middle of the last century marine ecosystems were perceived as providers of resources for humans to exploit or as convenient waste dumps. The environment at large was not a concern. The shift in perception was initiated in the 1960s by Rachel Carson's book "The Silent Spring" which brought environmental pollution to the attention of the public and led to the current polarisation of positions between "exploiters" and "conservationists". The media exploited the new concern for their own ends with headlines such as "Is the North Sea dead?" in the seventies. Some years later, public concern over pollution peaked again when the "killer alga" *Chrysochromulina polylepis* spread in the Kattegat and Skagerrak followed by mass death of harbour seals along the Dutch, German and Danish coasts in May/June 1988. Later that same year, much publicity was given to masses of slime that washed up on the tourist beaches of the Adriatic. The slime was of algal origin and, like the happenings in the North Sea, it was attributed to anthropogenic impact. Since then, none of the phenomena that appeared the same year 1988 and that have since been shown to be entirely independent of each other, have recurred.

The seal population is now larger than before the pandemic and slime blooms in the Adriatic have been shown to have occurred also in the past centuries, albeit sporadically. So what is the state of public perception now? To find out, natural scientists need help from their colleagues in the social sciences.

Why is it necessary to know public perception at a given time? Because on the one hand phenomena that occur naturally but rarely, ought not to cause concern, whereas insidious changes of the kind reported by Carson need to be brought to the attention of the public. A current example is tributyl tin (TBT) and its effect on the whelk mentioned above. This is not the only species to have disappeared from the North Sea. Some such as the Atlantic gray whale became extinct altogether about 300 years ago, whereas many species of benthic invertebrates are no longer found in the Dutch part of the North Sea. Some of these species are reported to be extinct or on the verge of extinction. Although extinction of species is a perfectly natural process, the rate of modern extinction is unacceptably high. Since the preservation of biodiversity has become a major global concern, the state of marine biodiversity should be brought to the attention of the public. The policy to be pursued following public education cannot be decided by scientists; their duty is to inform the public. Bridging the gap to the social sciences and involving them in research projects should be pursued more actively. The current rapid development of scientific knowledge should not blind us to the fact that many areas touched on above are still poorly understood.

The growth of the nature conservation movement and the increasing popularity of ecotourism are clear indications of future trends. Nature is being regarded as much a part of our cultural heritage as the evolution of our own societies. Because of the general improvement in the standard of living in the last decades, particularly in Europe, one can well anticipate an increase in the value of unspoiled nature. Indeed the last semi-intact ecosystems of Europe lie in its seas and will well be regarded as equally worthy of protection as ancient houses and monuments. Hence the need to protect the remaining habitats such as the Ems-Dollard estuary that have not yet been "captured" by humans.

The movement to protect the Waddensea as a national park is a case in point. Currently it is not known to what extent shrimp fishing is at odds with the aims of the park. Such issues are currently being decided and it is the task of the scientists to provide guidance to policy decisions. Forecasts of the kind required need to be based on a better understanding of marine ecosystems. This can only arise on the basis of comprehensive data sets which need to be collected on a standardised, long-term basis. In addition intensive interdisciplinary studies of marine systems will have to be carried out in order to provide the data necessary to construct simulation models that, through continuous assimilation and sensitivity cycles, might some day achieve a reasonably realistic rendition of nature. Hope comes from nature herself: the fact that, despite the apparent complexity of habitat and species biologies, specific patterns arise in widely separated areas that bear sufficient resemblance to one another as to indicate the operation of some fairly strong and predictable forces shaping geomorphology and, in tandem, also ecosystem structure.

Research Needs

Currently, our understanding of the structure and functioning of marine ecosystems is hampered by lack of knowledge of decadal and century –scale variability, both in terms of secular trends as well as abrupt shifts in the state of the system. It is clear that only long-term, integrated data sets can provide the context for evaluating observations of individual phenomena. Hence there is an urgent need not only for maintaining regular monitoring using the original methods but also to enhance them with new methodology that will extend coverage and detail. For example, sedimentary records could be exploited more systematically to ascertain past variability. It will also be necessary to routinely measure parameters which are now suspected of being important but could not be measured earlier. One obvious path is to link biological measurements with the coastal module of the Global Ocean Observation Systems (GOOS) now being developed and which is following goals similar to those outlined here. New methods such as gene probes and other biosensors combined with flow cytometry hold much promise for following changes in plankton populations, as also remote sensing combined with ground truth measurements.

Such modernised monitoring programmes can also contribute to enhancing basic knowledge on the functioning of marine ecosystems. For instance the factors driving species succession in the plankton are still poorly understood although the phenomenon was first described a century ago for Kiel Bight. The sequence and dominance status of the species involved had barely changed between 1906 and 1972/73 (Smetacek 1985). However, a decade later a fundamental shift in species dominance was reported. The current status is unknown and it would be of interest to repeat the measurements carried out in the early seventies. The hypothesis to be tested is that, following the reduction in nutrient input during the nineties, the Kiel Bight system will be reverting back to the "pristine" situation that prevailed for at least 75 years before eutrophication had an impact. Alternatively, the system has reverted to a state characterised by other species. In either case, the results will shed light on the resilience of pelagic systems. Such studies have been carried out in many lakes that have regained their pristine pre-eutrophication status following reduction in nutrient input but there are only few equivalent studies from marine systems.

Monitoring benthic systems will profit from demarcation of areas protected from beam-trawling and other destructive fishing methods. Reintroduction of vanished species or ecosystems (such as sea-grass beds) will be worth pursuing. Networks established by the various coastal stations will promote assessment of shifts in geographical distribution patterns. It will also be necessary to specifically study the impact and fate of introduced species as the results will shed light on patterns of interaction between indigenous species. Careful, coordinated assessment of the biodiversity of characteristic areas will serve as the context for evaluating future trends. Needless to say, modelling provides a powerful tool to systematically combine the results of process-oriented research and descriptive monitoring.

The Waddensea coast is widely believed to be unsuitable for aquaculture of fish, hence fishing of wild stocks may well continue into the future. The lesson learned from history is that sustainable yields are not to be expected. Regardless of the direction in which utilisation of resources will go - the neces-sity for management will increase. The more solid the knowledge on which management is based - as is the case with the food and health services - the more effective it will be. In this context it should be pointed out that coastal management is not management of nature but rather management of human activity.

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