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<Invited Article>

Protecting a trilateral coastal ecosystem: The Wadden Sea

[Shortened Title: Trilateral Wadden Sea protection]

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ABSTRACT

Coasts offer multiple advantages when topical combinations for optimal use are foreseen. The Dutch-German-Danish Wadden Sea region has been transformed on its landward half into drained arable land. This has been protected by seawalls against storm surges which frequently ravage this coast. The other half remained a dynamic seascape with the largest coherent tidal flats in the world. This had been perceived as a drenched wasteland with treacherous shallows for long but is now proudly regarded as a universally outstanding coastal wetland, listed as a World Heritage Site since 2009. Faced with accelerating sea level rise, a change in coastal adaptation is advocated. The prevailing fortress strategy should give way to living with more water and more natural areas, growing with and buffering against sea level rise. Such areas could also provide relaxation from stressful urban life, and tourism would develop into the main economy at modern coasts.

Key words: coastal transformation, living with more water, nature protection, sea level rise, tourism

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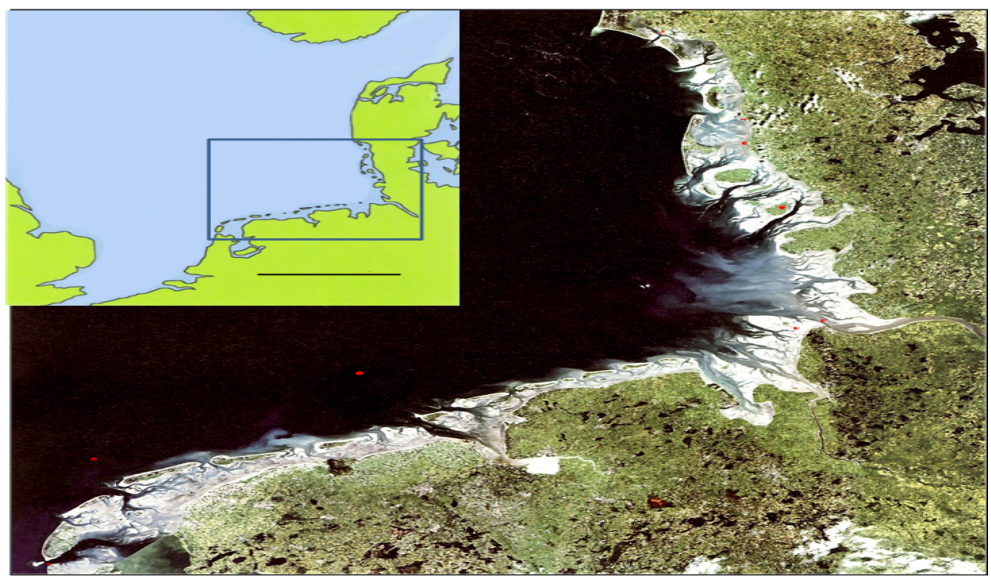
1. Introduction

Challenges at modern shallow coasts are unique in the history of our planet. Since continental drift concentrated land masses at the southern pole (Antarctica) and near the northern pole (North America and Eurasia), a net accumulation of snow resulted in extensive glaciations. These caused global sea level to fall. Due to astronomical cycles, recurrent warm intervals interrupted the glaciations, associated with sea level rising up to 120 m. We currently are near the end of such a warm interval. However, anthropogenic climate forcing over the last century has initiated renewed warming which is expected to be followed by further sea level rise (Cowie, 2007).

After an initial phase of rapid sea level rise with the beginning of the present interglacial, further rise had been slow (Vink et al., 2007). In this second phase, with a sediment supply outpacing sea level rise, wetlands have been expanding into the sea at most shallow coasts. Where sediments were supplied by rivers, large deltas have emerged over the last 8,000 years. Where sediment supply or redistribution was under the mercy of the sea and tidal range was small, coastal lagoons with extensive marshes developed. With a medium tidal range, barrier islands in front of tidal flats and marshes have formed. At very large tidal range, merely tidal flats prevailed. These coasts continue to change, and tidal range tends to increase with sea level rise (Bird, 2000).



Source: Eurimage, Common Wadden Sea Secretariat & Brockmann Consult

Figure 1. Satellite images taken of the Wadden Sea region in 2000-2002 are combined to show low tide conditions everywhere.
Beaches and tidal flats appear to be white and suspended matter in the water grey. Main line of seawalls along the mainland coast is highlighted in red. Inset shows position of image in the North Sea

Presumably, already at the hunter and gatherer stage, our species took advantage of coasts where land and marine resources could complement each other. Later, coastal wetlands attracted agriculture because floods renewed nutrients. Hydraulic systems of drainage, irrigation and flood defense were developed to overcome disadvantages of irregular and excessive flooding. However, these systems entered a viscous cycle. Due to soil compaction from drainage, due to saline intrusions from irrigation, and due to diminishing nutrient and sediment supply because of flood control, the maintenance costs kept increasing relentlessly over time (Syvitski et al., 2009). More safety from flooding allowed for an increasing population density and infrastructures accumulated. These in turn demanded for more safety, and once better flood protection was achieved, more people moved to the coast and established even more infrastructures. In the absence of flooding, industrial fertilizers had to be purchased by coastal farmers similar to those not burdened by the costs of flood control. Thus, a former coastal advantage turned into a disadvantage, while maritime trade, industry and tourism still take advantage from the coast.

The Wadden Sea region is located at the southeastern shore of the North Sea in a cold temperate zone and where moderate tidal conditions prevail (Figure 1). Economy has been traditionally dominated by agriculture. Maritime trade and industrialization remained confined to inner estuaries. The latter sectors prosper, while agriculture in the coastal periphery stagnates. There tourism is now taking over as the dominant economy, but young people continue leaving for the metropolitan centers (Bazelmans et al., 2012; Kabat et al., 2012).

The Wadden Sea region belongs to The Netherlands, Germany and Denmark. Since medieval time, Dutch economy, hydraulic expertise and culture dominated in this region, until the rise of modern national states terminated this coastal coherence. However, half a century ago, an idea of a natural integrity and identity of the Wadden Sea gradually took shape. This initiated a trilateral cooperation between the three nations in protecting the largest coherent tidal flat environment in the world (Kabat et al., 2012).

These efforts have culminated in the Wadden Sea being listed as a World Heritage Site by the UNESCO based on universally outstanding values in geology, ecology and biodiversity and their proper protection (CWSS, 2008, 2009, 2013; Reise et al., 2010). The capability of the nature area to grow with sea level rise and its importance for tourism, recently prompted the question whether a revitalization and adaptation of the embanked marsh may be accomplished by giving more room to nature.

In this article, the historical development of the Wadden Sea region is reviewed with an emphasis on nature protection, and future options are discussed in the face of climate change. This case study on the Wadden Sea region may not serve as a template for other coasts but hopefully could be a source for inspirations.

2. Transformation of the coastal marsh

In the Wadden Sea, a once gradual transition between sea and land became transformed by a coherent line of earthen seawalls, separating the coast into a dynamic intertidal nature area and an embanked marsh used primarily for agriculture (Figure 2). The historical course and causes of this landscape transformation is summarized below (Bazelmans et al., 2012; Reise et al., 2010; Reise, 2013).

Initially, human use of the coastal lowlands in the Wadden Sea region as a pasture for sheep and cattle was accompanied by building dwelling mounds (Phase 1). These kept housing dry and served as a refuge for life stock when storm surges flooded the marsh. This happened frequently with low pressure systems approaching from the northern Atlantic and hampered growing crops.

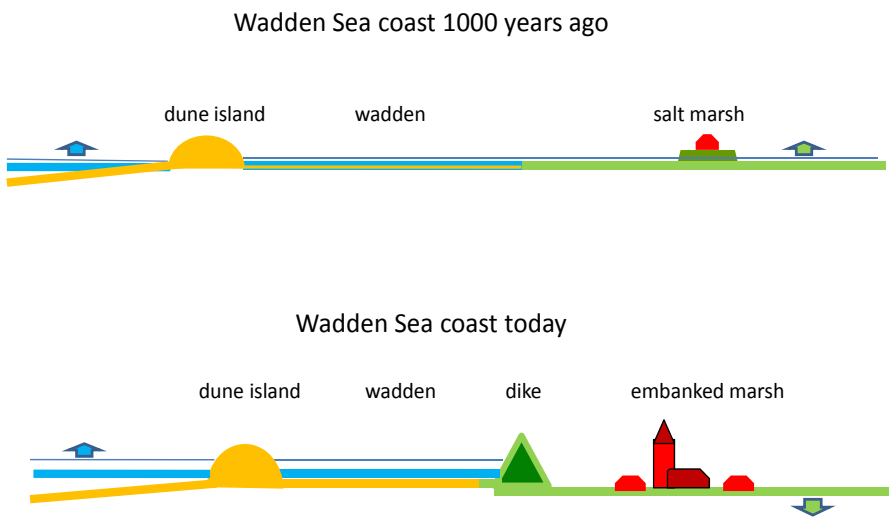


Figure 2. Schematic profiles of the Wadden Sea region 1000 years ago and today. Arrows indicate direction of sea and land level changes. Thin upper blue line indicates episodic storm surge flooding, bold blue line the tidal range. Dark green indicates artificial earth works

Nevertheless, attempts of culturing land commenced in the wet hinterland (Phase 2). Drainage resulted in soil compaction, and this required building earthen walls, named dikes, around such low terrain to prevent flood water intrusion. While the shrinking of soils aggravated behind dikes with ongoing drainage, the storm surges in front of the dikes rose higher the more of the land became embanked and less area remained to accommodate the flood waters. Farmers on unprotected areas were disadvantaged by this development.

Therefore, dike building quickly proceeded and by 1300 AD almost all of the marshland was protected against flooding by the sea with a coherent line of earthen seawalls (Figure 1; Phase 3). This wall separated land and sea, and the floods no longer provided the land with nutrients and new sediment. Rainwater had to be pumped upwards through sluices into the sea. This hydraulic system came under pressure. (1) As the sinking of the land continued, so did the rising level of the sea, creating a coastal gap which gradually became wider over the centuries, increasing the risk of irreversible seawater intrusions when dikes broke. (2) In some regions freshwater swamps and bogs became submerged by the sea and then were buried under marine sediments. The organic material (peat) was later mined, dried, burned, and from the ash salt could be extracted and exported as a precious commodity. This mining lowered the surface of the land. (3) From 1300 AD onwards, climate deteriorated (the so-called 'Little Ice Age'). Weather became colder and wetter, and extreme weather conditions occurred more frequent (Marcott et al., 2013).

These adverse developments entailed disastrous intrusions of the sea during storm surges far into the agricultural land (Phase 4). With technological improvements in dike building and capital investments from outside, part of the lost land was subsequently reclaimed but some areas reverted permanently into tidal flats. However, in spite of some fundamental criticism on the transformation of the coastal landscape by dike building and drainage, the hydraulic strategy did not change until today. Instead, the progressive embankment of tidal flats continued on a larger scale, particularly after 1900 AD (Phase 5).

The transformation of the coastal marsh affected the Wadden Sea region as a whole. Three bays created by former sea intrusions remained and there muddy tidal flats abound. In front of dikes, only a narrow belt of artificially created salt marshes exist. Most of the tidal flats there are sandy. Progressive embankments have narrowed the distance between the mainland and the barrier islands or sand bars. The latter slowly shifted landward with the rising of the sea. These and the slow and gradual rising of the sea accompanied by an increasing tidal range, caused hydrodynamics to become stronger in the Wadden Sea. Waves and currents stir up fine mud particles and sand becomes to dominate the sediment of the tidal flats (Figure 3).

Technological improvements in dam and dike building finally gave rise to plans of embanking the entire tidal zone by connecting the barrier islands and these with the mainland. The rational proposed was not only to gain agricultural land but also more safety against storm surges breaking the dikes. The southwest coast of The Netherlands was struck by an unusual flood in 1953, breaking dikes and more than 3000 people died. The German port city of Hamburg, located far upstream in the Elbe estuary, was unexpectedly flooded in its lower parts by a storm surge in 1962. About 300 people died. Presumably, this flood could rush into the city so fast because the bed of the estuary had been dredged deeper to ease passage for larger vessels. Both disastrous events alerted governments to the high

risk of living at the sea. Coastal protection programs were carried out all along the shores of the Wadden Sea by building new dikes and enforcing existing ones, building storm surge barriers at rivers, and stopping shore erosion by stone revetments.

3. The rise of coastal nature protection

Hunting and fishing pressure increased with human population growth over the centuries (Lotze, 2007; Reise, 2013). Marine mammals and coastal breeding birds became rare, large fish vanished, and the regional oyster population went extinct because of overexploitation (Figure 3). This development is reminiscent of the concept of fishing down the food web (Pauly et al., 1998), because the present fishery is confined to shrimp and mussels. Excessive use of fertilizers and pesticides on arable land, industrial wastes and insufficient sewage treatment by the cities first killed fish in the rivers and subsequently negative effects became also apparent at the coast in the form of diseased seals and fish, dead birds and algal blooms. Along the estuaries, power plants and industries sprawled. Shipping and aquaculture have entailed a tide of nonnative species invasions which irreversibly altered living communities (Buschbaum et al., 2012).

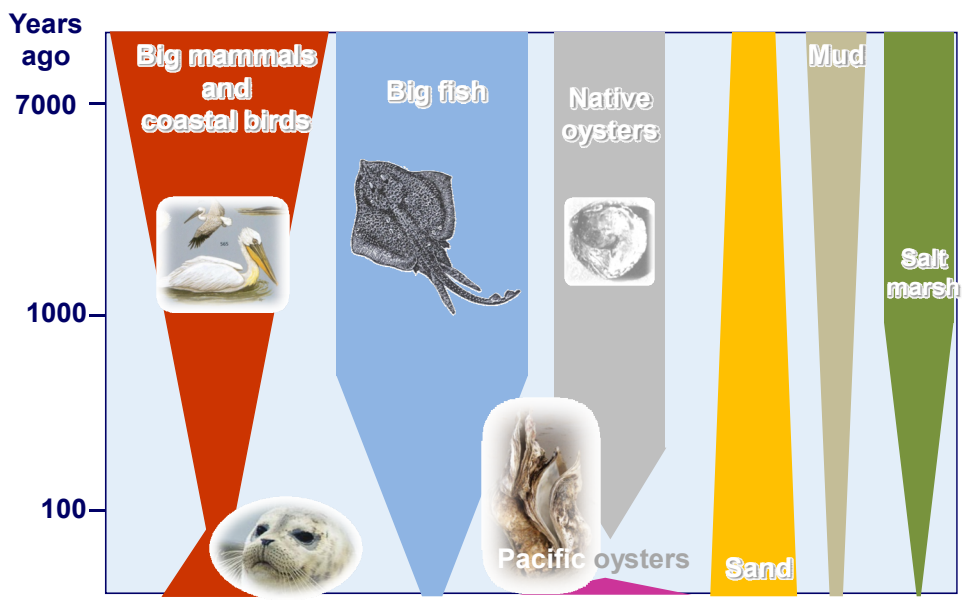


Figure 3. Schematic kite diagrams to indicate rough temporal trends (note logarithmic time scale) affected by human forcing in the Wadden Sea. For explanation see text

These adverse developments gave rise to a strong environmental movement. Already more than one hundred years ago, concern about birds prompted non-governmental organizations to buy small uninhabited islands in order to operate bird sanctuaries. However, the Wadden Sea was not yet perceived as a natural entity. This vision came to be generally known not before the 1960s. Then the Wadden Sea was recognized an essential staging area for most birds of the East-Atlantic Flyway. Also a dramatic decline in the seal population became public. Embankments which further reduced the area for salt marshes and tidal flats were met by fierce opposition.

In 1974, the Dutch government decided to stop plans of further large-scale embankments in the Wadden Sea. Urged by scientists, it also started to cooperate with Germany and Denmark to improve nature protection and environmental conditions. The idea of a common protection area was born in 1982. Regular meetings of the three environmental ministers were held and stepwise the protection regime became more comprehensive. In 1997 a common management plan with environmental targets was adopted (CWSS, 1998 and updated in 2010). Also a detailed trilateral monitoring program commenced. Many dedicated volunteers contributed to bird counts throughout the Wadden Sea. Results of monitoring and research are presented every five years in Quality Status Reports. Ongoing research played a significant role from the beginning. With popular books (Abrahamse, Joenje and van Leeuwen Seelt, 1976) and the book series The Ecology of the Wadden Sea (Wolff 1983) a comprehensive scientific assessment of natural processes, biodiversity and threats was achieved. Regular International Scientific Wadden Sea Symposia served to exchange insights and concerns between scientists and environmental managers.

In the national sub-regions of the Wadden Sea, protection regimes took various forms but attempts were made to harmonize the measures. Coordination is achieved through a Common Wadden Sea Secretariat since 1987 which also initiated the nomination of the Wadden Sea as a World Heritage Site. Since the early 1990s all parts of the Wadden Sea were declared Biosphere Reserves. These are confined to the protected area and therefore merely consist of core zones and lack development zones in the adjoining marsh or on the inhabited islands. The only exception is a group of small islands, the so-called Halligen, which are adapted to flooding during storm surges when only the houses set on dwelling mounds stay above the waves. These islets constitute the ‘Biospere Halligen’. By 2002, trilateral cooperation also commenced on the landscape and the cultural heritage of the Wadden Sea region by establishing a stakeholder forum in 2002 (Frederiksen, Enemark and Nuttall, 2013).

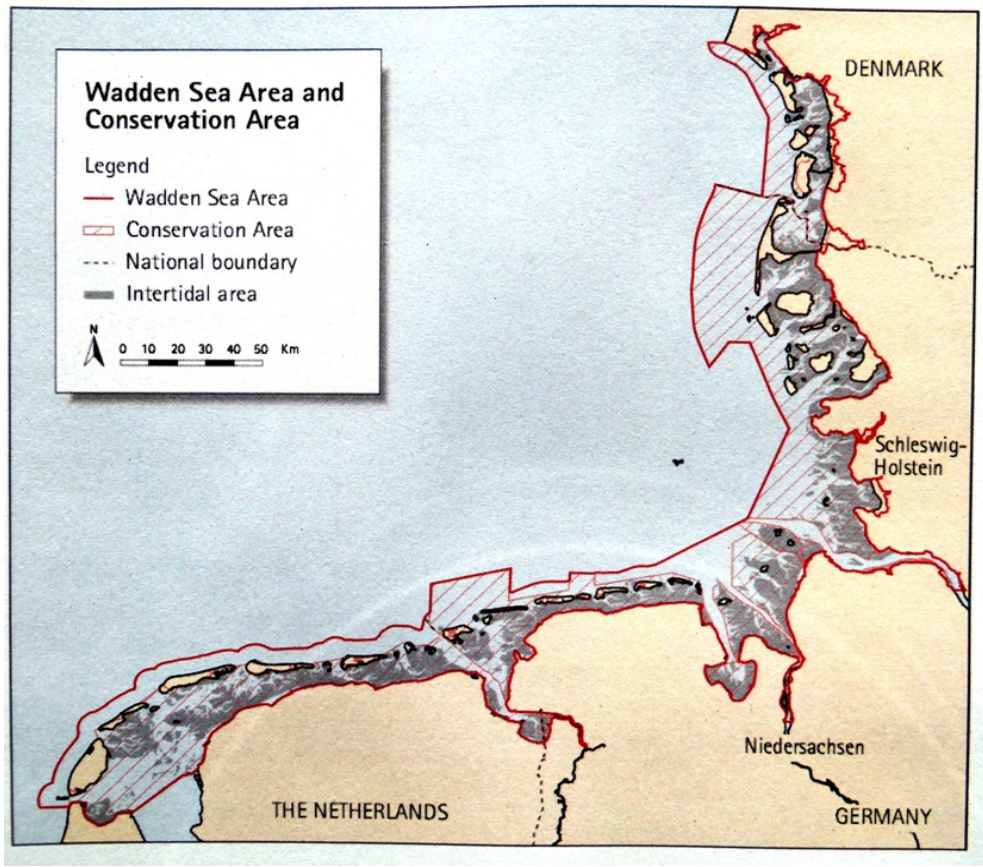
The success of the nature protection measures has been impressive. Breeding bird and seal populations have increased about ten-fold. Flight distance considerably decreased in species of birds and marine mammals because hunting has been phased out completely. Commercial shellfish exploitation has been restricted to certain zones. Seagrass beds affected

by eutrophication have begun to recover since the 1990s. Grazing by domestic animals on salt marshes has been reduced or even phased out. This increased vegetation height and the number of flowering plants considerably.

Non-governmental organizations and also National Park rangers conduct guided nature wet walks which are highly popular among tourists. Visitor centers have been set up on almost all islands and along the mainland coast. A trilateral school brings together young people from the three Wadden Sea nations in summer camps. Special events are celebrated like Brent Goose Days or Bird Migration Days. Fierce initial opposition by residents to nature protection gradually faded away, and since the 2000s the protection status is generally well appreciated by residents and visitors alike. In particular, the World Heritage Status has catalyzed a mind shift in favor of nature protection.

In the 1960s, most people perceived tidal flats as a wasteland. Often tidal flats were seen as a once flourishing farmland lost to a merciless sea. Salt marshes were looked at as potential arable land to be embanked with dikes. Awareness of the natural values grew slowly in the coastal population. On the other hand, with new agricultural policies by the European Community, incentives to gain more land for more agriculture came to an end. Nevertheless, embankments continued for the sake of improving water management or for more safety into the 1980s. These were finally stopped by an overwhelming opposition regretting the loss of salt marshes and tidal flats. No more embankments have been planned since then.

However, nature protection has to grant priority to coastal defense, and traditional use of natural resources such as artisanal fishery is also granted, although hunting has been banned. With a few exceptions, the protection area does not include inhabited islands, and stops at dikes and in estuaries (Figure 4). Particularly the latter have been exempted from the Wadden Sea protection regime because there the interests of maritime trade and industry left little chance for nature protection.



Source: Common Wadden Sea Secretariat, Wilhelmshaven, Germany

Figure 4. Map of the Wadden Sea Area and Conservation Area (hatched).

4. Adaptations to climate change

The transformation of the marsh has created a coastal gap which is inevitably widening as the land keeps on sinking and the sea is rising. Particularly towards the end of the last century, safety has been improved by reinforcing coastal defense. This in turn was perceived as an invitation for an expansion of infrastructures which may entail even stronger defense measures to compensate for the coastal gap.

Within the last 50 years, nature protection on a trilateral level has profoundly transformed the perception of the Wadden Sea from useless shallows to a touristic attraction. This may not have been achieved entirely by the strength of the environmental movement. Previous tensions relaxed with new European policies on agricultural development and with

an appreciation of the high level of safety against flooding.

However, with growing concern about global warming and expected regional effects, the coastal situation is changing again. The coastal gap may become unbearable when sea level rise starts accelerating, and the morphodynamics in the protected Wadden Sea may threaten its natural values. An obvious response to sea level rise, increasing storminess and other weather extremes, would be a managed coastal retreat. Not surprisingly, this option has found little support but met strong objections so far. Instead, two alternatives are on the agenda, the technological fortress strategy and the water strategy of adapting lifestyle to live with more water.

The fortress strategy is a continuation of traditional coastal defense measures which have successfully protected human life and property over the last 50 years. New dikes are already under construction which are wider and with a broad top onto which a 'climate cap' could be added when necessary. These measures are based on projections on sea level rise until the end of this century, as issued by the IPCC in 2007 and 2013. In addition, eroding shores are either more strongly armored with stones or concrete than before or sand nourishments to the beaches of the islands use larger volumes to compensate losses. The fortress strategy relies on technical solutions alone. However, a combination with spatial planning which divides the coastal lowland into categories of differential risks is also envisioned (Ahlhorn, 2009). In this concept, risk is defined as the likelihood of coastal defense structures to fail, which is multiplied by the potential number of people being affected and the value of infrastructures likely to be damaged.

The water strategy seeks to combine new technical approaches with a change in lifestyle towards living with more water. This is not yet part of any official policy. However, a growing number of innovative people are pushing this idea (i.e., Geuze, 2009; Helmer et al., 1996; Metz and van den Heuvel, 2012; Stokman, von Seggern and Rabe, 2009). In the paragraphs below these efforts are linked to nature protection as developed over the last decades. Other than the fortress strategy, a time scale also beyond the end of this century is taken into account and an attempt is made to close the coastal gap.

For the Wadden Sea with its very shallow waters and an adjoining land at or below the level of the sea, the rate of sea level rise is seen as a key variable. However, it seems unlikely that this rate can be predicted in the near future. The time lag between atmospheric warming and sea level rise as well as the dynamics of melting polar ice caps are insufficiently known. IPCC projections are based on those processes which are reasonably understood. Semi-empirical approaches incorporate more of the 'unknowns' and generally come up with higher estimates (Rahmstorf, 2007). A Dutch commission has suggested to coastal planners in the North Sea region a magnitude of 1 m until the end of this century, and a continued rise throughout subsequent centuries (Deltacommissie, 2008). For the last interglacial 115,000 to 127,000 years ago, a sea level of about 4-8 m above the present has been reconstructed with mean temperature being only slightly

warmer than now (O'Leary et al., 2013; Rohling et al., 2008).

Such figures may be sufficient to start with instead of postponing the issue of sea level rise. It is clear that an early start will become cheaper in the long run, and that in case of a disaster it would be good to have an elaborated strategy at hand for the period thereafter. The basic idea is to grow with the sea as salt marshes and tidal flats have done in the past for thousands of years. This natural process has been intercepted by the building of dikes and prompted the subsidence of land. The question is how the concept of growing land with the sea can be combined with the continued presence of people and a thriving economy.

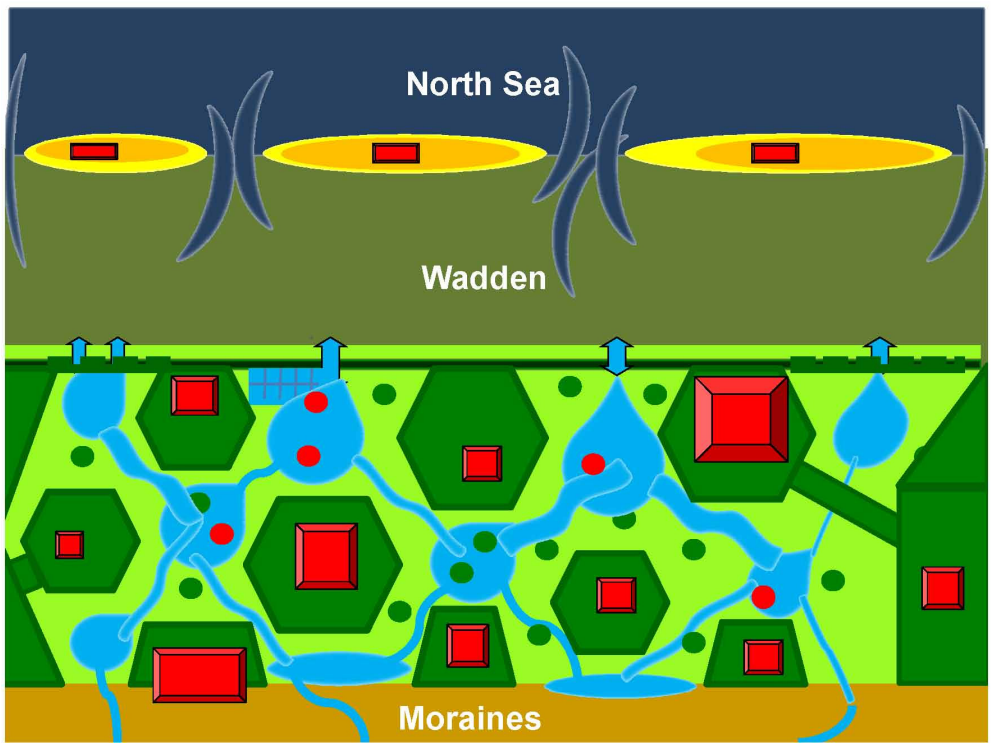


Figure 5. Scheme for adaptations to sea level rise for a sector of the Wadden Sea region with a chain of barrier islands between the North Sea and the tidal flat area (wadden), an embanked marsh area bounded by higher elevations of moraines of glacial origin. To keep dune islands in position, sand extracted from offshore bottoms of the North Sea is supplied (yellow). The main dike is supplied with overwash sections (toothed dark green) and sluices (arrows) connecting the marsh with the sea. Residential areas (dark green and red) protected by auxiliary dikes are interspersed into nature areas (blue and light green) subject to seasonal flooding. For touristic use, traditional dwelling mounds (green dots) and floating homes (red dots) are made available. For further explanation see text

A suggested solution for the Wadden Sea is schematically shown in Figure 5. For the sandy barrier islands continued nourishments with sand dredged from offshore areas in North Sea is seen as sufficient to keep the islands in position and to safe the touristic infrastructures which have arisen there over the last 150 years. Presumably, large amounts of sand nourished at a time would be more efficient than a piecemeal strategy at short intervals. Most tidal flat areas and the adjacent belt of salt marshes are expected to grow with the sea. Larger volumes of water swinging in and out of the Wadden Sea may also transport larger amounts of sediments. However, there is a time lag, and it is discussed at what rate of sea level rise the sediment accretion will lag behind (CPSL, 2010; Oost et al. 2012; Wang et al., 2012). In any case, where the sediment balance becomes negative, this could also be mitigated by sand nourishments with sand taken from offshore areas.

While the adaptive capacity of the natural system is assumed to be high, the embanked marsh has already demonstrated its negative capacity with respect to sea level rise over the past centuries. Measures are needed which stop soil compaction by keeping rain water in the land. Then the next step is reversing the trend of a sinking land by allowing tides with suspended sediment to enter the marsh, without precluding the potential to live and work safely in the area. This can only be accomplished by diversification of the landscape.

For safety, the present line of defense should be reinforced as in the fortress strategy. However, the defense structure could also be used for additional purposes. This could distribute costs or even allow for an income. For example, dikes could be widened to incorporate roads, housing and promenades. Sectors of the dike could also be built of concrete and be hollow, for use as restaurants or similar facilities with access from land and a view to the sea (Metz and van den Heuvel, 2012).

Residential areas may be surrounded by auxiliary dikes. The lowest level of houses should not be used anymore for permanent living. Also other infrastructures should be reshaped to withstand flooding if all precautions fail. Between such residential areas, the land should be no longer drained. This would stop the process of subsidence. Arising lakes should be linked by canals to prevent stagnant water.

The main dike could include sectors which allow seawater to overflow the structure during storm surges. The height of the overflow structures could be adjusted to limit the amount that enters the marsh behind. During storms, seawater is particularly rich in suspended sediments. These could be trapped behind the dike and there contribute to a growing level of the land. In addition, the wetland vegetation will accumulate organic material, also raising the level of the land.

To compensate the loss of agricultural land, a touristic use is envisioned. Where still preserved from former times, farmhouses on dwelling mounds could be converted into tourist accommodations. In addition, new dwelling mounds could be built. In particularly deep lying areas which presumably would stay permanently under water, floating homes

or homes on pilings could seasonally accommodate tourists. In such a watery landscape, living and travelling would be an adventure. More water would partly restore former living conditions. Thus, this water-rich landscape also provides room for time. It is assumed that touristic use could more than compensate for a loss of arable land although these areas could still be used as pastures or for aquaculture.

Episodically flooded areas could also serve as carbon sinks through strong vegetative growth as other wetlands do. Together with wind energy turbines and panels for solar energy, this coast could be developed into a climate-friendly region. This would improve the image of the area which depends on subsistence for coastal defense. The gradual restructuring of the coastal lowland with more water would increase the contrast with the interior land and make it more attractive. This attraction will depend on life style, the willingness to live with more water and nature. This may be a great challenge in a region where getting rid of excess water has a tradition of almost one thousand years (Blackbourn, 2006).

The new water management may even need more expertise than the former drainage system. Water needs to flow in order to avoid adverse effects such as mosquito plagues. The mixing of marine water with freshwater restores lost brackish water habitats which prevailed before dikes had transformed the coastal landscape. However, the mixing regime should be kept modest. Otherwise few plants and animals would be able to adapt. The main dike also needs sluices for boats as well as for migrating fish. It is important to train personal for water management within the coastal region to maintain the expertise and promote regional identity associated with coast and water.

A striking case of unsustainability has arisen in the estuaries. Shallow tidal rivers with ramifications and river islands have been transformed into deep shipping canals to serve major ports in upstream locations. Tidal range has increased and marine waters flow further upstream than before, causing irrigation problems for agriculture alongside the estuary, and requiring higher seawalls. Storm surges push water masses quickly into these waterways with a high risk for people in the adjacent lowlands in the countryside as well as in urbanized areas. To avoid disaster, it may become necessary to establish a swimming terminal for the transfer of cargo from large to small vessels in an offshore position. Then the estuaries may return to their former shallowness with high biodiversity and opportunities for recreation.

5. Conclusions

The Wadden Sea region comprises a dynamic tidal nature area with interspersed islands, separated by a coherent line of earthen seawalls from a transformed coastal marsh.

Draining the water out of the embanked marsh caused soil compaction and a sinking land while on the other side of the seawall the sea keeps on rising. When sea level rise begins accelerating in the wake of climate change, the resulting coastal gap constitutes an increasing risk.

The tidal nature area, on the other hand, has been upgraded from treacherous shallow waters to a World Heritage Site by trilateral efforts in nature protection. This area seems to be capable of adapting to an accelerating sea level rise without much support.

Therefore, it is suggested to smooth the strict separation and interlink the nature area with the transformed marsh. The latter could be diversified into high residential sites surrounded by episodically flooded marshes capable of growing with the sea.

This restructuring of the marsh would be feasible when former arable land is used for touristic purposes in an amphibious, seasonally flooded landscape which also serves as an effective carbon sink rich in wildlife.

Even if sea level rise will not accelerate as presently expected, the advocated water strategy would offset the coastal gap and increase the economic potential of the coast, while the traditional fortress strategy is heading in the long run towards coastal collapse.

This coastal case study demonstrates how dedicated nature protection could lead the way in coastal development rather than remaining confined to the conservation of endangered habitats and species.

The advocated water strategy is aiming for multifunctional and a multiple use of coastal structures and landscape elements. While in the past the coasts offered complementing land and marine resources, modern coasts mainly may offer recreation next to maritime trade.

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