A natural history of the Wadden Sea

Riddled by contingencies

Karsten Reise

People who are always praising the past
And especially the times of faith as best
Ought to go back to the middle ages
and be burned at the stake as witches and sages.

Stevie Smith
(1902-1971)

Contents

Preface

It is a privilege to write the preface of this booklet by Karsten Reise *A natural history of the Wadden Sea. Riddled by contingencies.* It is the fourth booklet in a series that is being published to mark the occasion of the special lectures being held at the symposia organised by the Wadden Academy.

Karsten Reise delivered the keynote address entitled 'Turning tides: A natural history of the Wadden Sea' at the 13th International Scientific Wadden Sea Symposium held on 21 November 2012 in Leeuwarden. This address provided listeners with a brief summary of the knowledge Reise has acquired during his scientific career. It was an exposé designed to explain the transformation of nature, and a petition to reinstate natural history as a concept for explaining and understanding nature in the Wadden Sea.

Karsten Reise has been a leading Wadden Sea scientist for more than a generation. His book *Tidal Flat Ecology,* published in 1985, is a key resource for the study of the Wadden Sea and tidal flat ecology. Along with his leading involvement in the German Wadden Sea Ecosystem Research project in the late 1980s and beginning of 1990s, he has been critically influential in shaping the protection and management of the Wadden Sea as we know it today, spearheading one of the world's leading conservation initiatives. His description of the Wadden Sea in the 2008 Wadden Sea World Heritage nomination is a key chapter of the document, as well as the most consistent and comprehensive overview that is available on the Wadden Sea. This excellent piece of work convinced the IUCN and the World Heritage Committee of the outstanding universal value of the Wadden Sea, resulting in the Wadden Sea's inclusion on the World Heritage List in 2009.

Contingency is a central notion in Reise's work and vision. It refers to space-and-time coincidences and accidental events. Contingency is almost always involved in natural patterns. The natural history of the Wadden Sea displays such contingencies. It cannot be understood as a self-sustaining and resilient system with an inbuilt capability to find a natural balance. Attention to contingency will strengthen realism and promote prudence when it comes to projections for the future, Karsten Reise argues.

This also has significant implications for the way we protect and manage Wadden Sea World Heritage. Reise advocates an individualistic approach in nature conservation rather than the more or less prevailing holistic approaches. The results of contingent sequences of events should be tolerated as long as they do not significantly spoil the unique natural values of the Wadden Sea. In my view, the latter position is, to a certain extent, already part of Wadden Sea World Heritage management, in particular through the ecological targets approach. With this booklet, though, Karsten Reise has provided arguments for reinstating natural history as a central theme for future Wadden Sea research and management. He has left us this legacy to nurture and develop. My hope is that he will continue to play a leading role in this endeavour in the years to come.

Jens Enemark
Secretary of the Common Wadden Sea Secretariat

Contents in a clamshell. A few preliminary comments by the author

Mudflat revisited by students to conduct comparisons on the occurrence of seagrass and worms mapped at this site in the 1930s.

A historical perspective on the origin and subsequent development of the Wadden Sea reveals cascades of coincidences and human impacts. This has transformed the coastal landscape and altered species composition. History points to a pluralistic development with rather flexible interactions among natural components, while the vision of a tightly interconnected ecosystem with equilibrium states seems less consistent with the natural history of the Wadden Sea. Accordingly, management targets cannot be derived from nature itself. The public should be involved to find desired trajectories for maintaining and improving the natural values of the World Heritage Site, while at the same time adjusting the coast and our lifestyles to accommodate the inevitable effects of global change, such as the rise in sea level.

Introduction

Emergence of the Wadden Sea on a misty day more than 7,000 years ago.

Late in the evening, during ebb tide on 21 May, 7,494 years ago, the Wadden Sea was born. In the drizzling rain, flocks of hasty waders headed north while a gull and a crow quarrelled over the carcass of a large ray. Coiled casts of lugworms' diet lay scattered all over the tidal flats, and in the distant salt marshes, a mighty aurochs called for its mate. What has happened since?

Naïve questions?

In the thousands of years since its birth, has the Wadden Sea grown up, matured and become senile? Or does it function like an old machine for which we may, at best, supply spare parts as needed? Was this semi-fluid edge of the landscape formed by the eternal laws of nature or did it surrender its fate to whatever tides swept by coincidentally? Was the Wadden Sea a drenched paradise or simply a muddy hell for most of its life, until humans managed to make it a hospitable and profitable coast?

The Wadden Sea of old may have resembled the Wadden Sea of today but it has certainly not remained the same. The tides turned many times before UNESCO included the Wadden Sea on the list of natural World Heritage Sites in June 2009. Why did that happen? And now, how will we pass this living coastal sea and landscape on to future generations? Does it have unique natural values which could persist in times of continued overfishing, greed for energy, maritime globalisation, climate change, and ambitious nature protection? Does conventional ecosystem research provide the answers, or can natural history offer a better perspective?

Historical approach to ecology

What does natural history mean today? In the first chapter I review meanings of this term and suggest how it may be applied today. Historical analyses in ecology have never been popular and few scientists pursue this neglected niche research.[1] Central to my historical approach is the concept of contingency (Chapter 2). This word refers to coincidences in space and time and is essential to explaining what happened, and when, where, and why it happened. In a third chapter I explore the role of contingency in the emergence of the Wadden Sea itself. Is this coastal configuration a mere lucky coincidence?

The Wadden Sea's emergence may be the first major turn of the tide in its history. As a second turn of the tide, I suggest the time when the Wadden Sea attained its peak size through incursions on populated land (Chapter 4). Had an unexpected gusty sea overtaken our brave ancestors or was their coastal design unsustainable? Finally, I consider our present time of environmental consciousness as the beginning of a third turn of the tide in the history of the Wadden Sea (Chapter 5). Is this consciousness warranted, and how should we proceed to keep the tide from turning again? I propose that contingency played a crucial role in all three turning points. If so, what does that mean to environmental management?

Human impact

Even before the Wadden Sea emerged, our ancestors were roaming across a territory now engulfed by the North Sea. The sea level rose rather quickly after the last glacial period ended. The shores of the Wadden Sea presumably provided opportunities for continued hunting and fishing, and later for herding, planting, housing, seafaring, and so on. All these activities left traces, if not serious impacts, on the natural components of the Wadden Sea (Chapter 6). So what might have been its natural state at the beginning and how has it changed since then? Is there a suitable baseline for targets set in a management plan?

The seventh and final chapter is concerned with the future of the Wadden Sea. What attitude is to be recommended for safeguarding the World Heritage Site against relapsing mentalities and adverse global change? Does natural history provide a cue? At the end, the reader may consider some conclusions and recommendations, born out of my walk through the foggy natural history of the Wadden Sea.

The phrase *The Turning Tides* not only describes major changes in the Wadden Sea but also in love affairs, here accentuated by a rude photomontage with the head of a wax figure, fouled with barnacles in Büsum harbour, overlaid on the lovely cover of a novel.

1. Why natural history?

Diatoms slide upwards on their mucus path when tides have covered the unicellular algae with deposits, and currents carve their way through the consolidated mud.

From the universe to the Wadden Sea

Nature has its own history. The universe has been expanding for more than 13 billion years without taking a break. The collision of proto-earth with another planet resulted in an earth-moon system 4.5 billion years ago. The tides owe their existence to this cosmic accident. Life on our planet has been evolving for 3.8 billion years. The mats of photosynthetic cyanobacteria at brackish edges of tidal flats in the Wadden Sea are the remnants of this early phase of life. In contrast, it is the diatoms on more recent mudflats that generate layered accretionary elevations, which geologists have termed stromatolites.

Most forms of life were extinguished by accidents. Examples are events such as *snowball earth*, when freezing conditions stretched down to the equator, or large meteorites hitting Earth. The few survivors then started a new evolutionary game. The reason for the extinction of trilobites 251 million years ago remains unknown. Many trilobites ploughed through the intertidal mudflats of their time, and no apparent substitute has evolved since then.

Sixty-five million years ago a gigantic meteorite splashed into the sea near Mexico's Yucatán Peninsula. This caused an extreme global climate event and the entire biosphere was pushed to the very edge of what life could bear. The sea-dwelling ammonites went extinct and the monstrous reptiles followed suit. Some of these had apparently crushed half-meter long oysters. Thereafter, mammals took their chance and radiated into high diversity, including whales and seals. Jurassic Park was followed by Quaternary Park, and now we have a protected wadden park.

Human-like apes appeared on the scene six million years ago. Global temperature was 2° to 3°C warmer than today and sea level about 20 metres higher. Upright apes evolved rapidly in small populations to become versatile humans. These luckily escaped extinction when a tremendous volcanic eruption occurred in Sumatra 75,000 years ago. About 40,000 years ago, some modern people migrated into Europe, where they later encountered a wide plain where fish now try to escape from nets of the fisheries.[2] We can be sure that our ancestors watched the very beginning of the Wadden Sea and affected its *natural history* from then on.

Natural history in antiquity

Not only does nature itself have a history, the definition of the term "natural history" has also changed over time. We still often associate the term with the names of famous museums that exhibit the diversity of life and the history of earth. However, this is not the term's original meaning. Aristotle used it to mean everything one can sense. The perceptible world was seen as counterpart to the abstract world of ideas where Socrates and Plato felt at home. This distinction was made 2,350 years ago. Separating nature from man or from the world of reason strongly affected our perception of the natural world around and in us, and continues to do so.[3]

In antiquity, natural history covered just about everything which seemed to be connected with nature. In the first century, Roman Pliny the Elder wrote his comprehensive *Historia naturalis*, which comprised volumes on astronomy, human life, animals and plants, minerals, and the geography of the known world. That work included the oldest written record of the Wadden Sea, which he visited in 47 AD. He saw land and sea in contest, leaving undecided as to which one the wadden area might belong. The people residing there seemed to him to have a miserable life, dwelling on artificial mounds in the midst of the sea. He mentioned that they could not hunt wild animals because there were no bushes in which to hide while stalking, and meals were cooked over fires fuelled by dried dung. The only drink available was the rainwater they collected in earthen holes near their huts.

Lonesome dwelling mound in the North Frisian Wadden Sea, Hallig Südfall, close to where the legendary town of Rungholt was drowned by a storm in 1362.

Natural history in the 18th century

Various disciplines, ranging from astronomy to ethnology, were emancipated from this wide and varied spectrum of knowledge. In the 18th century natural history became confined to what was known about minerals, plants, and animals. The most comprehensive account of this knowledge is from the French aristocrat Comte de Buffon in his *Histoire naturelle*. His detailed and well-illustrated descriptions were widely read throughout Europe. Buffon was rivalled by Carl von Linné. Both men were born in 1707. Linné grew up in Sweden and developed in his *Systema Naturae* a nomenclature for plants and animals which is still in use today. Similar organisms received the same genus name, and organisms which were alike and lived together received the same species name. To kindly honour his French colleague, he named the wrinkled common toad, which can be found on most wadden islands along with the more graceful natterjack toad, *Bufo bufo.*

Buffon, the toad, and Linné.

Linné wrote in a minimalistic style to be used for the identification of organisms, and named almost 6,000 species. Up to now, taxonomists have described 1.3 million species and many more are waiting to be defined. About 10,000 species are known to occur in the aquatic habitats, salt marshes, and dunes of the Wadden Sea region.[4]

Emerging temporality in natural history

Towards the end of the 18th century, traditional natural history began to dissolve. Organisms were generally ordered with respect to ascending complexity, with humans placed at the top. Only gradually was a temporal perspective gaining ground in natural history.[5] For example, in 1790, the philosopher Emanuel Kant wrote on cause and effect in nature that 'some aquatic animals may have developed gradually into amphibious animals and these further into terrestrial animals'. In his *Zoonomia, or the Laws of Organic Life,* Erasmus Darwin, a grandfather of Charles, suggested in the mid-1790s that every living organism on Earth had descended from *one* common ancestor. Jean-Baptiste Lamarck, professor of invertebrate zoology in Paris, explained structural similarities by common ancestry. Such ideas can be traced back even into antiquity, but Christian dogma on creation made scientists reluctant to pursue such ideas.

Natural history and Charles Darwin

As a young student in Edinburgh, Charles Darwin became an active member of the student-run Plinian Natural History Society in the 1820s. He developed a particular fondness for seashore animals, and he and his friends dredged oyster beds in the Firth of

Forth.[6] After his journey with the *Beagle*, he prepared for a breakthrough in natural history. However, before daring to publish *On the Origin of Species by Natural Selection*, he decided to first gain a scientific reputation with a meticulously detailed monograph on barnacle diversity. At the time, the position of barnacles within the invertebrates – animals without a backbone – was still undecided. By documenting the aberrant anatomy of a wide range of barnacle forms, he showed that they were all related to the crustaceans: shrimp, lobsters and their relatives. Darwin won the Royal Society Medal in 1854 for this study. He had written an essay on natural selection back in 1846, but kept it under lock and key throughout his eight-year obsession with barnacles.

The South Pacific barnacle *Austrominius modestus* (Darwin, 1854) was shipped to England a century after Charles Darwin had first described it. With mild winters and warm summers, this species became common in the Wadden Sea.

Feeling pressured by a manuscript received from Alfred Wallace, who had developed similar evolutionary ideas, Darwin finally went public with his theory in 1859. He explained the process of evolution by natural selection. Of those variations generated by chance, the fittest tend to survive. Thus, he could see no divine purpose in barnacles and other organisms which had evolved. The history of life was now extended far beyond the calculated 4,004 BC, when God had created the world according to the Bible. Likewise, geologists had accumulated evidence for a much longer history of rocks. The term natural history would have been very appropriate for the new research, which attempted to reconstruct the long timeline of the development of the planet and the evolution of life. However, in the mid-19th century, the term natural history was still too closely associated with the outdated science from which the new disciplines of geology, botany, and zoology had been emancipated.

Communities and ecosystems

The naturalist Charles Darwin also conducted ecological research. His last book, published in 1881, was on the role of earthworms in soil formation. At the time, Karl August Möbius was studying the oyster beds near Sylt in the Wadden Sea region, defining them as a *biocoenosis*, or living community.[7] All of the organisms at a site were assumed to have adapted to local conditions and to be maintaining themselves within limits by interactions with other species and the environment. This oyster bed community was being threatened with overexploitation when Möbius surveyed it, and while the beds ultimately vanished, his concept of an ecological community remained alive.

Karl August Möbius (1825-1908) investigated the oyster bed community in the northern Wadden Sea. The small, flat *Ostrea edulis* (Linnaeus, 1758), regarded as a delicacy, was overharvested and went extinct in the region.

Today, the dominant view is that environmental management for sustainable development should be based on ecosystem research. Ecosystems are defined as functionally well-integrated subsystems of the global biosphere. Interactions among organisms and between organisms and their environment, determine the subsystems' behaviour. Ecosystems are assumed to have the capacity to retain structures and functions via feedback when challenged by an external disturbance. This system behaviour is called resilience.[8] When subject to permanently changing environmental conditions, ecosystems may undergo adaptive cycles to maintain themselves. Society and nature may be looked at as co-evolutionary systems. This approach may lead to faulty recommendations, however, since ecological interactions may in actuality not be that tightly bounded. Components combine in various ways and rarely if ever attain equilibrium states to which they return by resilience.[9] The ongoing controversy on this issue is described in Box 1.

Box 1

Competing approaches

Within the science of ecology, ecological holism competes with an individualistic approach.[10] In *ecological holism*, ecosystems are natural entities that have evolved resilience. Systems change very little at first when challenged by natural or human disturbances. They have stable or multiple stable states. These constitute equilibrium conditions to which systems tend to return by resilience. The system is so cohesive that if it is disturbed beyond a limit, a sudden state change or even collapse may occur. The most natural states are assumed to be superior because of long co-evolution between the system's parts. Through ecosystem research, equilibrium conditions and resilience properties are identified that should then serve in guiding nature management.

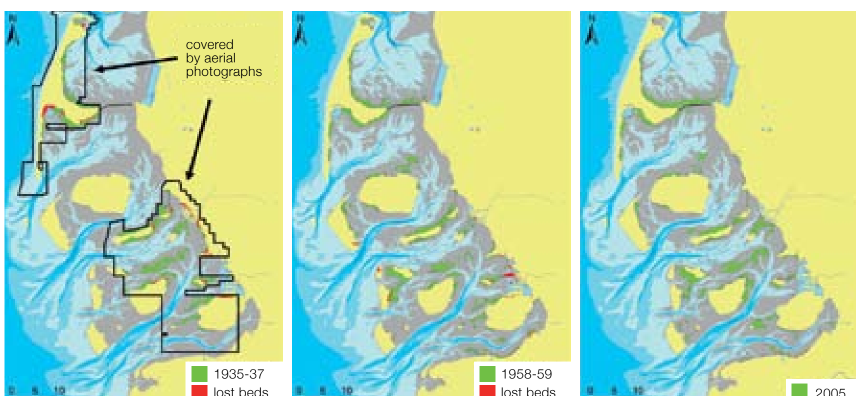
In an *individualistic approach*, ecological interactions tend to be flexible. Individual species respond in their own way rather than as parts of a whole. Not all components are linked to each other at all times and all sites. Instantaneous and continuous change prevails when an assemblage of organisms is faced with evolutionary innovations or with external events and trends, including challenges by human intervention. What may be seen as desirable for nature is not determined by nature itself. Instead, desired ecological compositions and conditions are up for public debate. Decisions depend on competing interests and visions of societal groups.

The historical dimension is essential to the individualistic approach, while ecological holism is primarily concerned with timeless system properties. These extreme positions are the end-points of a continuum. The truth may be somewhere in between. However, the different philosophies percolate all the way through to strategies in nature conservation and the phrasing in environmental communications.

The natural sciences are designed to discover order in nature, which creates the danger of reporting more lawfulness and regularities than there really are. A common method is to design simplified systems in a laboratory, declare observed responses to be general, and then interpret the outside world in the light of these principles by selecting phenomena which fit. This may nourish an illusion of understanding how nature works. History in nature is not considered to be an important issue.

However, historical ecology seems to be on the verge of a renaissance, also in the marine and coastal realm.[11-14] It is a field that is dedicated to reconstructing timelines of vegetation, animal populations, human impacts, and environmental conditions.

Pinpointing the time at which the climate changed, or when humans started engaging in burning, herding and other activities that effected landscape transformations – knowing what happened when, where, and why – is essential to managing present and future natural environments. This research is an indispensable and interdisciplinary endeavour. All kinds of information are incorporated from palaeontology and archaeology, from historical documents and tales, from repeating old surveys to allow comparisons with the present over long intervals of time, and from long-term ecological time series research. This knowledge of the past cannot be entirely revealed by analysing extant structures.



Extent of intertidal seagrass beds in the North Frisian Wadden Sea as reconstructed from aerial photographs taken at low tide.[15] The losses due to land reclamation aside, most of the beds have persisted over the last 70 years.

Such studies are often collectively known as environmental history. However, in the case of the Wadden Sea, I prefer to revive the old term natural history, and use it in its literal sense as the history of nature rather than descriptions of nature. This choice seems justified for the following reasons:

(1) The Wadden Sea is protected because of its natural values, and it has been listed as a natural world heritage site and not as our environment. The focus is therefore on its natural history.

(2) Human activities have divided the Wadden Sea region into a natural seascape and a cultural landscape, often strictly separated by a dike line. In this text, I am mainly concerned with the more natural part of this coastal region.

(3) Although humans are an integral part of nature, I focus on historical changes in nature rather than in coastal societies. The term environmental history is appropriate when natural history is integrated into human history.

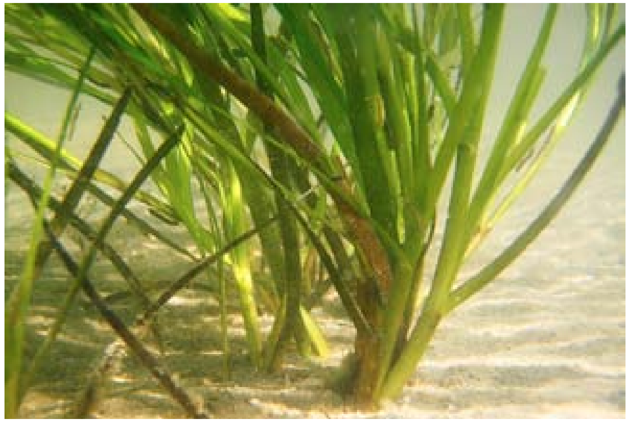
Natural world heritage is our legacy from the past. If we want to live with it today, it would be wise to know how it came to be the way it is now. If we want to pass this legacy on to future generations, our knowledge of its responses to challenges in the past is likely to provide the best information we could convey along with the heritage itself. Unfortunately, this knowledge is still rather rudimentary and more research should be funded to unroll the natural history of the Wadden Sea.

2. Contingency in natural history
What is contingency?

A mussel bed scoured by ice, with little more than empty shells remaining. What is the chance of recovery?

I do not deny that regularities and repetitive patterns are very common in nature, but nature is also riddled with chance events which by definition cannot be deduced from general laws or principles. Simply reflect on your personal history. Compare your changing tides – when you had good or bad luck, when you fell in love or when your relationship ended in disaster, when you laughed but no one else found it funny, when you won a lottery or had an accident – and then compare the aftermath of all these events with the plans you may have made for your life. This comparison reveals the difference between what should have happened and what actually happened in your life.

The difference is due to *contingency*, a term which refers to space-and-time coincidences and accidentalness. Historical analysts of ecosystems have to be aware of the concept of contingency. Natural phenomena can be explained in two different ways. Conventionally, the focus is on the functional relationship between cause and effect. The knowledge gained is then used to predict similar phenomena. The prediction is in turn tested by showing that the underlying functional relationship was indeed the same.



In the last century, seagrass became rare in the southern part of the Wadden Sea but remained common in the northern part. Did contingency play a role in this differential pattern?

This kind of explanation ignores contingency, which comes into focus when attention is shifted from general mechanisms to particular patterns. The latter can only be fully understood when the sequence of antecedent coincidences and the neighbourhood properties are revealed. If general mechanisms invariably determined all effects, the results of both types of explanation would be the same. This is not generally the case, however, demonstrating that contingency is almost always involved in natural patterns.

Narratives on the particulars

There is only a certain probability that a given effect will occur. Coincidentally, the relationship between cause and effect may be altered, perhaps because of an independent, unforeseen factor which arose by chance. Alterations may also result from a previous event that is still influencing subsequent responses. Similarly, the neighbourhood constellation may affect the outcome. The concept of contingency accounts for all coincidences which delimit the applicability of general principles in particular cases. In the language of logic, contingent phenomena are neither inevitable nor impossible.[3] They fall somewhere in between.

For evolutionary chains of events, Stephen Gould[16] suggested that explanations may take the following narrative form: The phenomenon E arose because D came before, preceded by C, B and A. Otherwise there would have been no E but something else. A historical explanation does not rest on direct deductions from the laws of nature, but on the reconstruction of an unpredictable sequence of antecedent states. Any major change in any step of the sequence would have altered the final result. Out of coincidence, a novelty might arise, while others stop or die. Different sequences occasionally converge to form the same pattern, while similar sequences may produce very different patterns when there are differences in the inherited material.

Contingency in ecology

Suppose that drifting ice floes were to destroy a mussel bed. If a substantial amount of shells remained at the bottom, and if mussel larvae swimming there later happened to encounter that substrate, and if crabs did not consume all of the young mussels before their shells became resistant to crushing, then and only then might the mussel bed reappear at the same site. Without shells left on the sediment for settlement, it might take a very long time before some other suitable substrate in the form of cockles, projecting worm tubes, or green algal strings were to become available to nourish a comeback of the mussel bed. The succession to the return of a mussel bed is a process with many alternatives, and one that is hardly predictable.

Contingency is also important for spatial patterns to become realised. Barnacles on a solid substrate tend to aggregate. Where exactly clusters of barnacles are found depends on a number of contingent circumstances. First, barnacle larvae ready to settle have to be lucky to encounter a suitable substrate when drifting back and forth with the tides. Once on a substrate, larvae crawl about to find a place that seems suitable for metamorphosis into a barnacle that is permanently cemented to its substrate. From then on, it dwells inside its cone-shaped house made of calcareous plates. Irregularities on the surface are preferred. The living neighbourhood is also important. Many barnacles close to one another are less vulnerable to predation than solitary individuals. Mates must be nearby because, unlike mussels, barnacles fertilise directly. If the nearest mate is too far away, reproduction will be impossible, or an extremely extended penis will likely be nipped off by a shrimp. Thus, understanding a particular pattern requires a lot of information on both functional relationships and coincidental events.

Inner oyster shell providing barnacle larvae with a substrate for metamorphosis into sessile adults. Oval cyprid larvae crawl about and tend to opt for unevenness and close proximity to other individuals during settlement.

Contingency in Wadden Sea history

Of course, contingency also affects human history. In January 1362, a devastating flood hit the Wadden Sea ('Grote Mandranck in Vreslande'; 'Mass Drowning in Friesland').[17] People were drowned and large losses of land were recorded in Nordfriesland, Eider estuary, Jadebusen, Harle, Leybucht, and Dollard. However, this disaster is not sufficiently explained by an exceptional storm surge.

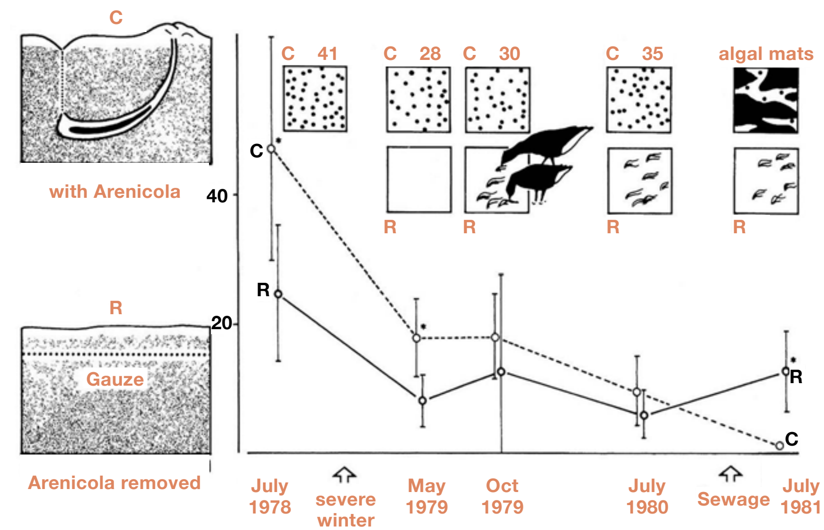
A plague epidemic had weakened the coastal population in previous years. The *Yersinia pestis* bacterium had spread from Asia to Europe. The death toll was particularly high in Hamburg and Bremen, cities in the Hanseatic league. By the time the plague ended in 1353, the coastal population had declined significantly. Extreme weather events had also cooled the climate, causing frequent crop failures.

Under these circumstances, the burden of maintaining the dikes in proper condition could not be met, bringing to mind the proverb that a misfortune seldom comes alone. The coincidence of these independent events – the storm, pandemic, and crop failures – explains why this flood has remained the severest of all in the coastal memory of the Wadden Sea region.

Historical knowledge versus universal understanding

Performing historical research is asking what happened when, where, and why. The aim is to reconstruct the relevant events in the context of their temporal and spatial relation to each other in order to understand present situations. The experience gained may then be used to cope with similar future situations. Both forms of explanations, those deduced from general functional relationships and those deduced from historical reconstructions, should complement one another in varying proportions, depending on the question asked and the issue at stake.

Attention to contingency will strengthen realism and promote prudence when it comes to making projections for the future. Scientific publications have a tendency to report general relationships, while contingent events remain underreported. It seems that the latter are often sacrificed as deviations, outliers, or suspect values. Contingencies may be a bump in the road on the way to the simple and elegant explanations that are hoped to lead to universal understanding. In contrast, nature protection is usually dedicated to particular patterns, and therefore relies more on historical explanations than the abstract and timeless laws of nature.



Experimental removal of lugworms *Arenicola marina* (Linnaeus, 1758) and the variable response of small turbellarian worms over the course of four years. Dots in and numbers above 1 m² areas indicate abundance of lugworm faecal castings, and curves show mean turbellarian numbers below 2 cm² with standard deviation. C stands for control and R for removal plot[18] (see text).

Contingency in an ecological experiment

How general relations and contingency come together may be illustrated by an experiment that went astray. I excluded lugworms from a sandy tidal flat to see what would happen to associated turbellarians.[18] These tiny flatworms dwell primarily in the interstices of sand. Most measure between 0.5 mm and 2 mm in length. Some feed on bacteria growing on organic debris, some on diatoms, and others on copepods, nematodes, or other turbellarians. All require well-oxygenated sediment. Therefore my hypothesis was that lugworm exclusion would result in a decline of the turbellarians. By feeding and by irrigating their burrows, lugworms keep the sediment permeable to pore-water fluxes and keep the upper layer well oxygenated.[19]

Lugworms were removed by inserting a fine nylon mesh horizontally at a depth of 5 cm below the sediment surface. This blocked vertical burrow shafts, and the lugworms moved out laterally. As long as the mesh remained in place, lugworms were excluded and new ones did not move in. About 30 species of turbellarians were encountered in the course of the experiment, which lasted from July 1978 to July 1981. As expected, 20 days after the lugworms were gone, the density of turbellarians at the removal plot was significantly lower than in the control area with lugworms. This suggested that the small turbellarians indeed benefited from the activity of the large lugworms.

Lugworm placed on sediment surface with feeding funnel and faecal casting (left), and excluded by a net in the sediment (right).

The subsequent winter was unusually severe. Lugworm density declined in the area, including in the control area, and so did turbellarian density. Nevertheless, the significant difference between removal and control persisted into the next spring. I should have stopped the experiment at that time, because afterwards factors other than the bioturbation and irrigation by lugworms became more relevant for turbellarians.

Seagrass spread into the removal plot. This in turn attracted brent geese in the autumn, when they returned hungry from their arctic breeding grounds. The geese dug out the seagrass rhizomes, causing too much variation in the number of turbellarians to detect any differences between plots. One year later, in July 1980, sampling occurred prior to arrival of the geese, but apparently lugworms and seagrass had similar effects on turbellarian density.

Finally, in the third year, a massive response of weedy green algae to regional eutrophication reversed the outcome of the lugworm removal experiment. This occurred because lugworms anchor threads of green algae in their shafts. Algal strings became trapped in feeding funnels, then slid down and blocked the shafts. The worms did not feed on these algae, opening new shafts nearby instead. The algal strings were then virtually "rooted" in the sediment and continued to grow into algal mats. The result was that the sediment in the control area became devoid of oxygen underneath a dense layer of algae, while the removal plot remained free of the harmful algal cover. Turbellarians were thus significantly more abundant at the removal plot at that time.

The turbellarian worm *Utelga scotica* (left) is a lurking predator almost 2 mm long. It has a toxic proboscis (top), a sucking mouth below two eyes, and a rear with complex reproductive organs. Green algal strings are trapped in the feeding funnels of lugworm burrows (right).

Taking the sequence of events together, the removal of the lugworms had all of the possible effects on turbellarians: negative, neutral, and positive. The effects depended on contingent events such as the occurrence of seagrass, geese, or green algae. The experiment was originally designed to learn what effects lugworms generally have on small, associated worms on tidal flats. Instead, a non-reproducible, unique sequence of particulars was revealed. Contingency precludes the repetition of the result. Nevertheless, such coincidental sequences provide the basis for patterns in nature and thus deserve our attention.

Natural history attempts to reconstruct what really happened. All particulars and coincidences count. Abstract models show what should generally happen or might happen in the future, provided that natural laws are not subject to deviations. Natural history, on the other hand, is particularly concerned about these deviations. The highly dynamic nature at the transition between sea and land may make the role of chance and coincidence in the Wadden Sea more apparent than in more stable regions.

3. On the origin of the Wadden Sea

Flock of knots foraging in spring on tidal flats in the Wadden Sea, gaining fat reserves before taking off for the long-distance flight to Arctic breeding grounds. They do the same in late summer before migrating back to Africa.

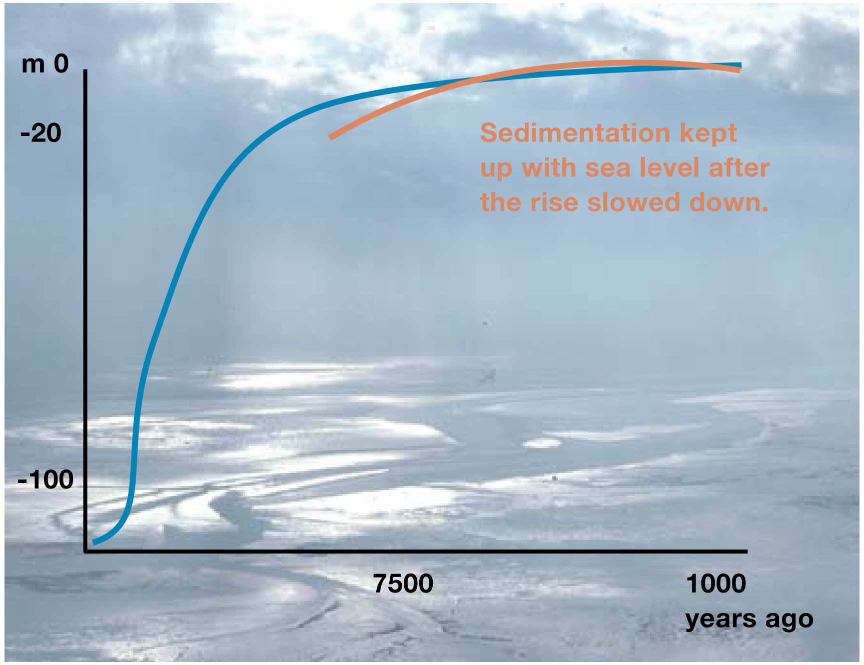
During the coldest phase of the last Ice Age, 20,000 to 18,000 years ago, so much frozen water was bound in glaciers and ice shields on land that the global sea level was 120 m lower than it is today. Where the waves of the North Sea now dance, there was a wide plain as large as the Netherlands, Denmark, and coastal Germany combined. On the tundra, in forests, near rivers and lakes, dwelled mammoth, woolly rhinos, bison, aurochs, wild horses, elk, reindeer, beavers, brown bears, wild boar and wolves, with our ancestors hunting and fishing among them.[2]

Sea level rise

After the peak of the last Ice Age, sea level was rising rather quickly, by about 100 m in 10,000 years. The flat plain in the southern North Sea was submerged. A channel opened between England and the continent, and Dogger Bank was drowned. We came by our knowledge of the large fauna through bones caught in fisheries' trawling nets and oyster dredges, and finds of hunting and fishing gear that belonged to our ancestors. On average, sea level was rising at that time by one metre per century. This is approximately the same rise that is expected to continue until the end of our century, triggered by the burning of fossil carbon and the warming the atmosphere and the upper layers of the oceans.

However, when the big ice shields of Canada and Scandinavia had largely melted and the melting water had entered the sea 8,000 years ago, the sea level rise in the North Sea region began to slow down to a mere 15 cm per century.[20] Only then was it possible for the Wadden Sea to emerge. Elsewhere in the world, as well, the almost stagnant sea level allowed sedimentary deposits to accumulate in coastal plains. The large deltas of the Nile, Mississippi, and Ganges-Brahmaputra also began to emerge at that time.

Schematic course of post-glacial sea level rise decelerating about 7,500 years ago, and then being compensated for by sediment deposited by a rough North Sea into the Wadden Sea.



Rough sea, tidal range, and sediment availability

The deceleration of sea level rise is not, however, sufficient to explain the birth of the Wadden Sea. A coincidence with other conditions was crucial:

(1) The shallow North Sea was and is a very rough sea. Low air pressure systems approached from the North Atlantic, generating heavy surf, particularly in winter. Where waves touched the ground, sand was transported towards the shore. During storm surges, water levels could rise 3 m or more above normal. Floods reached far inland across the flat terrain. These carried

suspended sediments from sea onto land, and this land could grow with the slowly rising sea.

(2) Tidal range increased with sea level rise. Where the tidal range is less than 1 m, currents and wind generate long, sandy spits. Today, these are found on the Atlantic coast of North America, in the southern Baltic Sea, and west and north of the Wadden Sea. Behind these spits extend lagoons, which may gradually silt up like Venice lagoon. At a higher tidal range with stronger currents, the long, sandy spits break into chains of islands or sand bars. This is characteristic of the southern and northern Wadden Sea. Where tidal range exceeds 3 m, currents become too strong for permanent islands to form, as is the case in the central part of the Wadden Sea between Jade and Eider. This increase in tidal range results from the right-angled shape of the Wadden Sea, with the funnels of Elbe and Weser in the middle.

(3) Finally, an ample sediment supply from the North Sea to the coastal zone contributed to the emergence of the Wadden Sea. The North Sea basin had filled with huge amounts of sand in the preceding millions of years. Waves and tidal currents mobilised the upper layer and this allowed sand bars, dune islands, and tidal flats to grow. The North Sea is probably a more reliable source of sediment than rivers are, particularly when rivers and river basins become modified by human activities.

(4) Tidal flats and salt marshes also grew through the deposition of suspended matter generated by North Sea plankton, and the deposition of suspended composite particles which formed out of dead organic material, bacteria, and minute mineral pieces in the brackish river mouths. This accounts for the formation of mud at sheltered sites.

The emergence of the Wadden Sea as a lucky coincidence

The Wadden Sea owes its origin to the unique combination of these four factors, meaning that its emergence was coincidental. The now slowly rising level of the sea became more or less compensated for by sediment deposits in a wide belt along the coastline. The coastline position was thus no longer shifting landward, as it had in the preceding period, when sea level rose too fast for sedimentation to keep up. The Wadden Sea created a kind of buffer between the open sea and the land. Salt marshes and tidal flats grew upwards, and islands migrated towards the shore in response to the slowly rising sea.

One should not regard the persistence of the Wadden Sea as a natural equilibrium generated by a self-sustaining feedback system. The details do not support this view.[21] In the West Frisian and North Frisian Wadden Sea, the outer coastline of sand bars and dune islands shifted about 10 km from north to south and west to east, respectively. In contrast, the sea between Weser and Eider had first intruded very far inland, and then subsequently deposited so much sediment that the land could extend into the sea. The Danish Wadden Sea received sufficient sediment from the North Sea to allow seaward growth as well.

Furthermore, geological drilling behind the East Frisian islands revealed an alternating sequence of sea and land.[22] In cores 20 m long, deep layers of peat alternated with marine sediments at least three times. This has been explained by phases in the rise and fall of sea level, but that would lead one to expect to find synchronous layers all along the North Sea coast. No such consistency has been found.

I suggest a more plausible explanation: locally alternating phases of sediment over-supply relative to sea level rise, with sediment deficits or a balance between sediment supply and sea level rise. Thus, sediment availability is viewed as the variable which changed between sites and from time to time. Sea level rise was the same throughout the North Sea, and has remained rather continuous over the last several thousand years.

Peat formed during freshwater conditions centuries ago. This peat is now occasionally found below marine sediment near the island of Pellworm.

From the perspective of the present, the birth of the Wadden Sea was a lucky coincidence that involved a concatenation of more than four independent processes. The region continued to develop with much temporal and sub-regional variation. Only by taking a rather cursory view will the picture emerge of a coast in natural balance with the processes of the sea. In addition to sea level rise and sediment import by waves and tides as mentioned above, other processes had a significant effect on the Wadden Sea. These included a rather stable climate over the last 11,000 years, exceptional storm events and rainfalls, slow tectonic subsidence – mainly in the central Wadden Sea – and changes in vegetation and fauna, including the lifestyle of the coastal people.

The geographical position of the Wadden Sea happened to be ideal for coastal birds breeding in the high Arctic and wintering in western Africa.[23] It is located approximately halfway between breeding and wintering sites within a radius of 4,000 to 5,000 km. This is a perfect place for the main restaurant along the flyway for long-distance travellers. This geographical position presumably had a major effect on the evolution of migration strategies in waders of the East Atlantic flyway.

4. Invited to drown

Drowned medieval farmland exposed during low tide in 2011. Overlying sediments had been washed away by a growing tidal channel north of the island of Pellworm.

Minor landscape effects of people until 1,000 years ago

When the wide plain in the southern part of the North Sea basin became covered by the sea as a result of the melting land ice, animals and their hunters had to retreat to the Wadden Sea region. As they did elsewhere in Europe and Asia, hunters contributed to or even caused the extinction of megafauna. The abundance of large grazers presumably had a strong influence on proportions of wood and open land.[24] A more direct effect of the coastal people on the landscape commenced 6,000 years ago with settlers of the Younger Stone Age. These people kept domestic animals and grew crops. Many traces of these settlers have been found on the elevated terrain which owes its existence to the glaciers of the penultimate ice age. On Sylt, the many grave sites suggest that settlement was rather dense over a long period of time.[25]

Permanent use of the low-lying but fertile marshes commenced along the river banks and outer edges of the salt marsh belt approximately 5,000 years ago. Increasing numbers of artificial dwelling mounds were built starting 2,800 years ago.[22,26,27] These helped residents stay above storm surge level when the surrounding marshland was flooded. Gradually, as noted by Pliny the Elder, a landscape characterised by these dwelling mounds had developed. Mounds were built continuously higher to account for storm surge heights and the property at stake. The surrounding salt marshes were grazed by domestic animals, while elevated bogs further inland remained untouched. The effects of early settlers modified the landscape, but had not yet transformed it into another state.

Stone Age grave site once set up on a moraine elevation, but now at the level of tidal flats near the island of Sylt. Boulders provide good settlement for barnacles.

The consequences of diking

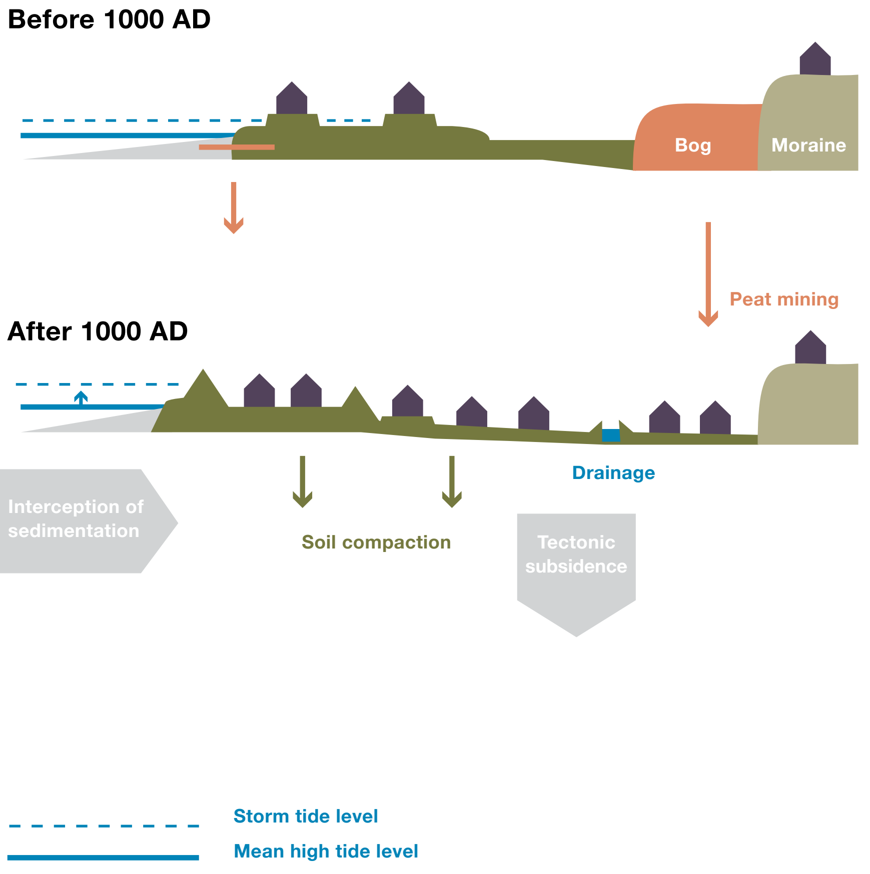
Between 1000 and 1500 AD, a dramatic change was executed in the coastal landscape.[28,29] This transformation commenced in the hydraulic societies of the Netherlands, and from there the new landscape architecture expanded to the east and north of the Wadden Sea. Early dikes surrounding the property of local communities were connected to each other. This resulted in an almost uninterrupted dike line that has defended the entire lowland since 1300 AD against flooding from the sea and the rivers. This diking has had far-reaching consequences.[30]

(1) Accommodation space for the water masses during storm tides decreased. Less wave energy could be dissipated on salt marshes before the waves hit the dikes. The larger the area that was embanked, the stronger the dikes had to be in order to cope with storm surge situations.

(2) Dikes intercepted sediment deposition by storm tides, and the enclosed land could no longer grow with the sea.

(3) In the embanked area, rainwater was temporarily stored in ditches and from there channelled through sluices out into the Wadden Sea during low tide. This water management facilitated mineralisation processes and soils contraction.

Schematic profile of marshland with consequences of diking and peat mining after 1000 AD, resulting in an unsustainable coastal configuration with a high risk of drowning when severe storm surges hit insufficiently maintained dikes (see text).



An unsustainable landscape transformation

The embanked land began sinking below the level of the sea and the growing risk had to be managed by ever stronger dikes. This lowering of the landscape level was aggravated by large-scale peat mining. The peat was used as fuel, with the soil underneath the peat layer used for agriculture. Peat mining was also practiced in front of the dikes. There, the peat, soaked with marine water, was dried and burned to extract salt from the ash. This developed regionally into an important trade, bringing wealth but entailing the inevitable loss of land.

In spite of the advantages of dikes for agriculture and safety, and the wealth gained from peat mining, the entire coastal landscape had embarked upon an unsustainable course. Large areas sank below the level of the sea. Excessive rainwater often had to be pumped upwards to the sea using wind energy. Where this was unsuccessful, malaria became a problem.[31] As long as marine waters were being episodically flushed through the ditches, the mosquito *Anophelis atroparvus* was kept out.

The larvae developed very well in freshwater and brackish ditches, however, and adults could hibernate in barns and houses. These mosquitoes transmitted the flagellates *Plasmodium vivax* and *P. malariae* to humans. Children in particular died of the fever, with stricken adults remaining weakened for the rest of their lives. The extra work required to maintain and strengthen the dikes became difficult to accomplish after epidemics. It is likely that Roman soldiers had introduced malaria to the North Sea region. The Frisians later developed partial immunity by natural selection, but malaria became a barrier to immigrants.

Advancing risk and tragedy

Behind dikes, dwelling mounds were no longer adjusted to compensate for higher storm surges and new houses were built on level terrain. Population density increased in the enclosed lands because dikes improved agriculture. The first line of dikes now had to guarantee safety for all, as the risk was not spread. If the dikes could not withhold a storm surge, the effects would be catastrophic. Only by continuously strengthening dikes could this highly vulnerable cultural landscape be maintained.

People knew this of course. However, when additional burdens were imposed from within or outside, such as malaria or plague epidemics, hunger, social unrest, political contest, or even war, then the level of precaution for the defence system became insufficient. Now contingency demanded its tribute. Again and again dikes were overtaken and broken. The intruding water masses were difficult to drain from land lying below the level of the sea. The Wadden Sea became larger than ever.[30] The Zuiderzee, Middelzee, Lauwerszee, Dollard, Leybucht, Harlebucht, Jadebusen, and the North Frisian Wadden Sea extended into places where people had been living and agriculture had thrived.

The storm surges were not the sole cause of this development. The long-term consequences of diking had not been foreseen when the first dikes were built. Social structures were not up to the task of the increasing efforts to meet the coastal defence requirements imposed by a rising sea and sinking land. Disasters became almost inevitable. Many people died in the floods, and those who lost their property had to leave. The landscape did not return to a natural coastal configuration. The remaining and repaired dikes maintained the rigid boundary between sea and land. The gradual transition – from tidal flats to a wide belt of salt or reed marshes, and from there to bogs or wood – which had been lost never re-emerged. There was no reversal of history.

5. Beginning of a new wadden alliance?

Guided tidal walk with a lecture on animal life below the boots.

Conquering the Wadden Sea

After the storm surge disasters in late mediaeval and early modern times, one might expect a strategic turn in the making of the coastal landscape, but this never happened. Although the horrors became deeply engraved on the coastal mentality, and the violent North Sea was met with distrust and hostility, warning voices were rejected by the mainstream.[32] Instead, a solution was seen in the technological progress which allowed people to build dikes that were stronger than ever before. In addition, new land reclamation methods were employed to facilitate sedimentation and the growth of salt marshes. This helped to win back the lost land.

In front of the dikes, a foreland was created that was intended to help break the energy of the waves before they hit the dike directly during storm events.[30] Forelands could be drained after flooding with a system of parallel ditches. Forelands were also used for domestic grazers. On the seaward side, brushwood groynes attenuated waves, facilitated sedimentation, and fostered vegetation. Artificial forelands replaced natural salt marshes, and habitat diversity decreased substantially.

Coastal defence became more and more expensive and was finally taken over by state authorities.[29] The safety of dikes no longer relied on the health and wealth of local municipalities, making the entire defence system more resilient. Downward spirals in defensiveness and vulnerability could be halted by state investments. In the 20th century, coastal defence technology and professional engineering were sufficiently developed to conduct large-scale embankment projects. Dams were built across tidal flats and deep gullies. Most bays were embanked and turned into arable land. The incentives for these activities were not solely economic in nature. An obligation was felt to regain the land once lost to the sea. As a result of these efforts, however, land was reclaimed even from tidal areas where there had been no land before. The Wadden Sea became smaller again, in large steps.[30]

The most spectacular project was the damming of the 3,800 km² Zuiderzee in 1932. This large, brackish bay was turned partly into arable land and partly into a freshwater lake (IJsselmeer). To improve island economy, Sylt and Rømø were connected to the mainland by solid dams running across tidal flats, built in 1927 and 1943, respectively. The dams were also meant to facilitate sedimentation and gain new land.

The last and most controversial large-scale embankment (33.5 km²) was completed in 1987 (Nordstrander Bucht, now Beltringharder Koog). To compensate for its impact, the polder became a nature reserve with pastures, marshland, freshwater reservoirs, lakes, and a lagoon with limited tidal amplitude (40 cm compared to 3.5 m outside the dike). Foreland with brushwood groynes has been partly closed to grazing sheep to regain salt marsh diversity (lower right). The polder in the foreground was embanked in 1926.

Lorentzsluizen, a complex of locks near Kornwerderzand, Friesland, in the Netherlands. The locks are part of the Afsluitdijk, a dike that dammed the Zuiderzee in 1932 to create both arable land and IJsselmeer, a freshwater lake.

Plans were even made to connect the islands with one another by damming deep tidal inlets and then turning entire tidal basins into land.[33] Unexpected flood disasters in the Rhine delta (1953, known in the Netherlands as the North Sea flood [*watersnoodramp*]) and in Hamburg (1962) prompted state authorities to massively strengthen coastal defence structures all along the coast. Dike lines were straightened and storm surge barriers were built at river mouths. This aggravated the structural confrontation between sea and land.

Habitat loss

In the estuaries, water level increases during storm surges were higher because the water masses had been restricted to a smaller area and because deep channels were dredged for ever larger ships.[30] The embankment of bays and the straightening of dike lines decreased the length of shores. Mudflats close to sheltered shores vanished behind dikes. Salt marshes became degraded to managed foreland. The long-term effect was a decrease in the area of the tidal zone and a disproportionate loss of muddy flats. The latter also may have been lost because the dissipation areas for waves during storm tides had become smaller as a consequence of progressive diking. This increased the hydrodynamic energy input per unit area in the entire tidal zone. As a result, more mud remained in suspension and muddy flats turned into sandy flats.

Where coastal defence structures had no foreland, shores were armoured with steel, stones, concrete, or asphalt. Particularly on the islands, eroding shores were armoured and migrating dunes were planted to protect residential areas and tourist facilities. Most shore habitats were significantly transformed.[30]

Armoured dike on the
Dutch island of Texel.

A major shift in coastal mentality

A new attitude towards the Wadden Sea has emerged as a result of independent developments since the 1960s.[28] This happened parallel to an ever more powerful and offensive coastal defence strategy which increased safety but deteriorated natural habitats.

(1) The economic demand for new land to increase food production ceased. New dikes were built not to gain arable land but to improve safety. Cost-benefit analyses stopped plans to further embank tidal flats.

(2) People living behind dikes began to feel rather safe after comprehensive programs of improving coastal defence had been implemented.

(3) The general public began to worry about the health of nature.[34,35]

Pollution, excessive hunting, overfishing, urban sprawl, industrial agriculture, and eutrophication in rivers and coastal waters became important issues on many coasts. In the Wadden Sea, each new loss of salt marshes and tidal flats was met by a growing opposition.[28,35] The perceived value of remaining natural areas began to overtake values of traditional land use. Where a further loss of natural habitat could not be avoided, compensation was required by law. Natural tidal flats and salt marshes attained a positive image.

Intact nature became an important economic factor for the booming tourism industry in the wadden islands. The recreational value of the coast was not confined to sandy beaches, surf, and clean air, but included flocks of coastal birds and cute seals, with guided tidal walks becoming important tourist attractions. Scientists published comprehensive volumes on the ecology of the Wadden Sea.[36,37] Tireless young volunteers explained the natural value of dunes, salt marshes, and mudflats to visitors. Youth camps for studying endangered nature were hosted, and school children were taught the value of the unique Wadden Sea. Books and films depicting the pristine nature and the natural dynamics in the Wadden Sea reached a wide audience. All of this contributed to a shift in mentality.

Since 1978, the Netherlands, Germany, and Denmark have pursued a common conservation policy for the Wadden Sea.[33] A Joint Declaration on the Protection of the Wadden Sea was agreed in 1982, and a Common Wadden Sea Secretariat for coordination was established in 1987. Since 1991, environmental quality parameters have been monitored in a standardised format. A trilateral management plan was adopted in 1997 and updated in 2010. Uninhabited parts of the German Wadden Sea were declared as National Parks in 1985 and 1986. In 2009, UNESCO listed the Dutch and German Wadden Sea as a World Heritage Site because of its universally outstanding natural values and high level of nature protection. The Danish Wadden Sea is expected to follow suit in 2014.

A majority of the coastal population is now proud to have a World Heritage Site. However, this shift in mentality was accompanied by fierce debates. The traditional perception of a coastal landscape created by human enterprise was now challenged by nature lovers and was despised as backward and stubborn. Local politicians associated with the fishing and hunting lobbies, as well as those who saw the priority of coastal defence endangered, denounced the new perception of wadden nature as modern romanticism. Nevertheless, the coastal mentality had changed fundamentally within about 30 years. The North Sea, once primarily perceived as a threatening sea, now came to be perceived as a threatened environment. The Wadden Sea, once predominantly perceived as a dreary, useless, and lost land, or a waterway that was too shallow to be safely navigated, now came to be seen as a unique nature area worthy of protection.

The new perspective: lugworms are deposit feeders and cockles are suspension feeders. They are prey to flocks of migrant birds, linking the unique Wadden Sea to distant coastal regions.

This shift in mindset cannot be regarded as inevitable. Instead, it was the coincidence of four independent developments: (1) it was no longer economically rewarding to reclaim more land from the Wadden Sea, (2) behind massive new dikes people no longer felt directly threatened by the sea, (3) sensitised by the global environmental crisis, the public was prepared to protect life in the sea, and (4) promotion of tourism achieved prime importance, as tourists valued the region's world heritage status. These contingent developments created a new alliance that is likely to further influence forthcoming perceptions and the future of natural history in the Wadden Sea.

6. How natural is wadden nature?

Herd of reindeer crossing tidal flats in the Arctic. They may also be well adapted to swimming across tidal inlets and foraging in the dunes of the wadden islands.

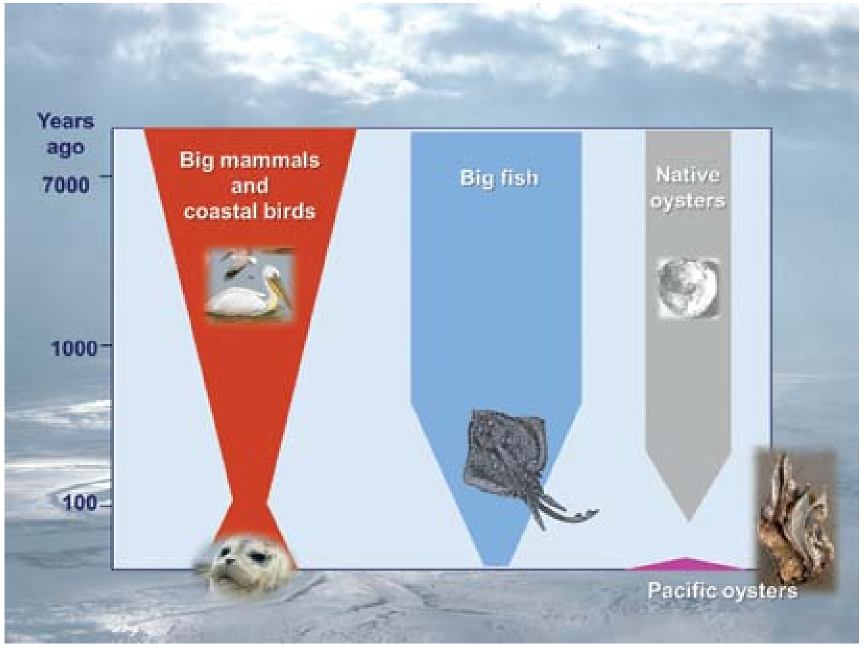
Exerting influence, however, requires orientation. Can this orientation be derived from natural history? Is there an indisputable natural state which constitutes the ultimate reference state which is still feasible and desirable? Can an objective reference situation be found in the past which can serve as a template and provide specific targets for management?

Human impacts from the very beginning

Nature should not be viewed as an entirety, and it should by no means be viewed as something which lies outside humanity.[3] We ourselves are nature when we cough, have children, or use reason. Admittedly, humans were not with nature from the very beginning. However, in spite of a late start, humanity has made an impressive career for itself. Unfortunately, humanity also created a fundamental change, causing the entire world stage to be reset. This is also true of man's role in the Wadden Sea, where people were on the scene right from the beginning. Of the large animals which lived alongside humans in Doggerland, almost none have survived on this coast – most likely due to hunting. Instead, domestic animals such as horses, cattle, sheep, and dogs abound, while aurochs in salt marshes and reindeer in the dunes would seem exotic to us nowadays.

The distant past lies in darkness. The early natural history of the Wadden Sea still needs a great deal of research. While the origins of the Wadden Sea are severely underexposed, the last few decades have been overexposed. As a result, the tacit assumption prevails that it is only recently that man has had a significant impact on the region. This fosters the belief that the paradise lost can be retrieved with proper nature restoration. This seems unrealistic, however, not least because the aurochs went completely extinct in 1627. Back-crossing projects are attempting to create similar animals, but how could they fit into our present landscape, except in special reserves? The past can only be simulated by active intervention.

Occasionally, skulls of the extinct aurochs are found in the northern Wadden Sea.



Schematic losses, reversals, and gains for selected groups of animals since the beginning of the Wadden Sea, shown on a logarithmic timeline.

Losses, reversals, and gains

Looking at the long-term balance, larger organisms have vanished because of hunting and fishing, while many smaller organisms have been added to the fauna and flora of the Wadden Sea by maritime globalisation which – intentionally or unintentionally – has introduced species from overseas to European coasts. More than 60 of these have also invaded the Wadden Sea.[38] Since the mid-20th century, successful nature protection has led to a partial recovery in marine mammals and birds. Fish are left to dream of such protection. The biological communities of the Wadden Sea have changed considerably in composition over the course of time, as a result of various human interventions (see Box 2, next page). In the wake of global warming, more species are expected to immigrate from the south than are expected to emigrate to the north. Thus, the overall biodiversity is likely to increase. Although most changes appear to be irreversible, coastal eutrophication may be an exception.

Box 2
Timeline* of changes for species and habitats in the Wadden Sea

Before 6000 BP	Terrestrial megafauna, reindeer, and other mammals extirpated.
After 6000 BP	Introduction of domestic animals and removal of wood on moraines began; bog (peat moor) development between salt marshes and moraines.
4000 BP	Use of salt marshes as pasture commenced; pelican and flamingo possibly hunted to extinction.
± 0 AD (2000 BP)	Scattered dwelling mounds on high salt marshes, small-scale gardening, and low grazing pressure on salt marshes.
1000 AD	Great transformation began by separating sea from land; diking, draining and peat mining on large scale, salt marshes and bogs lost in turn; increased hunting pressure on wild animals.
1350 AD	Plague epidemic raged in coastal population, followed by a major flood (1362); malaria became endemic in embanked marshes; grey whale, grey seal, aurochs, and white egret hunted to extinction; introduction of rabbits to wadden islands.
1500 AD	Peak size of the Wadden Sea due to flood incursions into diked, low-lying land, followed by intensive land reclamation; sand gaper *Mya arenaria* became dominant shellfish in estuarine parts of the Wadden Sea.
1650 AD	Commercial fishing on flat oysters commenced.
1750 AD	Land claim by ditching salt marshes and building brushwood fences on tidal flats had displaced most natural shore habitats at the mainland.
1800 AD	Population density had doubled since 1500; coastal birds under increasing pressure of hunting and egg collecting; almost 200 duck decoys in operation.
1850 AD	Armouring shorelines with hard materials; deepening of estuaries for large vessels began; mining of mussel beds and shell beds for mortar production; systematic planting on dunes; arable farming eliminated almost all wetland in polders.
1880 AD	Commercial mussel fishing commenced in Dutch Wadden Sea.
1900 AD	Shrimp fishing with efficient motor cutters began; hunting tours for harbour seals; protection of coastal birds was prompted by dramatic decline during previous century.
1925 AD	Large-scale offensive diking of tidal flats began; extirpation of sturgeon, salmon, and oyster beds; introduced grass *Spartina anglica* invaded pioneer zone of salt marshes.
1932 AD	Damming of brackish Zuiderzee, where local herring population vanished; wasting disease wiped out eelgrass beds in shallow waters; except for the estuaries, almost all brackish water bodies eliminated at mainland coast.
1950 AD	Native oyster went extinct; fishing of shrimp, whelk, and mussels proliferated;

	mussel bottom cultures commenced; peat resources on mainland depleted.
1965 AD	Pesticide incidence at the Rhine killed coastal birds in Dutch Wadden Sea; hunting on seal and several bird species ceased.
1970 AD	Massive enforcement of coastal defence; storm surge barriers and embankments strongly modified estuaries; cockle fishing proliferated; catching small shrimp for animal fodder terminated; thornback ray extirpated.
1980 AD	Creation of artificial wetland in polders; return of grey seal; increased breeding by shelducks, avocets, oystercatchers, and gulls; unintended release of American razor clam larvae from ballast water initiated razor clam dominance in shallow coastal waters.
1990 AD	Eutrophication peaked with massive phytoplankton blooms and green algal mats; declining chemical pollution; virus had killed half of seal population but recovery was fast.
2000 AD	Estuaries now three times deeper than before dredging and tidal range doubled; salt marsh recovery underway; Pacific oysters invade intertidal mussel beds.
2005 AD	Mechanical cockle fishing terminated.
2010 AD	Severe eutrophication effects have ceased; tenfold increase in harbour seal population compared to 1960s; cormorant and spoonbill common breeding birds again; sand replenishment now common practice.

*Most years rounded; main sources.[26,29,30,33,38-46]

No place for naturalistic ideology

Considering all the changes mentioned above, what can be regarded as natural in the Wadden Sea? This question leads to an inextricable tangle from direct to indirect, from prehistoric to actual, and from local to global effects of human impacts on the components of wadden nature. Partly, the question originates from the misconception of a primordial, paradise-like natural condition which could serve as a baseline for management aims. This belief holds that before people entered the scene, nature was still in a harmonic balance. The assumption is that it may bounce back to that imaginary natural state by resilience once impacts have ceased. However, even before humanity appeared on the stage, living communities were continuously changed by immigrations and emigrations and by evolution. These probably occurred at a much slower pace than human impacts, but they still ensured continuous change.

Due to our exponentially decreasing knowledge with the passage of time, we can almost never and nowhere be sure to see primordial or pure nature – except in its individual parts such as species, symbioses, or the meanders of tidal creeks or rivers. The natural balance is a mere ghost of the past or an esoteric dream. The myth of an ecological balance is a residue from the old type of natural history before temporality was introduced by evolutionary thinking. The natural history of the Wadden Sea shows that the equilibrium concept is not a proper model for the long sequence of changes which have occurred.

7. What does the future hold for the Wadden Sea?

Introduced Pacific oysters became established on mussel beds, and will be a legacy of our generation to all who walk across tidal flats in the future.

What heritage will be passed on?

The world heritage status of the Wadden Sea begs the question of how and in what state can this coastal zone be passed on to future generations. If earlier states are regarded as more desirable than the present one, then a detailed restoration programme must be established for the coming decades. That stated, we have already realised that irreversible changes have taken place and that it is impossible to reverse history. All that can be done is to re-introduce some lost components, subject to the proviso that they are compatible with current conditions and are agreed upon after public debate. Aside from pelicans breeding on the islands and wild horses galloping through salt marshes, might these efforts include the re-introduction of even the grey whale and the aurochs?

Protection of godwits along their entire flyway would require a large-scale international program.

Protection measures confined to the Wadden Sea will not be enough. Migratory animals play a key role in the ecosystem as well as in public perception. For birds, all of the countries along the East Atlantic flyway, as well as those that serve as breeding grounds, would have to cooperate in a common protection scheme. For many species of fish, river restoration would be necessary even in countries outside the Wadden Sea region. In the adjacent North Sea, sustainable international fishing would have to be implemented. Considering all this, it would be an illusion to believe we could keep the present state of the Wadden Sea unchanged like a monument of cultural World Heritage.

Present natural values will undergo changes despite being protected by national and European laws. New chemicals with unknown effects will escape unnoticed into the environment. It is unlikely that the Wadden Sea will be spared from oil spills larger than those that have already occurred. The future Wadden Sea might be a narrow recreation area sandwiched between major economic centres on the mainland and offshore industrial parks in the North Sea. This may result in a squeezing effect that further changes wadden nature.

As long as transoceanic shipping continues, further species introductions from overseas cannot be completely avoided. A warmer climate will trigger species immigrations from the south, and bring advantages or disadvantages to established species, regardless of whether they are native or not. Thus, change will go on.

What would be desirable?

Inevitably, compromises will have to be made between nature conservation and other interests. To prevent excessive damage, it will be essential to further improve public knowledge of the natural values of the Wadden Sea. This will be an ongoing race against other attractions, and will require innovative approaches in communication as well as novel research on natural history. More comparative studies with other coasts and joint protection programs with related World Heritage Sites are needed.

We may also question the completeness of the natural habitat spectrum which is included by the present World Heritage Site. Are extensions desirable, such as protected dune areas or entire wadden islands, parts of or entire estuaries, seaward extensions to the 15 m depth contour line? Is the cultural landscape of the Wadden Sea region worthy of inclusion?

This heavily armoured shore is replenished in 2013 to decelerate downstream erosion. Former dunes and a sandy beach are restored.

There are several controversial issues involved, such as confining shrimp fishing to the coastal zone seaward of the islands, turning from seed mussel harvesting at the bottom to suspended seed mussels collectors, and moving mussel and oyster cultures to offshore energy farms. Will we continue to replenish eroding island shores, or will mobile homes be a better solution where islands are shifting? Will armoured shorelines be restored back to natural shores by achieving safety with new, high dunes or with sand bars fronting the shores? Will we consent to present eutrophication, or how low will we go? Will we continue cleaning up beaches, or can we somehow prevent all that garbage from washing ashore? Will we try to eradicate introduced species which threaten native ones? Will we continue to sacrifice the large estuaries to the requirements of upstream ports, or would it be better to move the ports offshore? These and similar questions need to be worked out in more detail before being put to public debate.

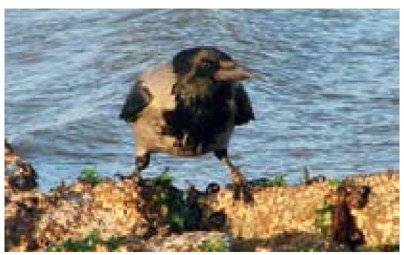
Would eradication of Pacific oysters be feasible if each of the ten million visitors to the Wadden Sea each year were to fill two buckets with the oysters and deliver them to road construction or coastal defence?

Perhaps passing on this heritage will not be that difficult after all. A coastal land and seascape and a coastal ecosystem are not like a historic building or a genuine artwork which would be worthless if "modernised". Landscapes and ecosystems are inherently changeable without necessarily losing value. Ecosystems do not function like oiled machines with all parts interacting according to an engineering design. An ecosystem is also not like an organism in which organs develop according to inherited genetic information.

Such exaggerated analogies may lead one astray, presumably towards overprotection. Too much repairing, too much redevelopment and too much stabilisation could result in an ecosystem that is unable to adapt to new circumstances. Unintended feedback could entangle nature managers into drawing ever more sophisticated interferences until the ecosystem is managed like a botanical garden or zoo. Nature management may finally take the form of ruling over nature and a loss of the sense of wilderness.

An alternative would be following the individualistic approach in nature conservation rather than the ideology of ecological holism (see Box 1, page 18). Accepting an ecological pattern as a flexible plurality of individual organisms leaves more freedom to management options. The individualistic approach allows for the incorporation of novel phenomena. Some of these may turn out to be highly successful and be followed by cascades of change.

Conversely, other novelties may turn out to be failures and the individuals involved will die at some point. The functions of these individuals may then be taken over by others or lie fallow – at least for a while. These phenomena may happen entirely without human influence or be initiated by human activities. The difference is often very subtle, such as when eroding shores are replenished, when the level of eutrophication changes, when small and rare species are lost or introduced or genetically modified, when raptors or naïve visitors scare away birds, etc. In such cases the degree of the impact will always determine whether it is acceptable or not and whether intervention is desirable.



Hybrid crow foraging at a groyne at low tide. Crows breed more often on wadden islands, often stealing the eggs of coastal birds. Nature management should refrain from intervening in this process.

Nature conservationists attempting to preserve or exclude subtle details in flexible ecosystems must be permanently on the alert for the many unexpected, contingent developments that could occur counter to their intentions. It would be wiser to intervene as little as possible in these ecosystems and instead focus on managing the prerequisite conditions. Setting targets that are too specific or too fixed could doom their efforts to failure and disappointment. For example, the EU habitat directive sometimes prohibits proper habitat restoration because the present state has been fixed as the formal standard. The history of the Wadden Sea with all its contingencies may serve as a warning against attempts to cement living components.

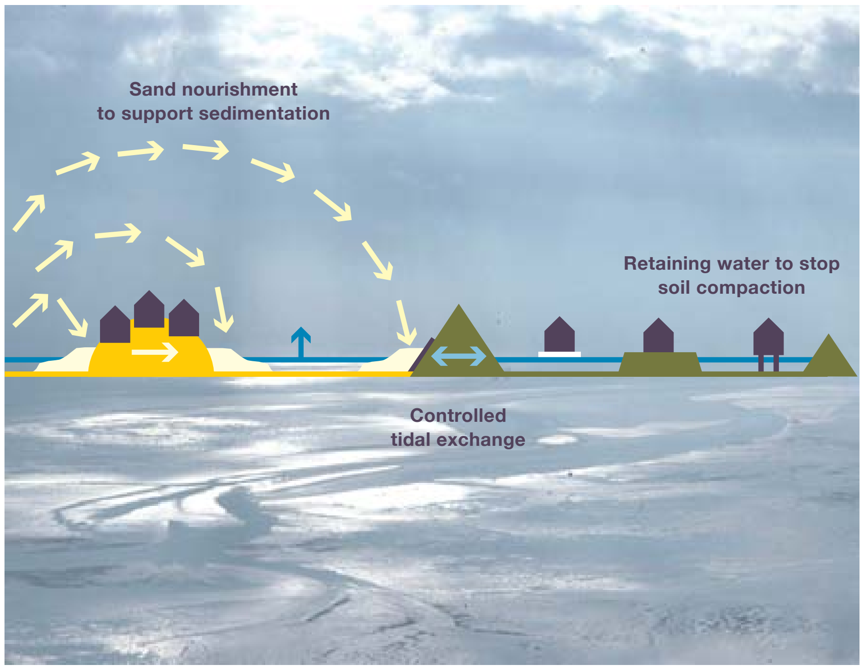
Returning to an upward growing coast?

Sea level is expected to rise – perhaps as fast as the rate immediately after the last Ice Age. This global change may be the most influential on the future of the Wadden Sea World Heritage in the long run. We may take it for granted that, despite an accelerating sea level rise, people would prefer to stay on the coast rather than move up to the mountains or float on the ocean. The challenge is therefore to keep people where they are and adjust the coast to the higher levels of the sea, while still preserving natural values. Would that be possible?

When sea level rises ever higher in the wake of global warming, the conventional strategy of enforcing coastal defence structures may eventually lead to collapse. A sea level much higher than the defended land constitutes an unsustainable coastal configuration. Costs may become unbearable or the required structures for safety may become so massive that they will ruin the landscape beyond an acceptable level. Higher dikes are adequate protection against storm tides, but against an unlimited sea level rise, this defence strategy can only be a temporary solution.

Alternatively, development towards a convergence between the levels of sea and land may be pursued.[47] Would it be possible to live with more water on land? If housing and other infrastructures were set onto floatable pontoons, inflatable boats, or hydraulic stilts, and agriculture were converted to aquaculture, with transport done by amphibian cars, wind surfing, and paddling, then sea water could flow into embanked land in a controlled way. It could run through the landscape, with suspended matter being deposited in special areas. If these areas needed to be excavated, the excavated material could be used to elevate other areas.

Schematic profile of the wadden region with (from left to right) barrier island, tidal basin, and embanked marshland, and possible adjustments for keeping up with accelerated sea level rise (see text).



A permeable boundary between sea and land would entail a coastal life which could partly revive old traditions but which would otherwise require futuristic new life styles. The aim would be to create a landscape that could grow with the sea. Living with more water might be the basis for new revenue from tourism. A future Wadden Sea that is no longer rigidly divided by a dike line into a cultural landscape and a natural seascape might be able to adapt to higher levels of the sea and maintain or even improve natural values.

Most likely, more sand would have to be piped from offshore to inshore areas than is currently being done. This nourishment would be needed once sea level rise exceeds sedimentation rate in the tidal basins of the Wadden Sea. Massive sand replenishment operations would be detrimental to natural values, but a timely start with small additions here and there could allow organisms to adjust without losses in the long run. Losses would be inevitable if tidal flats were to be permanently submerged and the Wadden Sea were to become a lagoon.

Lugworms would not occur in high densities in murky lagoons. They rely on diatom growth on intertidal sand grains.

Conclusions and recommendations

In the Wadden Sea, purple sandpipers rely on armoured shores and would not appreciate nature restoration with mud and sand. Sorry birds!

The term *natural history* as used in this booklet refers to the reconstructed timeline of the sea and landscape development and changing species composition in the Wadden Sea, with special reference to regional human history.

The natural history of the Wadden Sea is riddled with coincidences. Predictions and scenarios should be formulated prudently, because novelties could arise more often than is commonly expected.

The emergence of the Wadden Sea 7,500 years ago was a lucky coincidence of declining sea level rise and ample sediment supply by a rough sea with strong tidal currents.

Diking and peat mining entailed an unsustainable landscape transformation. Coinciding coastal and societal vulnerabilities invited storm surges to inundate vast expanses of inhabited land, and the Wadden Sea attained its peak size around 1500 AD.

Instead of a strategic turnaround, lost land was reclaimed by progress in the field of coastal defence. Although offensive diking came to an end and the Wadden Sea became a World Heritage Site, when land reclamation was no longer profitable, people felt safe behind enforced dikes, and environmental consciousness and tourist interest in natural values increased.

Since the birth of the Wadden Sea, species composition has been altered by hunting, fishing, habitat loss and transformations, introductions of alien species, and successful nature protection. The natural history does not offer an objective baseline for nature restorations.

It is impossible to reverse natural history or to prevent all further change in the World Heritage Site. The results of contingent sequences of events should be tolerated as long as they do not dramatically spoil the unique natural values of the Wadden Sea or other vital interests.

Beware of simplistic analogies such as machines to be looked after or homeostatic organisms for the Wadden Sea ecosystem. Nature management would then begin ruling over unruly nature, thereby taking on more than could be handled.

Perceiving ecological patterns as flexible pluralities of individual organisms rather than a resilient ecosystem tending towards equilibrium state leaves more freedom for management options.

Nature management targets that are too specific and too fixed may be doomed to failure and disappointment, and they could even hinder proper nature restoration.

Global change beyond the control of regional management initiates developments in nature which require adjustments rather than conventional defence.

Adjusting to the expected sea level rise may be achieved with controlled inundations, potentially allowing the land to grow with the level of the sea.

If sea level rise outpaces natural sedimentation rates in the tidal zone, then gentle additions of sand piped in from offshore areas might prevent the Wadden Sea from turning into a lagoon without tidal flats.

The author

Life is a coincidence. Infected by his family and friends, Karsten Reise became a dedicated naturalist as a young boy. He permanently shifted his interests from birds to plants to molluscs to grasshoppers and so on. He studied biology at various universities, finally deciding to become a marine ecologist while abroad at Friday Harbor Laboratories south of Vancouver Island. From there, he managed to get a PhD position on Sylt in the northern Wadden Sea. He commenced his research with predator exclusion cages on tidal flats in 1974. His conclusion was that predation pressure by young shrimp and crabs on young bivalves had a strong influence on prey population dynamics. The vagaries of funding, accidental observations, interests of his students, and the growing concern for nature protection in the Wadden Sea prompted his further research. His studies included the microscopic fauna dwelling in the interstices of marine sand, long-term changes in bottom fauna and vegetation, worm burrows, seagrass, oysters and alien species introductions, and the consequences of coastal defence strategies on wadden nature. Although he has visited many coasts of the World, the Wadden Sea has remained his core interest. He also contributed to the text for the World Heritage Site nomination. Professionally, he has taught at the universities of Göttingen, Hamburg, and Kiel in Germany, and has been the long-time head of Wattenmeerstation Sylt, which is part of the Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung. He retired in 2013.

Acknowledgements

For comments and discussions on natural history, I thank Gerald Cadée, Norbert Dankers, Karel Essink, Peter Herman, Marieke van Katwijk, and Wim Wolff. I thank Katja Philippart for weeding out errors and Jens Enemark for writing the foreword for this publication. The reference to Buffon, Linné, and the toad I owe to Hartmut Roweck. I also thank Maartje Smeets for structuring the manuscript and Danielle van Gils for her punctual support of the editing process.

Endnotes

1 Crumley, 1994.
2 Gaffney, et al., 2009.
3 Hampe, 2011.
4 Reise, et al., 2010.
5 Lepenies, 1976.
6 Stott, 2003.
7 Reise, 1980.
8 See www.resalliance.org
9 Kirchhoff, et al., 2010.
10 McIntosh, 1985.
11 Jackson, et al., 2001.
12 Holm, et al., 2002.
13 Lotze, et al., 2005.
14 Lotze, 2010.
15 Dolch, et al., 2013.
16 Gould, 1989.
17 Panten, 1995.
18 Reise, 1983.
19 Volkenborn, et al., 2007.
20 Vink, et al., 2007.
21 Oost, et al., 2012.
22 Behre, 2008.
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24 Bunzel-Drüke, et al., 1994,
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27 Meier, 2006.
28 Wolff, 1992.
29 Knottnerus, 2005.
30 Reise, 2005.
31 Knottnerus, 1997.
32 Jakubowski-Tiessen, 2011.
33 Kabat, et al., 2012.
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41 Prummel and Heinrich, 2005.
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44 De Jonge, et al., 1993.
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Colophon

A publication of:
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Project coordination and editing Synergos Communicatie
English correction Balance
Graphic design Glamcult Studio B.V.
Photography Karsten Reise,
except photo on page 56: Ronald van Wijk, Buiten-beeld,
and photo on page 63: Hans Joachim Kühn
Printing Platform P

ISBN 9789490289294
Lecture series number 4


KONINKLIJKE NEDERLANDSE
AKADEMIE VAN WETENSCHAPPEN
Waddenacademie
25 YEARS
Common Wadden Sea Secretariat
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WORLD HERITAGE