Environmental Conditions at the Coast: Shoreline Ecosystems

6

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Abstract

This part addresses the environmental conditions at the Southern Baltic Sea coast shoreline ecosystems providing knowledge of the natural conditions on which anthropogenic alterations act. The chapter starts off with some details on the geological formation of these coasts that build the geomorphological template on which ecosystems have established. Since this region has been covered by ice during the last glaciation, all landscapes and, thus, also the coastal ecosystems are comparably young. Due to the post-glacial dynamics, these coastal ecosystems are themselves highly dynamic on several temporal scales. Whereas cliffs change on millennial scales, dunes are much more dynamic and change on annual scales. In shallow low-lying sections peatlands developed and natural dynamics here would likely act on centennial scales. All the above temporal dynamics are strongly impeded by anthropogenic activities and can only rarely be observed today in the wild with strong implications for the development of the shoreline ecosystems in the future. On coastal peatlands long-term anthropo-zoogenic influence lead to the development of an alternative ecosystem. While under natural conditions plant species of brackish grasslands were confined to small areas below cliffs, grazing in reed belts over centuries caused the development of extensive areas of brackish grasslands featuring brackish specialist plant species. Today, the latter are rather rare because many of these areas have been diked for more intensive agricultural use in the past century.

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6.1   Introduction

Besides the marine features (Chap. 8) and the characteristics of the "Hinterland" (Chap. 5), a coastal systems analysis has to consider the coast itself, i.e., the zone that is influenced by both the "Hinterland" and the sea. The coastline forms a unique sea–land transition zone due to the exchange processes between environmental compartments (Jurasinski et al. 2018). The focus of the sea–land connection is often on extreme scenarios, for instance, flooding events (Jurasinski et al. 2018). Estuaries are another focus of coastal exchange research, whereas the coastline itself is rarely considered as an exchange interface for energy, water, and substances, yet this interface is very important as it operates continuously and may have far-reaching effects on (micro-)biological and hydro-biogeochemical processes on either side of the coast (e.g., Rullkötter 2009; Gätje and Reise 2012).

6.2   Southern Baltic Sea Coastal Geology

As a basis for understanding ecosystem and landscape structures some additional information to the basic geological background, given in Chap. 4, is necessary. The German coast of the southern Baltic Sea is part of the northern German lowlands, which has experienced a long-term trend of subsidence (since about 250 Ma, Permian, and still active today). Superimposed on this long-term trend are isostatic movements of the crust after the last ice age in combination with eustatic sea level rise. Since large parts of the German Baltic Sea coast are located south of a deep-reaching rupture zone which runs in NW-SE direction through Skane, the southern Baltic Sea north of Rügen, Koszalin, Bydgoszcz, Warszawa, and Lublin, the coast is slowly sinking with up to 1.6 mm per year (Lampe et al. 2010). In contrast, the major part of Scandinavia and the Baltic Sea proper shows a long-term uprising trend. The boundary between rising Scandinavia and the subsiding German lowlands is known as the Tornquist or Teisseyre-Tornquist Zone.

South of this zone stretches a thick sequence of Mesozoic and Cenozoic sediments. The surface sediments in MV and at the southern Baltic coast originate from the youngest (Vistula) glaciation, with very few exceptions, whereas north of it, the exposed surface rocks consist of old (paleozoic and often much older) magmatic and metamorphosed sequences (Pharaoh 1999). This has important ramifications for the coastal types in different parts of the Baltic Sea: Whereas in Scandinavia, the coast consists in general of hard rock formations with a well-differentiated coastline, the coast of the southern Baltic Sea is formed mainly by unconsolidated sediments which are prone to erosion and consequently result in a smooth, graded shoreline ("Ausgleichsküste," Lampe et al. 2007), and Fjord coast (Fördeküste) in SH (see also Chap. 3). This graded shoreline is of very recent origin and has developed only after the last glaciation, since about 10,000 years BP. Immediately after the Weichsel glaciation, the landscape of the present coastline consisted of an irregular, hilly topography formed by a succession of glacial moraines and troughs. Due to the eustatic sea level rise, marine waters entered the Baltic from the North Sea at
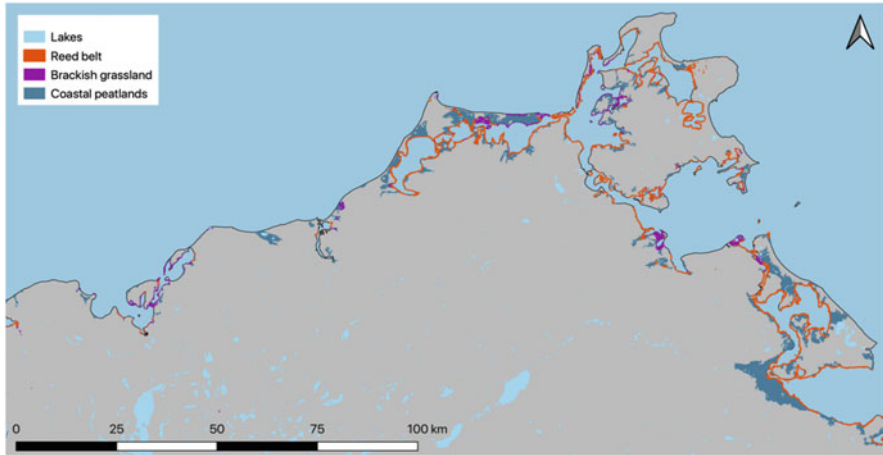
Fig. 6.1 Baltic Sea coast of Mecklenburg-Vorpommern with shallow low-lying areas dominated by reed belts, brackish grasslands, and coastal peatlands. The latter either formed as reed belt or as brackish grassland but was then cut off from the coast by a dyke. Map created by G. Jurasinski based on publicly available data sourced from https://www.umweltkarten.mv-regierung.de. Original data sources: Lakes—Technical information system for water bodies (DLM25W), LUNG MV 2015; Reed belt, Brackish grassland—Official map of biotopes and geotopes (BNTK), LUNG MV 2015; Coastal peatlands—Konzeptbodenkarte 1:25.000 (KBK25), LUNG MV 2016

8.000 BP via the Danish Straits (Great Belt, Little Belt and Oresund), and the brackish water Littorina Sea stage began. Only with the Littorina Transgression, the present graded coastline started to develop: Under the influence of west-east marine currents (induced by predominantly westerly winds), peninsulas formed and moraines were eroded, and interjacent bays were filled with sediments (Börner et al. 2019).

Today, the eroded parts form the cliff coast, at which the yearly coastal erosion rate may be as high as 50 cm even today. The eroded sediments are transported parallel to the coast and are deposited at coastal areas with weaker currents to form sandy beaches and sand dunes. At such coastal stretches, the sedimentation may result in a seaward progradation of the coastline of up to 1 m per year (at the beach of Warnemünde for instance). Further to the east (Darss), coastal sedimentation resulted in the graded Bodden coast of Vorpommern, with characteristic peninsulas (Nehrungen) and shallow brackish lagoons (Bodden, Haff).

The larger part of the total coastal length is comprised of "inner coast," i.e., within estuaries and lagoon systems, which are prominent especially in MV. Only 377 km of the total costal length of MV is outer coast, whereas 1568 km are protected inner coasts (MLUV-MV 2010). These inner coasts are almost entirely lined with coastal wetlands of varying widths (Fig. 6.1), which are dominated by common reed (*Phragmites australis* (Cav.) Trin. ex Steud.), like other regions along the Baltic sea (Dijkema 1990; Karsten et al. 2003; Selig et al. 2007; Meriste et al. 2012; Altartouri et al. 2014). The area of coastal wetlands along the Baltic Sea is not

precisely known. Sterr (2008) reports for the German part an estimated area of about 1800 km^2.

6.3   Cliffs

Prominent examples for cliff coasts are the Stoltera cliffs and the Nienhagen forest west of Rostock. Ecologically, cliffs are interesting as habitat for specialized avi- and arthropod fauna as well as for a few specially adapted plant species. Although most cliffs are protected by law, they are—under natural conditions—essentially ephemeral on a centennial to millennial basis, but the general public often views them as stable. In the literature the distinction between "active" and "passive" cliff developed with the first denoting cliffs that are in the direct influence of the sea waves, whereas passive cliffs are not directly influenced by the sea anymore, for instance, due to coastal uplift or decreasing sea levels. Passive cliffs at the coast, like the Königsstuhl on the island of Rügen, can still be reached and eroded by higher storm surges. Protecting cliffs from erosion is therefore a high priority of contemporary politics. The vegetation below the cliffs is comparable to the areas closest to the sea in the dune series (see next section), whereas the vegetation at the cliff and especially at the escarpment is typically not specific for marine environments but is driven by the respective bedrock at the cliff.

6.4   Dunes

Eolian sand dunes are frequently found along the outer coast. They are in general very young sediments of Holocene age. A prominent example is the conspicuous dune and strand sediment sequence of the Neudarss, which started to develop around 3000 years ago. Previously, during the Littorina transgression, a cliff had developed at the then northern edge of the Darss. This cliff became inactive around 3.000 years ago due to a change in the coastal sediment transport system concomitant with diminished sea-level rise rates (Schumacher 2000). Since then, about 120 well-preserved beach ridges accumulated in a cuspate foreland and the shoreline prograded in northern direction, forming the Neudarss. At the Darsser Ort, the northernmost tip of the Darss peninsula (Fig. 6.1), the recent natural dynamics of dune series formation (see Fig. 6.2) can be studied, since the area is protected as core zone of the National Park "Vorpommern Bodden coast." At the "Weststrand," some of the former dune valleys are now developing as coastal paludification fens (see below for details on this type of coastal wetland).

The vegetation on sand dunes strongly changes within small distances from the coast (or better from the mean annual water level) following a distinct sequence of plant community types (Fig. 6.2). While the wash margin features ephemeral appearances of coastal vegetation, different dune vegetation types develop driven by the horizontal and vertical distance from the shore line. These are typically displayed along a regular transect but in reality the arrangement of the different
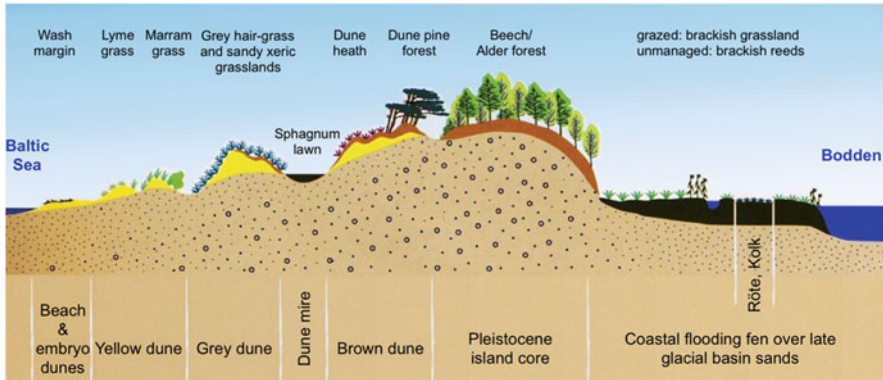
Fig. 6.2 Typical succession series of dune vegetation at the Baltic Sea coast of Mecklenburg-Vorpommern. Source: Umweltministerium Mecklenburg-Vorpommern (2003)

types is much more patterned in space as can be observed very well in one of the last natural dune-forming areas on the Northwestern tip of the Darss peninsula.

Due to its graded nature, the Bodden coast features an outer as well as an inner coast with a typical sequence of vegetation types. Brackish grasslands or reeds very rarely develop at the outer coast. If so, they are still protected behind small natural dunes and are only episodically flooded with sea water when storm surges breach through the dunes. As a consequence, coastal paludification fens develop. In contrast, coastal flooding fens developed at the majority of the shores of the inner coasts.

6.5   Shallow Low-Lying Coast

Large parts of the German Baltic Sea coast are graded and shallow. These areas are characterized by a relatively wide ecocline from land to sea (Jurasinski et al. 2018) and are, under natural conditions, often covered by extensive wetlands with specific flora and fauna. Natural coastal wetlands deliver many ecosystem services including coastal protection by providing space for water retention during storm surges, carbon storage and sequestration, retention and conversion of sea-borne nutrients, faunal and floral biodiversity (e.g., Narayan et al. 2017). In their assumed natural state, coastal wetlands of the German Baltic Sea Coast are thought to be dominated mainly by Common reed (*Phragmites australis*) and other emergent macrophytes tolerant to brackish conditions, like *Schoenoplectus tabernaemontani* (Grey Clubrush) or *Bolboschoenus maritimus* (Sea Clubrush). From the early 1950s on, however, many of the coastal wetlands were cut off from the sea or from the Bodden by dykes and subsequently drained for intensive agriculture. Today coastal areas in the region are therefore either characterized by fringing reed belts, coastal flooding peatland, pasture, or meadow. Which vegetation develops in a non-dyked coastal wetland is mainly driven by the prevailing soil substrate, the salinity, the elevation and, thus, flooding dynamics, and by land use.
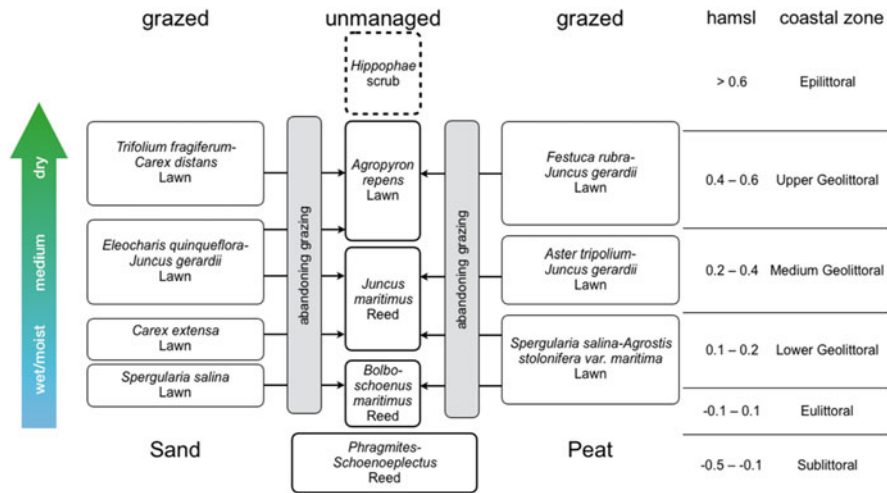
Fig. 6.3 Model of the vegetation development in the beta-mesohaline area of the Baltic Sea, as a function of substrate, position relative to mean water level and grazing (developed based on a Geolittoral only model from Jeschke 1987). There are slightly different vegetation types developing in the alpha-mesohaline (higher salinity) and the oligohaline (lower salinity) regions

Substrates dominated by sand cause a fundamentally different vegetation development on shallow, low-lying coasts compared to those dominated by silt (including organic sediments and peat, i.e., sedentary organic substrates) (Jeschke 1987). Upon abandonment, the vegetation communities converge and the differences between these two types of substrates disappear (Jeschke 1987, see also Fig. 6.3). Salinity is an important factor determining the distribution of halophytes (Dijkema 1990), because high salt contents require plants to develop effective adaptation mechanisms. The salinity of the Baltic Sea water along the German Baltic Sea coast decreases significantly from west to east, which leads to a large-scale zonation of the vegetation communities (Krisch 1974; Jeschke 1987). The colonization of the flat coasts with plants and animals is mainly determined by distance and exposure to the mean high tide line, as well as by the flooding frequency and the salinity of the soil (Seiberling 2003; Seiberling and Stock 2009). The lower the elevation of the flooded areas, the higher the influence of saline water. Therefore, elevation is an indicator for dominant plant communities (Jeschke 1987; Jutila 2001) (Fig. 6.3).

Since the Baltic Sea is almost free of a regular tidal range (Dijkema 1990), the delimitation of coastal zones is more difficult compared to the North Sea (Fig. 6.3). However, there are seasonal and inter-annual fluctuations in water levels, which have a significant influence on the establishment and development of vegetation in the Geolittoral (between 10 and 70 cm > MW). In the area of the Baltic Proper, which also includes the coastal sections considered here, there are only very small variations in mean water levels between spring and summer (Tyler 1969). However, there are marked variations between years, so that relatively low and high water level years alternate (Dijkema 1990). Low spring water levels are important events for the

re-establishment of, e.g., *Schoenoplectus tabernaemontani* (Grey Clubrush) or *Eleocharis palustris/uniglumis* (Marsh or Slender Spike-rush) on areas not previously colonized (Dijkema 1990) but also low water levels in late summer and autumn in otherwise flooded coastal peatlands seem to trigger major vegetation re-establishment events (Koebsch et al. 2020). However, high water levels (MHW at 1.10 NHN) occur mostly due to floods in autumn and spring, as they are linked to storm events. Storm-induced high water levels naturally fall relatively quickly. Therefore, the effective discharge of water from any flooded coastal wetland area is of importance. Just as important as the elevation zonation and, thus, the access of sea water to a coastal wetland is the speed at which the water runs off again after flooding events.

Previous land use plays a central role in the release of nitrogen and phosphorus after rewetting and in the status of soil organic matter. These factors in turn not only influence biogeochemical conversions after rewetting, but also the establishment of plant species. A second dimension of land use lies in the fact that some of the vegetation communities typical of coastal floodplains (e.g., brackish grasslands) are suggested to be only able to develop in the presence of appropriate disturbance or grazing regimes (Jeschke 1987; Berg et al. 2004). It has been suggested, that most of today's salt—or rather ‚brackish—grassland at the Baltic Sea coast has developed as salt pasture through the influence of human livestock (Krisch 1974; Jeschke 1987; Berg et al. 2004). Jeschke (1987) estimates that only 10% of the area of approx. 13,000 ha previously populated by this vegetation type had been preserved as early as in the 1980s.

It is assumed that without any influence from land use, large parts of the shallow Baltic Sea coast would be characterized by reed belts instead, which colonized the coastal flooding fens at the bottoms of the coastal dunes and the shores of the beach lakes (Härdtle 1984). As early as in the thirteenth century, the coastal inhabitants began to use these areas for pasture, mainly with cattle. The treading of the cattle compacts the soil and promotes the incorporation of fresh litter, which is thus removed from direct decomposition (Jeschke 1987). This stimulates peat formation and allows the brackish grasslands of the southern Baltic Sea coast to grow above the mean high water line by means of peat growth, thus improving the site conditions for the development of salt grassland in a self-reinforcing process (Dijkema 1990). Therefore, it has been suggested that the brackish grasslands of the southern Baltic Sea coast can only be preserved in the long term through appropriate grazing (Jeschke 1987; Dijkema 1990).

Investigations after rewetting the polder Ziesetal (Seiberling and Stock 2009) show that grazing of too low intensity (less than one livestock unit per ha) can lead to monotonous *Agrostis stolonifera* floating lawns. However, decreasing or ineffective grazing with less robust breeds alone can also lead to a rapid expansion of the reed belts, which in turn leads to a positive feedback through lower grazing pressure because the animals avoid areas with high reed growth (Sweers et al. 2013). Seiberling and Stock (2009) conclude that a grazing pressure of 1–1.5 livestock units per ha should be guaranteed if the development goal is species-rich brackish grassland. In addition, Sweers et al. (2013) conclude that grazing with water

buffaloes seems to be suitable to push back reed belts and to achieve species-rich salt grassland. In addition, an early mowing of the previous year's overgrowth seems to have a positive effect, as it can further enhance the species spectrum (Seiberling and Stock 2009).

6.6   Coastal Reed Belts

Before the influence of humans took hold in these ecosystems many centuries ago, large areas of coastal wetlands were occupied by relatively uniform stands of large emergent macrophytes like Common reed, Sea Clubrush, Grey Clubrush and other similar species (Jeschke 1987). To date the reason behind the large-scale dieback of reed belts in the 80s and 90s of the last century is still not completely understood (e.g., Gigante et al. 2013). While coastal reed belts may be less interesting in terms of plant species diversity today, they have likely hosted more species than today in their natural form because of generally much lower nutrient loads. It is to assume that due to natural disturbance events species which today have their focal habitats in brackish grasslands occurred also in natural shallow coastal areas in an essentially ephemeral way following disturbances and the thereby instigated favorable conditions. Land-ward natural or near-natural coastal reed stands are today either replaced by Brackish grasslands or by pastures and meadows behind dykes, although they may have been biodiversity hotspots, not necessarily for plant species but for biodiversity in general, hosting a variety of highly specialized species, like the ground beetle *Agonum monachum monachum* and their complex communities (Schmidt and Trautner 2016) and can be found only very rarely.

6.7   Pastures and Meadows Behind Dykes

Early on, however, the large majority of low-lying coastal wetlands have been converted into agricultural land, mainly for grass and fodder production. Later, often starting in the second half of the nineteenth century, but also much later in the second half of the twentieth century, the large majority of these areas were diked and then drained and used as intensive grassland mainly for fodder production, leaving only small remnants of the anthropo-zoogenic brackish grasslands of the Baltic sea coast. As a result, wetland sediments behind the dikes—often organic peat soils or mineral sediments with high organic matter content—degraded because of a mineralization of the organic compounds. Along with the degradation of these organic soils goes a massive CO_2 release (Jurasinski et al. 2016), a modified nutrient cycling and a shift in the hydraulic properties (Liu and Lennartz 2019). In addition, agricultural treatment loaded the wetland soils with nutrients, mainly nitrogen and phosphorus. Often, the surface elevation of artificially drained coastal wetlands is now below mean high-water level because of the subsidence of peat soils during degradation.

In general, the productivity of coastal wetlands is low in an agricultural sense (not including freshly reclaimed tidal marsh soils) because of a difficult soil moisture management. Productivity decreases over time and soil management becomes challenging because of soil degradation, subsidence, and rising water levels. A continuous agricultural usage is bound to a constant maintenance of the artificial drainage system consisting of the tile-drain and/or ditch network as well as pumping stations. A shift in the perception of agricultural activity especially on marginal land such as coastal wetlands has led to the abandonment of agricultural fields in selected coastal regions, for instance, on the southern Baltic Sea coast. The decommissioning of pumping stations may result in elevated water tables (fresh water) and positive hydraulic heads from land to sea with possible sub-marine groundwater discharge (Jurasinski et al. 2018).

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