THE WADDEN SEA

Physical Features

The Wadden Sea stretches over 450 km along the southern North Sea coast from Den Helder in the Netherlands to Esbjerg in Denmark with a total area of 13,000 km² (Fig. 1). It is a mesotidal barrier island system fringing the flat and low-lying coastal plain that only has minor river influences. The shallow southern North Sea borders a flat marshland which is only occasionally intersected by moderate elevations of glacial origin or of dunes on barrier islands. These elevations generally remain below +50 m in height. Even in the tidal inlets with strong scouring currents the depth rarely exceeds -50 m. Thus, over a total length of 1000 km of coastline, the topography remains within the narrow vertical limit of about 100 m. With its estuaries, marshes and particularly its wide intertidal zone intersected by deep gullies, the Wadden Sea functions as a gigantic coastal filter system.

Fig. 1: The Wadden Sea (Landsat TM satellite images of the period 2000–2002, Source: http://www.waddensea-secretariat.org).
The Wadden Sea is the world’s largest unbroken system of intertidal sand and mud flats. Since 2009 it belongs to the UNESCO world heritage and is protected in framework of the Trilateral Wadden Sea Plan, which entails policies, measures, projects and actions agreed upon by The Netherlands, Germany and Denmark (Fig. 2). It encompasses a multitude of transitional zones between land, the sea and freshwater environments.

A network of tidal channels, sandbars, mudflats, salt marshes and islands creates these transition zones between land and sea characterized by daily changing flood and ebb tides and high dynamics in salinity, light, oxygen and temperature. This has resulted in a complex system which provides a unique habitat for a rich flora and fauna specially adapted to the challenging environmental conditions. The great productivity and size of the Wadden Sea provide a foundation for the reproduction of North Sea fish stocks and for its function as a turntable of bird migration. The ecological importance of the Wadden Sea thus extends from the Arctic to South-Africa.

The Wadden Sea is an open system and there are many interactions with the adjacent North Sea. The quality of water, sediment and marine habitats is, to an important degree, influenced by the North Sea and activities in the catchment area of the debouching rivers (see World Heritage Site Wadden Sea at http://www.unep-wcmc.org).
Climate

The climatic conditions of the Wadden Sea are characterized by the interaction of humid maritime air masses coming from westerly directions, and dry continental air masses from the east. The eastward moving depressions originating in the North Atlantic dominate with their westerly winds. This explains rather mild winters and cool summers. The mean annual air temperature is around 8.5°C. The mean annual water temperature is about 9°C, with a summer average of 15°C and a winter average of 4°C. In spite of humid air from the sea, precipitation in the Wadden Sea region is moderate, with some 700 to 800 mm per year.

Flora

The Wadden Sea is home to about 2,300 plant species. The terrestrial vegetation is predominantly related to salt marshes with the highest biodiversity found in sandy salt marshes and in the transition zone to dunes. Dune grasslands and scrub also occur. The marine vegetation is characterized by seagrasses that occur in mixed stands on the tidal flats. Some of the salt marsh halophytes are succulents, compensating a high salt content by extending the vacuoles in their cells (e.g. *Salicornia spp.*, *Suaeda maritima*). Others are capable of excreting salt through special glands (e.g. *Limonium vulgare*, *Spartina anglica*) or salt bladder cells which fill with salt, then die or burst, releasing salt from the plant (e.g. *Atriplex spp.*). Still others accumulate salt in their leaves until they die at the end of the season (e.g. *Juncus gerardi*).

Under conditions of sea level rise, salt marshes will persist as a habitat by accretion of sediments. This is accomplished by inorganic sediments deposited during inundations from the seaward tidal flats and by organic matter which is supplied by the marsh vegetation itself. Vertical accretion rates tend to decrease with increasing marsh elevation and with increasing distance from tidal flats or creeks meandering and branching across salt marshes. Vegetation height and density also facilitate accretion. These variations generate a rather irregular topography and a complex mosaic-like vegetation pattern. In the absence of grazing, often reed (*Phragmites australis*) takes over. Depending on sediment supply and wave action, the seaward edge of salt marshes may show a variable width of pioneer zone composed mainly of glassword (*Salicornia spp.*) and the cordgrass (*Spartina anglica*). While the former are annuals and rather short, the latter grows in dense tussocks which extend laterally and, finally, may merge into continuous belts.

Fauna

About 4,200 species of fauna, mostly invertebrates, can be found. The Wadden Sea is also an essential staging area for fish migrating between rivers for spawning and the oceans for feeding or vice versa. The Wadden Sea is of outstanding international importance as a breeding, staging, moulting and wintering area for birds.

Survey results suggest that over 6 million birds may be present in the Wadden Sea at the same time each year, and an average of 10-12 million birds pass through the property annually on their way between their breeding grounds in Siberia, Scandinavia, Greenland and Northeast Canada and their wintering grounds in Europe, Africa and even further South. Most species reach highest numbers during autumn migration; numbers of waders are almost as high during spring, whereas ducks and geese over-winter in high numbers; only gulls reach considerable numbers in summer.
Conservation value

The Wadden Sea is one of the last remaining natural large-scale inter-tidal ecosystems where natural processes continue to function in an undisturbed manner. Excellent and broad scale examples of biogeomorphological processes can be found in the coastal dunes, the salt marshes, and on the tidal flats on mussel beds and sea grass meadows. This transitional environment between land and sea is characterized by the constant change of flood and ebb tides, great fluctuations in salinity, high temperatures during summer and occasional ice cover in winter. These circumstances have created numerous ecological niches, colonized by species that are adapted to the extreme environmental conditions.

The Wadden ecosystem represents one of the internationally most important wetlands. It is internationally recognized as a biologically highly productive ecosystem of great natural, scientific, economic and social importance. The Wadden Sea area in Lower Saxony became a national park in 1986 (‘Nationalpark Niedersächsisches Wattenmeer’).
GEOGRAPHY AND GEOLOGY OF THE EAST FRISIAN ISLANDS

Geographical setting of Spiekeroog in the Wadden Sea

Spiekeroog is one of the seven East Frisian Islands (Fig. 3), which constitute typical barrier islands in a mesotidal system. These are from east to west: Wangerooge (which is actually from a political point of view the only not East Frisian Island but belongs to the Oldenburger Land, a very important border for the people in our district, called the golden line!), Spiekeroog, Langeoog, Baltrum, Norderney, Juist and Borkum. The tidal range at Spiekeroog is 2.80 m.

![Image of the German North Sea coast with its tidal flat areas depicted in light grey.](image)

Evolution, movement and sedimentary record of the East Frisian Islands

Today’s East Frisian islands developed as barrier islands. It is supposed that once they were so called ‘Geestkerninseln’ (islands with a ‘core’ of Pleistocene sediments, Geest is the regional description for Pleistocene deposits), as all of them except Wangerooge have plateaus of Geest material in the underground, submerged between 7000 and 5000 BP and were covered by marine sediments. The description ‘Geestkerninsel’ is used for islands formed around Pleistocene or even Tertiary material exposed in the tidal flats. This can still be be seen in Northern Frisia at the islands Sylt, Föhr and Amrum or in the Netherlands at Texel.

At Juist the so far oldest salt marsh horizon could be dated to about 2000 years BP. There is no evidence yet, that the islands existed before that time.
For Wangerooge, Langeoog and Juist fossil tidal flat and salt marsh horizons have been mapped, showing a north to south movement of the islands. Occasionally fossil salt marsh horizons originally from the southern (landward) coast are cropping out at the northern (seaward) beach underneath recent coastal sediments, showing that the islands are dislocating themselves. Analyses of these horizons document a southward movement of about 2 km during the last 2000 years.

The morphology of the ‘Geestkerne’ underneath the islands excludes a west to east movement of the islands as in this case also the tidal inlets would move, this again would cause erosion at the Pleistocene material in the underground which is not the case. Still, there is an oscillation of the sediment budget from west to east at the moment. For example, during the last years Langeoog, the westward neighbouring island of Spiekeroog, shows sediment loss. Some dunes bordering the beach in the north get more and more vulnerable. Spiekeroog in contrast has been growing during the last years. Looking at the northern beach of the western part of the island, about five years ago there was a big sandbank at the main beach, from year to year it was growing, today it reaches over about 4 km from the main beach to the western end of the island, building a kind of bight perfect for kite surfers to practise and for children to bathe but also getting more and more muddy.

Geography of Spiekeroog

Between the village of Spiekeroog and the beach an extraordinary large belt with vegetated dunes of up to 25 m height is situated (Fig. 4), partly with little forests in the valleys in between the dunes with alder, birch and oak.

During the last 100 years the Spiekeroog has grown in eastern direction and is still growing more than all other East Frisian Islands. The eastern part of the island, the so called ‘Ostplate’ (Fig. 4), is characterised by salt marshes, in the northern district by large areas of very small and young primary dunes and spacious sheets of brackish water. The ‘Ostplate’ has a length of about 7 km to the east and a width from north to south of about 2.5 km. It is habitat for many insects and important breeding-place for birds as for example the oystercatcher, eider duck, herring gull, little tern, Kentish plover and great ringed plover.

![Fig. 4: Spiekeroog (picture from the Marco Polo tour guide) with its main geographical structure.](image-url)
Sea-level rise

The development of the East Frisian coast is closely connected to late Weichselian and Holocene sea-level rise. At 18,000 BP sea-level was about 120 m, at the beginning of the Holocene about 65 m lower than today. Today’s island chain was reached by the sea about 7000 years ago. Until then there was a strong sea-level rise of more than 20 m/1000 years, after that sea-level rise lowered to 1 m/1000 years in average until today.

Sea-level research of the last 10 years shows, that ideally for every tidal basin an own relative sea-level curve is necessary to filter local effects as isostasy, different tidal situations, compaction rates and paleogeography causing different ratios of accommodation space and sediment supply. For the tidal basin of Langeoog, the island west to Spiekeroog, a relative sea-level curve has been published (Bungenstock & Schäfer 2009, Fig. 5). Although every island has its own tidal basin, so far the Langeoog curve is regarded as representative for the coastal section of the East Frisian barrier islands.

![Sea-level data since ~6000 BC](image)

**Fig. 5:** Sea-level data since ~6000 BC (for further information see Bungenstock & Schäfer 2009).

Hydrogeology of the East Frisian Islands

As the islands do not have any natural drainage systems on the surface most of the rainfall seeps away in the sands. Therefore, especially underneath the dunes the groundwater reservoirs are filled with fresh water having a lower specific weight than the salty groundwater. It develops a body of fresh water swimming on the salty water which is named as fresh water lens because of its typical shape. The top of the fresh water lenses can be found up to +1 to +2 m NN in the dune areas, the base at -30 to -40 m NN, on the island Norderney.
even at -70 m. Lateral of the fresh water lenses there is a permanent drainage of fresh water to the North Sea and the tidal flats being in balance with the generation of groundwater in the dunes during rain.

This natural and permanent regenerating fresh water reservoir on the islands is sufficient to cover the daily need of drinking and tap water even during the main holiday season. Only the islands Baltrum and Wangerooge have a fresh water pipeline connection to the mainland.

Eventually the top level of the fresh water lenses reaches up to the surface in the dune valleys building swampy areas with fen peat and temporary and even permanent fresh water lakes (as for example on Borkum, Norderney and Juist).

**Geological record of the East Frisian tidal flats**

During the Holocene sea-level rise a wedge-like sediment body accumulated in the coastal zone. It consists of a basal peat, fine-grained sand, silt, clay and intercalated peat beds. The alternation of transgressive onlaps - marine and brackish deposits overlying peat - with regressive onlaps - semiterrestrial peat overlying brackish and marine sediments - is indicative of repeated landward and seaward shoreline displacements of several kilometres due to a change of accommodation space and sediment supply. The wedge-like sediment body occurs within a 10 to 20 km wide zone (measured perpendicular to the coastline). Holocene sediments have an average thickness of 10 to 12 m and wedge out against the Pleistocene hinterland. Seaward, the sediment body ends at a steep slope to a water depth of about 25 m. Fig. 6 shows a representative cross section through the tidal flats of the island Langeoog.

![Geological cross section from Esens at the mainland to Langeoog](image)

Fig. 6: Geological cross section from Esens at the mainland to Langeoog (from Bungenstock & Schäfer 2009 modified after Streif 2004).
FLORA AND VEGETATION OF THE EAST FRISIAN ISLANDS

The dunes at the northern exposed (seaward) side of the islands

Along the seaward coast of the barrier islands, the constant supply of sand lead to the formation of dunes which are a characteristic element on barrier islands. Sand grains, ground-up mussel shells and organic material washed ashore by wave action are transported by wind above the high water mark and deposited behind obstacles. Particularly important as dune builder is the grass *Ammophila arenaria*, a grass which traps sand between the stalks and is able to persist on the growing dune due to its rhizomes.

A series of plant communities takes part in the formation and further development of the coastal dunes (Ellenberg 1988). These are typically arranged in a series of successional zones (Fig. 7). However, because of their importance for coastal defense, the natural geomorphological patterns have largely been modified and artificially fixed today, thereby losing their dynamics.

Along the drift lines, decomposing organic matter at the extreme high water mark facilitates the occurrence of annual nitrophytes (e.g. *Cakile maritima*, *Beta maritima*, *Atriplex litoralis*). Further inland, *Agropyron pungens*, *A. junceum* and *Ammophila arenaria* form ‘primary dunes’ which later developed to high ‘white dunes’ by continuous accumulation of sand. Typical plant species include *Eryngium maritimum*, *Lathyrus maritimus* and *Viola tricolor*. Eventually, sand accumulation ceases and more organic-rich ‘grey dunes’ develop with a plant cover consisting of short grasses and low herbaceous plants (e.g. *Jasione montana*, *Sedum acre*) as well as of mosses and lichens. This is accompanied by a rapid leaching of carbonates, leading to the formation of ‘brown dunes’ characterized by dwarf-shrub heathlands (e.g. *Empetrum nigrum*, *Calluna vulgaris*). Quite often, bushes can be found growing on the lee side of the dunes (e.g. *Hippophaë rhamnoides*, *Salix repens*). Neophytic species found in the dune vegetation include *Rosa rugosa*, *Senecio inequidens* and *Prunus serotina*.

Fig. 7: Schematic zonation of dune vegetation along the North Sea Coast. In the absence of disturbance by man or domestic animals, trees or at least bushes would be found growing in the small depressions (valleys) and on the brown dunes (heath dunes) and probably also on the grey dunes. Leaching of carbonates takes place rapidly once the dunes stabilized. In larger dune complexes it is possible to find freshwater. This is rainwater which has drained through the sand is collected as a “cushion” above the more dense salt water (Ellenberg 1988, see also section ‘Hydrogeology of the East Frisian Islands’).
Salt marshes and upper tidal flats at the southern sheltered (landward) side of the islands and at the mainland coast

The flora of a salt marsh is differentiated into levels according to the plants' individual tolerance to salinity and water table levels. The plant species must be able to survive high salt concentrations, periodical submersion, and a certain amount of water movement, while plants further inland in the marsh can sometimes experience dry, low-nutrient conditions.

The most common salt marsh plants are glassworts (*Salicornia* spp., Fig. 8). They are the first plants to colonize a mudflat and begin its ecological succession into a salt marsh. Their shoots lift the main flow of the tide above the mud surface while their roots spread into the substrate and stabilize the sticky mud and carry oxygen into it so that other plants can establish themselves as well. Plants such as sea lavenders (*Limonium* spp., Fig. 9), plantains (*Plantago* spp.), and various sedges and rushes grow once the mud has been vegetated by the pioneer species.

Fig. 8: *Salicornia* spp. as pioneer species (photograph by K.E. Behre).

Salt marshes form the upper parts of the intertidal zone, the interface between land and sea, and are strongly controlled by geomorphological, physical and biological processes, such as sedimentation in interaction with the vegetation, tidal regime and wind-wave pattern (Fig. 10). They constitute a habitat for a wide range of organisms. On a European scale, among 1,068 plant species that are bound to coastal habitats, nearly 200 are restricted to salt marshes (van der Maarel and van der Maarel-Versluys, 1996).

Three main salt marsh zones with different vegetation can be distinguished: the pioneer zone where plant growth starts at about 40 cm below mean high tide (MHT); the low marsh, inundated during mean spring tides (100-400 floods/year), and the middle/high marsh with less than 100 floods per year. In addition, the sandy green beach and the brackish marsh can be differentiated by a special type of vegetation. Adjacent to the salt marshes fresh (anthropogenic) grassland occurs.
Fig. 9: Salt marsh with *Limonium vulgare*. The species composition of salt marshes is determined by the frequency of flooding as well as by the intensity of grazing (photograph by K.E. Behre).

Fig. 10: Schematic zonation of terrestrial plants at the German North Sea coast. The habitats depend on their position relative to the mean highwater mark (Ellenberg 1988).

The mainland salt marshes have a clearly different character than the island salt marshes; due to coastal protection activities the artificial mainland salt marshes show a higher proportion of the pioneer zone compared to the islands.
**SOME TOURIST INFORMATION**

*Visitors and visitor facilities of the Wadden Sea world heritage*

Approximately 20 million tourists stay overnight and 30-40 million day trippers visit the Wadden Sea region every year (the region being the Wadden Sea, the Wadden Sea Islands and the adjacent mainland areas). Through an extended net of information centres, visitor information systems, print and digital information and an increasing number of professional guides along the Wadden Sea, the quality of nature experience for visitors has improved significantly, benefiting both the visitors and nature. The information and interpretation centres adjacent to the property are placed all along the shore.

*The port of Neuharlingersiel*

Neuharlingersiel is a 300 years old fisher’s port with a still existing active shrimp fishery. The North Sea shrimps are called ‘Granat’ which means garnet, because they get the colour when cooked and they are of course as precious as garnet. Most shrimps fished at the North Sea go to Marokko to be peeled by hand because workers are much cheaper there. Shrimps from Neuharlingersiel get a special treatment, they get peeled in special machines of the fisher’s association. These are called ‘Krabbenpulmaschinen’ and have been invented about ten years ago.

*The character of Spiekeroog*

Spiekeroog has about 800 permanent residents, which just overslept the tourist developments of the 1960ties, 70ties and 80ties. Almost no modern architecture can be found, all houses are built in a very traditional style, some of them several hundred years old. The little village of Spiekeroog is existing since about 1600 at the same place which is different to the villages of the other islands which had to move several times because of the island’s changes, especially breakthroughs after storm surges. For this, many old trees can be found in the narrow streets of the Spiekeroog village.

Spiekeroog has no bike rental outlet and as on the most other East Frisian Islands there are no cars allowed. This gives the island a very remote character.

One of the cultural highlights of Spiekeroog is the old church in the village centre, built in 1696. It is the oldest still existing church of the East Frisian Islands. When the church was built, it was big enough for all island people. The church is open for visitors for about one hour per day, usually at noon. It is absolutely worth a visit.

Another highlight is the old horse train. Coming from the port go west and follow the signs. It takes about 12 minutes to go by train - driven by one horse power - to the western part of the island. The only and final station the ‘Westend Café’ with a direct passage through the dunes to the beach. When it was founded in 1885 the horse train was going to the men’s beach in the western part of the island.

Since a few years there is a new investor on the island, who not only founded a wellness hotel and some restaurants (all in the traditional Spiekeroog architecture) but also an artist’s house offering cultural events during the summer and regularly workshops for painting, goldsmith and video art etc. This gives Spiekeroog an even more special character among the other East Frisian Islands.
References and further reading


Marco Polo Reiseführer (2003) Ostfriesische Inseln. Mairs Geographischer Verlag 120 S.


Websites:

http://www.waddensea-secretariat.org

http://www.unep-wcmc.org