Coastal Habitats, Shallow Seas and Inland Saline Steppes: Ecology, Distribution, Threats and Challenges

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Abstract Coastal and inland saline habitats are distributed worldwide. The coastal habitats occur at the border between land and sea in various landscape formations, such as rocky shores, shallow coasts and protected bays, as far as to offshore areas. The inland saline habitats are predominantly part of inland steppe ecosystems. The complex underlying geomorphology, ecology, specialized flora and fauna, temporal and spatial dynamic, diverse ecosystem services and the general importance for human populations, settlements, fisheries, trades, and tourism make coastal habitats a unique part of the world's landscape.

In this chapter, we briefly outline the historic significance of coastal habitats and their ecosystem functions and services. We describe recent threats affecting coastal habitats and their flora and fauna. Owing to their spatially close relation or similarities in vegetation composition to saltmarshes, we additionally describe the characteristics of shallow sea communities and inland saline steppe vegetation.

Today, many of the characteristic plant and animal species showing special adaptations with respect to challenging environmental, as well as subtidal, coastal and inland saline habitats are threatened worldwide and thus, are under serious pressure. Main threats comprise residential and commercial building development, artificial coastal defence, tourism, overexploitation, pollution, increasing pressure of invasive and other problematic species, anthropogenic influence on water dynamics and climate-change induced changes in coastal dynamics.

Theoretically, many climate-related extremes such as floods and hurricanes imply a much higher risk for humans and human buildings at the coast than for natural

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habitats which evolved under dynamic conditions and are adopted to strong coastal wind and water dynamics. However, as the natural resilience of these habitats is now often impaired by anthropogenic factors and climate extremes facilitate previously unknown variation to natural dynamics, climate change has become a growing threat to coastal ecosystems.

We outline past and currently applied projects and activities, which we perceive as promising examples of science-based nature conservation measures in relation to main threats and socio-economic issues. We conclude with discussing future perspectives of coastal habitats on global and regional scale, in the light of global change, i.e. human influence on natural dynamics, land use change, climate change, and coastal protection.

Solutions to reduce the pressure on coastal habitats and biota comprise, among others, e.g. to enlarge nature reserves and zero-use zones, to reduce human impact at landscape scales, and to give space for natural dynamics. Pollution and the impact of fertilizers may be locally reduced by buffer zones and technological solutions. However, the local interest in reducing sewage and nutrient release can only be limited by national or supra-national recycling policies and related regulations.

One of the problems which cannot easily be solved is the irreversible introduction of alien species. Invasion of native biota can also become a problem if environmental conditions are altered. In this case every problem has to be monitored at regional scales and managed by hand, if possible.

At the same time, we assume that current tendencies, e.g. growing settlements and cities at the coasts, increasing tourism and climate change cannot be reversed in a short time.

Furthermore, political decisions are often unpredictable.

1   Introduction

The term *coastal habitats* comprise all habitat types found within the transition zone between land and sea. It refers to diverse ecosystems within the shallow subtidal and intertidal zone. At the terrestrial side, these often relatively narrow strips are naturally bordered by rock formations, sea cliffs and, in more gradual transitions situations, by sand dunes (supratidal zone) or saltmarshes. The coastal landscape as such include coral reefs, seagrass beds, mangroves, saltmarshes, algal communities including "*giant kelp forests*" (Schiel and Foster 2015), lichen and vascular plant communities of rocky shores and sea cliffs, as well as sandy dune habitats in diverse stages of development. Although natural coastal landscapes only cover a small percentage of the Earth's surface, they are unique ecosystems with a highly diverse flora and fauna.

The coastal landscape is subject to intense spatial and temporal dynamics, most strongly influenced by flooding and aeolian dynamics, fluctuating salinity, and succession processes. Flora and fauna are specifically adapted to these processes. The availability of various niches related to strong gradients in abiotic and biotic conditions make the coastal landscape one of the most biodiverse systems on our planet, of which still a lot is unknown. Moreover, coastal ecosystems are highly interconnected, at local as well as at global scales. Changing conditions and processes in one place, may affect coastal habitats thousands of kilometres away.

Since very long times, coastal landscapes, shallow waters along the shoreline and estuaries belong to the important regions for human society, offering various ecosystem services However, in recent times, characteristic coastal ecosystems undergo a dramatically decline in quality and quantity (Janssen et al. 2016), although their values and threats have been noted already for a long time (Jefferies and Davy 1979; Westhoff 1985; Duarte et al. 2008; Nellemann et al. 2009; Vierros 2017). They occur under serious pressure through various—mostly human-induced—threats adversely altering abiotic and biotic conditions. These threats include land-use intensification as well as abandonment, land reclamation (Spalding et al. 2014), large-scale destructions for industrial, artificial coastal defence, harbour and commercial purposes, residential and commercial building development, tourism, extraction of oil, gas and drinking water, pollution, increasing pressure of invasive and other problematic species, sea-level rise, and the increase of climate-related extremes. Many of the artificial conversions of coastlines obstruct natural dynamics and may lead to dysfunctions in sediment availability and the interruption of alongshore sediment transport. Furthermore, the introduction of—often invasive—alien species is becoming a serious threat, for native species and communities. Dune protection went along with over-stabilization of the remaining complexes by planting trees and huge amounts of Marram grass (*Ammophila arenaria*; Martínez et al. 2013).

Some of the coastal habitats, e.g. saline shrubland or saltmarshes, may be less charismatic than other habitats, e.g. coral reefs, which leads to a decrease in public awareness of their losses, results in the continuation of detrimental practices and thus, contributes to their continued decline. More effective communication of scientific knowledge about these assumed uncharismatic, but ecologically important coastal habitats is required (Duarte et al. 2008).

In the following, we describe and analyse recent environmental conditions and challenges of subtidal, intertidal, supratidal (terrestrial) as well as inland saline habitats, which in comparison with saltmarshes reflect quite similar ecological conditions and species compositions. We quantify the pressure on the flora and fauna of coastal habitats in different regions, habitat types and taxonomic groups. Furthermore, we present selected examples of effective nature conservation concepts and measures. As climate-change induced changes in coastal dynamics, such as severe floods and hurricanes represent an increasing threat for uninhabited as well as populated coastlines, we conclude with a brief discussion on nature-based solutions, which may offer new opportunities for coastal defence.

2   Historical Meaning and Ecosystem Services

Archaeological findings in Israel, located at the shore of the Sea of Galilee, and in a near-coastal site on Triquet Island in British Columbia, belong to the oldest human settlements in the world, dating back to about 19,500 and 14,000 years BP, long before agriculture was invented. In more or less the same period, the first evidence of human fishing has been detected (e.g. Presland 1997; Blainey 2004; Mcintosh 2009). These old settlements and the recent position of cities in the world indicate the preference of humans for the proximity to coastal landscapes and freshwater habitats. However, since the sea level during the Last Glacial Maximum (c. 30–16,000 years ago) has risen by 120–140 m, it can be assumed that most of the old settlements at the coasts are inundated today. Meanwhile, many offshore artefacts, ruins and artificial structures have been secured, indicating submerged settlements that are several thousand years old (Badrinaryan 2006).

Coastal habitats played a central part in many societies as they offer access to food resources (e.g. fish, seafood) and provide manifold additional ecosystem services, such as water purification, preservation of genetic diversity, coastal defence or recreation improving quality of human life (e.g. Willaert et al. 2019). Thus, the resilient and long-term stable occurrence is of considerable importance for the longevity of our coastal landscape and its intrinsic natural and cultural value. However, current activities, including exploitation of coastal resources and the construction of artificial barriers are rapidly threatening these services. Coastal cities and industries strongly decrease the area for natural habitat and emit light, noise and toxic substances. Today, more and more people live in large cities and settlements at the coasts. Furthermore, an increasing number of people is attracted by beaches during holiday. Sea harbours became gateways for trade and exploration, but also for invasive species. People are flying around the world to visit coastal cities, coastal beaches and other scenic landscapes, for sunbathing, diving, reef-, wale- and birdwatching, to eat fresh fish, or simply to go shopping. As a consequence, many coastal regions are dramatically impacted by human activities, wastewater, plastic or other kinds of pollution, and the pressure to certain habitat types and species populations is extremely high.

The hilly landscape of sand dunes provided shelter against winds and flooding from the seaside. In the past, small-scale agriculture could be performed in dune systems, and dune grasslands were used for the maintenance of fishing gear and bleaching of linen. These small disturbances, that locally increased biodiversity, are still visible in the species-rich vegetation near the Sea villages in the Netherlands and Belgium or in the calcareous *machair* grasslands in Ireland and Scotland. The large volume of sand harbours huge fresh water supplies and till now drinking water companies provide dune filtered water to millions of people (van Rooijen and Schaminée 2014).

Other coastal habitats also provide ecosystem services of high economic value. For example, since more than a century, coastal wetlands have been recognized for their ability to stabilize shorelines and to protect coastal communities. Saltmarshes

and mangroves are able to reduce wave heights, property damage and human deaths (Jin-Eong 2004; Gedan et al. 2011). Particularly coral reefs, mangroves, seagrass meadows and saltmarshes capture and store huge amounts of carbon, up to 50% of all carbon sequestered in marine sediments (Union et al. 2005). Costanza et al. (1997) mention it has been estimated that coastal habitats deliver the highest annual value, in terms of ecosystem services, of all-natural ecosystems on the planet. This is in strong contrast with their conservation states, as these ecosystems are being degraded and disappear at rates five to ten times faster than rainforests (Nellemann et al. 2009). An open dialogue between scientists, conservation practitioners and policy makers is urgently needed on the national and international level and with respect to global change (Vierros 2017).

Today, more and more people live in large cities and settlements at the coasts. Furthermore, an increasing number of people is attracted by beaches, dunes and warm water during holiday. People are visiting scenic places at the coast, e.g. for sunbathing, swimming, diving, reef-, wale- and birdwatching, or simply relaxation. Thus, tourism to coastal areas such as beaches implies both economical attractivity and pressure to natural systems (Martínez et al. 2013).

3 Selected Habitat Types

Coastal habitats can be classified in relation to landscape formation and genesis (geomorphology, e.g. Valentin 1952; Owens 1994) which provides a sound basis for other ways of classifying coastal landscapes (Finkl 2004).

Apart from submerged algae in the sub- and intertidal zones, coastal vegetation requires moderate water conditions and a relatively high substrate stability, ranging from seagrass beds on mud flats, algal, lichen and vascular plant communities on rocky shores, productive saltmarshes, halophytic shrubland and (tropical) mangroves, as well as more or less open grassland of coastal dunes. Everywhere, the vegetation interacts with water conditions and sediments, and therefore are often used for habitat classification. As such, coastal habitats can be classified with respect to water depth, duration of inundation, proximity to the shoreline, salt content, type of substrate, and geomorphology, among others. They often undergo strong spatial and temporal dynamics, strongly influenced by wind and water, flooding, salinity, and periodicity of drought and precipitation. The flora and fauna in these habitats are often highly adapted to dynamic habitats. Unvegetated habitats of the sublittoral and littoral zones can be classified by substrate, e.g. rocky ground, gravel, sand or clay, or by the time of inundation (Goetting et al. 1988; IUCN 2019). Parts of the beaches and rocky shores which are inundated during high tides belong to the intertidal zone, higher elevated parts or areas which are not flooded on a regular basis, belong to the supratidal zone.

The classification of coastal vegetated habitats is furthermore supported by the underlying substrate, location in relation to the water level or in proximity to the shoreline, and salinity. Going more into detail, dynamic processes such as the force

of the coastal surf and currents, the characteristic of the tidal system, and fluctuations in sea level help to refine basic classification schemes. Transnational schemes of classifications on habitat or plant community level and with respect to biogeography, ecology, structure and species composition have been published by, among others, Davies et al. (2004), Janssen et al. (2016), IUCN (2019), and Pätsch et al. (2019).

Plant communities at the coast with the same structure and a comparable species composition may be called *saltmarsh*. These are generally assigned to specific coastal vegetation units, whereas their inland counterpart, called *salt steppes*, are mostly assigned to grasslands. Like other names for habitat types or vegetation units, many of them are defined in different ways. Moreover, different names are sometimes used for the same unit. Therefore, we try to unify the terminology.

With respect to the mentioned classification schemes, related groups of habitats can be ordered as described in Table 1.

In the following, we briefly consider environmental conditions including human influence of selected habitat types from the marine environment to the shoreline, and from coast to inland.

3.1 Coral Reefs

Corals are marine invertebrates (*Anthozoa*). Many of them use the photosynthesis of symbiotic microscopic algae (*Zooxanthellae*). Therefore, they need sunlight and prefer clear water. However, nearly as many deep-water coral species without symbiotic algae exist. Corals, algae and sponges are reef-building organisms. Most reefs occur in shallow tropical marine environments between latitudes 38° N and 25° S. Deep and cold water coral and sponge reefs, bioherms or banks exist to a smaller extent outside of the Tropics, for example in the North Atlantic, Canadian Arctic and Antarctic continental shelves (Freiwald and Roberts 2006).

All these systems provide habitat to a multitude of other species and are rich e.g. in terms of fish, mollusc, crustacean, echinoderm, sponge, and tunicate species. They cover less than 0.1% of the marine ground. However, it is estimated that they harbour round about a quarter of all marine species (Murphy 2002; Hopley 2011). Coral reefs have an important function as fish nurseries and are therefore, ecologically, closely linked to other coastal habitats (Unsworth et al. 2008).

Damage and decline of coral reefs are caused by destructive fishing, tourism, land-based pollution and runoff, and climate effects including severe weather, temperature stress and coral bleaching (Cesar et al. 2003; Rinkevich 2008). Interactions within the disturbance factors often lead to an exacerbation of the situation (Ellis et al. 2019). Coral reefs belong to the most charismatic ecosystems in the world. The attraction to humans results in a massive coral reef tourism. This has both effects positive and negative ones. The recent challenge is to intensify nature conservation efforts and to reduce disturbance (Lirman and Schopmeyer 2016; Finea et al. 2019).

Table 1 Overview of coastal and inland saline habitats

Environment	Habitat
Subtidal (near-coastal, shallow, permanently submerged)	Rock; Sand; Mud; Coral reefs; Macroalgal/kelp; Seagrass beds (submerged)
Marine intertidal (between high and low spring tide)	Seagrass beds (regularly inundated); Rocky ground with/without algae, lichens, barnacles or others; Sandy beach (SiO_2, coral sand, other), gravel beach, shingle beach; Clay/mud and/or peat flats; Drift line with/without characteristic vegetation; Saltmarsh (dominated by grasses and herbs, grassland or steppe habit); Swamp/reed; Halophytic shrubland; Mangrove
Coastal supratidal (not inundated normally, occasionally influence of salt spray)	Rock pool; High elevated beach; Dune without vegetation; Pioneer vegetation; Closed dune grassland vegetation dominated by grasses, herbs, bryophytes, and/or lichens; Dune dominated by shrubs; Machair, Zeedorpenlandschap (coastal plain with sand and shell sediment, characteristic vegetation and use); Dune valley; Inundated or (seasonally) wet dune slack; Sea cliff/rocky shore
Inland saline (separated from the sea/coast)	Unvegetated; Salt lake (permanent inundated or seasonally dry); Salt steppe Swamp/reed; Halophytic shrubland

3.2 Tidal Flats

Intertidal mud flats occur in sheltered areas, where finer sediments can deposit. Each tide new sediments are brought in or washed out, creating an environment shaped by tidal cycles. The deep muddy sediment offers a habitat for a variety of species of molluscs, worms, crustaceans and other invertebrates which are often extremely abundant. Therefore, these ecosystems are important feeding grounds for fish and especially for birds. Many millions of migratory birds, migrate via these muddy ecosystems to forage. Large areas of mud flats are rare, but combined mud flats form an extensive coastal habitat of almost 128,000 km^2 (Murray et al. 2019). The only

natural hard substrate in these systems are mussel or oyster beds, which give shelter to many other species.

Apart from algae, often attached to hard substrate such as mussel, or oyster banks, sea grasses (*Zosteraceae*, *Posidoniaceae and Cymodoceaceae*) can grow on mud flats of shallow subtidal and intertidal substrates. In well-functioning sea grass beds, the vegetation forms a semi-open self-organized vegetation, caused by nutrients and sediment availability, much alike mussel banks. Here eel grass species (*Zostera*) form a symbiosis with other biota in the soil (Van der Heide et al. 2012).

3.3 Mangroves

Mangroves are woody habitats of saline and brackish lagoons, shorelines and estuaries between latitudes 25° N and 25° S (e.g. Fig. 1). Substrates are often muddy or sandy, less often stony or rocky, and normally located at the transition between low and high tide. The habitat is often characterized by deposition of fine sediments with high proportion of organic material (Bowen et al. 2001; Jin-Eong 2004; Spalding et al. 2010).

In general, the composition of vascular plants is rather species-poor whereas the water fauna can be classified as relatively species-rich (Goetting et al. 1988; Hogarth 1999).

Mangroves of the Indic Ocean and western coasts of Pacific Ocean harbour more tree and shrub species than mangroves of the Atlantic Ocean and eastern coasts of the Pacific Ocean. This *anomaly in mangrove vegetation* has been explained by

Fig. 1 Mangroves at Bonaire are presently dying off at a large scale, because of the inflow of *Sargassum* algae that decomposes in the salinas (photographed by Joop Schaminée)

different evolutionary histories combined with limited occupation of the stressful marine environment from terrestrial lineages (Jayatissa et al. 2002; Ricklefs et al. 2006).

Natural coastal protection, timber production, fishery, and aquaculture belong to the ecosystem services. More than one third of the mangroves have been destroyed during the last decades by clearing, dams and irrigation, construction of aquaculture, and overharvesting (Hogarth 1999; Jin-Eong 2004). Changes in severity and frequencies of storms increase the pressure on mangroves in Indian ocean and Northern America.

Sargassum brown tides are examples of the global context of coastal ecosystems. Large amounts of *Sargassum* algae wash seasonally ashore on Caribbean islands, creating a thick layer of toxic organic biomass which suffocates the mangrove trees. The brown tides formed mid-Atlantic and are caused by nutrient loads originating from erosion in the Amazon, Orinoco and Congo river (Van Tussenbroek et al. 2017).

3.4 Saltmarshes

The 1960 classic study of Chapman on "salt marshes and salt deserts of the world" already revealed the almost infinite diversity of saltmarshes, referred to as saline areas of land bordering on the sea. In some parts of the world, they carry a highly varied vegetation, whilst in other places only one or two species dominate. Sites covered with vegetation frequently alternate with bare sites, often at close distance to each other. Salt marshes can develop around dune complexes on (barrier) islands, where water dynamics are limited, on the foreland of mainland coasts (often of an anthropogenic origin) or on isolated mainland remnants, so-called Hallig salt marsh islands (Esselink et al. 2017).

Generally, a saltmarsh can be divided into a seaward section (lower saltmarsh), naturally inundated by the tide more frequently, deeper and longer than a higher positioned landward section (upper saltmarsh), but the picture is often more complex. The area under influence of the tidal regime is generally referred to as the intertidal zone (e.g. Esselink et al. 2017). The marshes may be intersected by irregularly twisting creeks, that empty at low tide and fill up again at high tide, showing their own zonation from the creek margins to the lower flats a bit further away. Another important gradient relates to estuaries. When a river reaches the coastal plain, it will come within tidal influences: the barrier effect of the flooding tides reduces the flow of the river water, enhancing the deposit of sediments and as such the development of marshes. The distance to the sea has a direct effect on the salinity of the water, ranging from saline in open sea over brackish to completely fresh further stream upwards in the river.

Other important factors relate to the magnitude of the tides, ranging from more than 16 m to almost zero. The highest tide in the world is found in Canada at the Bay of Fundy, with other extremes at the Atlantic Coasts of Great Britain and France.

Fig. 2 Grazed salt marsh with *Salicornia europaea* (red) and *Tripolium pannonicum* (syn. *Aster tripolium*, pink) on Læsø, Denmark. Because of tectonic uplift the range of saltmarches of this island will still grow despite rising sea level (photographed by C.H.)

This is in sharp contrast to more or less enclosed basins, such as the Baltic Sea (Fig. 2), Black Sea, Caspian Sea and Mediterranean Sea. Here, the differences between high and low tide measure only a few decimetre at the maximum and are to a large extent depending on wind conditions (e.g. Pätsch 2019; Medvedev et al. 2016). Of major influence on the vegetation is also the type of substrate that may range from sandy over silty to clayey and from mineral to peaty.

On global scale, saltmarshes are primarily associated with middle and higher latitude regions, because in the tropics and subtropics their position on the landscape is largely taken by mangroves or other woody vegetation on brackish ground. Here, grassy saltmarshes may develop at places where the mangroves have been cut over, like in Brazil, where *Spartina brasiliensis* may form such grassy patches. Chapman (1960) distinguishes 9 groups of marine saltmarshes along the world, starting with a north European group, ranging from the Iberian Peninsula northwards to southern Scandinavia. The salt marshes of the American and Canadian arctic regions, together with their European and Asian counterparts are treated as a separate group, just like the Mediterranean marshes. Herbs, grasses and algae form the major component in the temperate and arctic communities (with a few bryophytes and lichens occurring at the higher elevated zones), whereas the Mediterranean marshes are mainly characterized by shrubby vegetation. In temperate North America, Chapman distinguishes between a western and an eastern group. On the Pacific coast, the marsh formations are not so extensive as those occurring on the Atlantic Coast. On the

southern hemisphere, Chapman recognizes (outside the tropics) a South American Group and an Austro-New Zealand group. On the pacific coast of South America, distinct effects of a climate gradient on the species compositions are shown by Fariña et al. (2017). Here, the salt marshes are divided in arid coastal habitats dominated by *Sarcorcornia fruticosa* as well as temperate habitats in the South with high *Spartina densiflora* abundance. In Australia and New Zealand, salt marshes form extensive habitats sometimes over 10 km wide, but mostly confined to estuarine environments or barrier estuaries. Mangrove encroachment is one of the major threats for salt marshes, mainly in northern Australia (Saintilan et al. 2009).

In many parts of the world, saltmarshes are directly or indirectly influenced by human activities. Moreover, large areas are used for grazing (Fig. 2), hay making or food harvesting. Especially in regions with protected saltmarshes, the question of the intensity and reduction of grazing has intensively been discussed during the last 50 years. Many saltmarshes along the North Sea, for instance, are heavily overgrazed by domestic animals (mainly sheep). Natural grazing takes place by geese and hares. The majority of rather brackish plant communities found along the Baltic Sea coast rely on (very) moderate grazing regimes (Pätsch et al. 2019) in combination with other factors of which elevation is most dominant (Jutila 2001). Where grazing does not take place, succession stages dominated by *Bolboschoenus maritimus*, *Elytrigia repens*, *Phragmites australis* or *Schedonorus arundinaceus*, or even willow shrubland and *Alnus glutinosa* woodland, would be able to replace them. Moderate grazing might facilitate coastal ground-breeding birds that profit from the structure of salt pastures, as has been demonstrated in National Parks of the German Bight (Looijen and Bakker 1987; Kirsch 1990).

3.5 Rocky Shores

Rocky shores are hard transitions from sea to land often accompanied with a steep difference in altitude. Water currents and erosion form strongly accented coastlines, sometime with cliffs rising hundreds of metres above sea level. Also, artificial structures may show similar characteristics as rocky shores. Examples are docks, dikes or even ships and buoys can function as comparable hard substrate for algae and invertebrates.

The lifeforms living on rocks are distributed over several zones depending on their contact with salt sea water and wave action. Brown and red algae, molluscs and crustaceans like barnacles inhabit the sub-, low- and mid-tidal zones, while higher up mussels and periwinkles are attached to the rocks in high tide zones. In the splash zone lichens can start growing (Denny and Gaines 2007). On less inclined areas between the rocks, rock pools can form with stagnant sea water. In these small pools, many species of the lower zones or even marine species can find temporal refuge. The limited size of the rock pools facilitates extreme conditions as salt levels rise due to water evaporation. Higher up on the cliff, on the edges of the rock faces vegetation with salt tolerant plants such as *Armeria maritima* develops. These rock edges are

home to sea birds that need to nest in the vicinity of their fishing areas. Sea gulls, Albatrosses and Puffins form colonies that nest together on the same cliffs, sometimes with hundreds of thousands of birds at the same time. On some islands the amount of guano produced by these birds covers entire cliffs and is sometimes mined by local industries as a resource for fertilizer.

Even forests can develop along rocky shores, for example the pine forests in the sheltered bays and fjords in Scandinavia or the cloud forests on the eastern shores of the Azores Archipelago, where Atlantic rainforest reaches the ocean (Elias et al. 2016). In northern California, dense forests of the immense Redwood trees (*Sequoia sempervirens*) also cover the rocky shores of the Pacific coasts. Again, here the system is comparable with a rain forest system but fed by incoming sea mist (Sawyer et al. 2000).

Natural disasters, pollution and the change in sea water temperature can also have a negative influence on the biota of rocky shores. Especially mollusc species are susceptible to pollution. Additionally, exotic, sometimes invasive, species can easily enter coastal rocky ecosystems.

3.6 Dunes

The transition between sea and land can be either very swift and hard, when we talk about rocky shores and cliffs or either very gradual and soft when looking at mud flats and saltmarshes. However, there is also an intermediate system, where sand, water and wind take control: the coastal dunes (e.g. Figs. 3 and 4).

Coastal dunes are aeolian driven ecosystems which are located on the boundary of sea and land where there is a sufficient availability of coarse sandy soils. Therefore, dune ecosystems are azonal distributed across the world. The dynamic processes in dunes are driven by interactions between water, wind and vegetation succession, starting at a beach moving inland via pioneer dunes, white dunes, grey dune grassland and (moist) dune slacks to dune shrublands and forests.

Fig. 3 Dune landscape with white dunes with Marram grass (*Ammophila arenaria*) in the front, to grey dune grasslands, wet dune slacks and forests in the distance (photographed by Nils van Rooijen)

Fig. 4 Dune complex with *Euphorbia paralias* (foreground) of Istmo de la Pared, Fuerteventura, representing one of the oldest and largest, and only moderately affected dune areas of the Canary Islands (photographed by Carsten Hobohm)

Dunes are formed in coastal areas where enough sediments are available, and the sand supply is continuously replenished. Moderate marine currents can supply beaches with sand derived from estuaries or old sediments on the nearby sea floor. For a sufficient sedimentation gradual shores are necessary. Here, water currents are slowed down, sedimentation occurs, and beaches are formed. These shores can stretch for great lengths, for example the kilometres-long beaches in north-western Europe, Brazil and south-eastern Australia or can form small patches in sheltered corners between rocks and cliffs. However, in the latter there is no room for an entire dune system to form. Nonetheless, beaches can harbour some diversity. Many bird species rely on beaches for food or even nesting grounds. In addition, crustaceans, insects and even some amphibians find their habitat on beaches. Plants and fungi form drift line communities on organic matter washed ashore.

The presence of wind is another important variable necessary for dune formation. Wind transports the sediments land inwards and is the main driver for the formation of dune structures and a condition to which the entire ecosystem is adapted.

The general geomorphology of dunes consists of a classification which follows dune succession land inwards. The spatial sequence is called xeroseries. Pioneer dunes are formed when pioneer vegetation catches and collects sand particles transported by wind or water. With a growing pioneer dune more sand, water and organic material is concentrated eventually succeeding into a vegetation with species such as Marram grass (*Ammophila*) which is a dominant genus distributed around

the world. As these plants accumulate more sediments, the dunes start growing. The roots of Marram grass can follow the growth of the dunes and their leaves are resistant to sharp blowing sands. This system is called the primary or white dunes, where sand transport is still one of the major driving processes. The dunes grow up to several tens of meters forming a natural dyke between the coast and inland areas. Where sand and wind availability are optimal dunes can grow up to more than 100 m, e.g. along the western French coast or the Namibian coastline. Where less sand is available, the white dune area may reach only 3 m in height, as can be seen along some Mediterranean coasts (Doody 2005). Due to the continuous aeolian activity, white dunes are very dynamic and can move up to several meters year or more during storms (Martínez and Psuty 2004).

On the lee side of the primary dunes, aeolian processes have a less omnipresent impact. Here, the sediments can settle, and vegetation is able to develop. Due to soils poor in nutrients, extremes in temperature and water availability, dune grassland often develops in sediments with a higher lime content. In less calcareous soils heather species become dominant. The prominent presence of mosses and lichens give these grasslands a grey appearance, thus they are also known as 'grey dunes'. Open sandy spots in the grassland, some caused by the digging of rabbits or larger grazers, are vulnerable for the dominant winds and form blow outs. If the direction of the wind is dominant, blow outs can initiate the formation of parabolic dunes, a very distinct pattern in the landscape. Where parabolic dunes accumulate sediments, the blowouts may be wind excavated down to the ground water level. Here wet dune slacks may form of even small lakes which show a remarkable diverse vegetation (Goudie 2011).

Eventually dune grasslands accumulate organic material in the otherwise rather sandy soil and wind and sand become a less dominant factor. Encroachment with larger grasses and forbs as well as the establishment of shrub species lead up to the dune forests in moderate climates or dense shrublands (e.g. maquis vegetation) in Mediterranean areas. Also, the wet dune slacks accumulate organic matter and eventually form an environment where birch forests can develop.

3.7 Inland Saline Habitats

In former times, inland saline habitats were often seen as badlands, and the landscape scenery was not always perceived as beauty in the eyes of residents. However, especially during the last decade's scientific publications have pronounced the uniqueness of these habitat types (e.g. Evans and Roekarts 2015, factsheets of the European Environment Agency 2019, and pers. comm. with farmers).

Natural inland saline habitats can occur under arid or semi-arid conditions where evaporation causes increasing salt concentrations, and in regions where saline or alkaline waters flow out of the geological surface (salt springs). Such habitats may also occur where excavation material of mining activities is deposited (Pernik and

Hulisz 2011). Various animal and plant taxa are adapted to high and/or fluctuating salt concentration, little freshwater and desiccation. Vascular plant families which regularly occur in saline flats are e.g. *Chenopodiaceae* (*Salicornia*, *Sarcocornia*, *Suaeda*, *Enchylaena*, *Sclerolaena*, and many others), *Plumbaginaceae* (e.g. *Limonium*), *Poaceae* (*Puccinellia*) and *Aizoaceae* (e.g. *Gunniopsis* in Australia). Many genera represent higher species numbers inland than in coastal saltmarshes.

Salt steppe, brackish swamps or halophytic shrubland, salt lakes and crusts of salt without any vegetation but characteristic fauna can be found in the surrounding of depressions, sources or running saline or brackish waters In many cases the salinity of soils and waters is not stable and may change periodically in relation to the precipitation regime, or increases or decreases over a long time (Williams 1978; Westhus et al. 1997; Luo et al. 2013, 2017).

4 Species Diversity and Threatened Biota

4.1 Diversity

In general, the biodiversity, i.e. number of species or individuals per unit area, and biomass declines when comparing coastal to deep sea regions. However, as the scientific exploration of the deep sea is expensive and the community of ecologists working on deep sea ecology is small, also the knowledge on the deep sea is limited (Tittensor et al. 2010).

The diversity of organisms at higher taxonomic levels is much greater in the seas than on the land. This fact has to do with the high age of oceans and the long evolutionary history (Goetting et al. 1988; Mora et al. 2011).

Taking into account that only a very small proportion of the Earth's surface is covered by coastal habitats, the amount of species and endemism adopted to the this small transition zones is high. In general, tropical regions harbour higher marine, coastal and near-coastal biodiversity and almost the whole range of marine biodiversity hotspots in comparison with higher latitudes (Roberts et al. 2002; Worm et al. 2005; Ramírez et al. 2017).

4.2 Threatened Biota and Threats

Table 2 gives an overview of numbers of threatened species in shallow (subtidal) coastal waters. According to the numbers in this table, the related habitats are highly vulnerable and impacted by humans. Figure 1 gives an example of a recent vegetation dieback at Bonaire.

The Pacific Ocean harbours the largest number of critically endangered (CR) or threatened species (CR, EN, plus VU). The Indian Ocean and Atlantic Ocean are

Table 2 Numbers of threatened species of shallow (subtidal) coastal waters with respect to geography, taxonomy and threat (IUCN 2019; threat categories: *CR* critically endangered, *EN* endangered, *VU* vulnerable; marine neritic categories 9.2–9.9). Note that several species can live in more than one region and may be threatened by a combination of different factors. Thus, not all numbers are additive

	CR	CR, EN, VU
In total (globally)	92	756
Arctic Ocean	0	1
Atlantic Ocean	27	201
Mediterranean and Black Sea	11	40
Indian Ocean	31	359
Pacific Ocean	40	473
Tracheophyta (vascular plants)	0	11
Rhodophyta (red algae)	5	6
Actinopterygii (ray-fin fishes)	21	258
Aves (birds)	14	28
Reptilia (reptiles)	3	12
Mammalia (mammals)	0	10
Chondrichthyes (cartilaginous fishes)	33	122
Myxini (hagfishes)	1	6
Sarcopterygii (lobe-fin fishes)	1	2
Arthropoda (arthropods)	0	3
Mollusca (mollusks)	4	42
Cnidaria (coelenterates)	7	236
Echinodermata (echinoderms)	0	15
Threatened by residential and commercial development	25	360
Threatened by agriculture and aquaculture	4	27
Threatened by energy production and mining	6	32
Threatened by transportation and service corridors	11	265
Threatened by biological resource use	73	586
Threatened by human intrusions and disturbance	13	280
Threatened by system modifications	10	46
Threatened by invasive and other problematic species, genes and diseases	32	313
Threatened by pollution	25	392
Threatened by geological events	1	3
Threatened by climate change and severe weather	37	398

taking position number two and three and the Mediterranean and Black Sea together number four.

Fishes, birds, coelenterates, red algae, molluscs, reptiles and mammals all harbour taxonomic groups with high numbers of critically endangered species. For both groups of Red List categories, critically endangered and threatened species, the most important threats are biological resource use, climate change and severe weather, pollution, residential and commercial development, and invasive and other problematic species, genes and diseases.

Table 3 Numbers of threatened species (IUCN 2019) of intertidal, coastal supratidal and inland saline habitats with respect to habitats (categories 1.7, 5.14–5.17, 12, 13), geography, taxonomy and threats (threat categories: CR = critically endangered, EN = endangered, VU = vulnerable, habitats 1.7, 12, 13). Note that several species can live in more than one region and may be threatened by a combination of different factors. Thus, not all numbers are additive

	CR	CR, EN, VU
Number of threatened species	191	1043
Intertidal rocks, sands, mud flats, tidepools and seagrass beds, coastal saltmarshes and halophytic shrubland	41	269
Mangroves (intertidal and above high tide level)	45	276
Marine coastal/supratidal lagoons, cliffs, dunes, and dune slacks	111	567
Inland saline, brackish or alkaline wetlands	22	113
North America incl. Greenland and excl. Hawaiian Islands	4	56
Mesoamerica and Carribean Islands	41	210
South America	11	132
Europe	43	183
Africa	43	292
North, West and Central Asia	11	109
East, South and Southeast Asia	32	230
Antarctic	1	16
Tracheophyta (vascular plants)	73	307
Bryophytes	0	0
Rhodophyta (red algae)	1	2
Actinopterygii and Chondrichthyes (fish species)	18	176
Aves (birds)	25	213
Reptilia (reptiles)	24	116
Amphibia (amphibians)	2	6
Mammalia (mammals)	8	121
Mollusca (mollusks)	7	27
Threatened by residential and commercial development	80	511
Threatened by agriculture and aquaculture	60	419
Threatened by energy production and mining	23	152
Threatened by transportation and service corridors	23	133
Threatened by biological resource use	76	519
Threatened by human intrusions and disturbance	33	221
Threatened by system modifications	40	260
Threatened by invasive and other problematic species, genes and diseases	88	403
Threatened by pollution	35	285
Threatened by geological events	9	41
Threatened by climate change and severe weather	55	320

Table 3 gives an overview of numbers of globally threatened species which live in or depend on intertidal, supratidal and inland saline habitats. According to the IUCN Red List (2019) most critically endangered (CR) or threatened (CR, EN, plus VU)

species of coastal and inland saline habitats belong to a few taxonomic groups: vascular plant, reptile, fish (Actinopterygii and Chondrichthyes), bird and mollusc species (most of the latter are sea snails and slugs). Coastal supratidal habitats harbour more threatened species than intertidal or inland saline habitats (cf. also Table 2).

Europe, Africa, Mesoamerica and the Caribbean Islands represent high numbers of critically endangered and/or threatened species of the related habitats; North America, South America and the Antarctic represent smaller numbers.

5 Examples of Restoration Projects

Restoration measures can be related to both ecological and societal goals. Societal goals comprise fishery, energy production, shoreline protection, tourism, the scenery and beauty of the landscape, and are linked with human survival and health, and economic benefits. Ecological goals for example, aim at the conservation or re-establishment of native biodiversity, reduction of threats to the biota, and/or zero-use and wilderness. These goals may be discussed at different spatial scales from local to global. Nature conservation measures can easily be applied if these also follow social goals and financial investments are manageable. It is, however, more tricky to look for solutions in complicated situations with competing interests of invasive humans, invasive biota, and natural biodiversity (Schuster and Doerr 2015). The lack of public awareness of losses of less charismatic ecosystems results in the continuation of detrimental practices and therefore contributes to continued declines of coastal ecosystems. More effective communication of scientific knowledge about these uncharismatic but ecologically important coastal habitats is required (Duarte et al. 2008).

The following examples partially face promising projects with respect to habitat restoration and species conservation.

5.1 Restoration Projects on Coral Reefs

Coral reefs and mangroves are often linked to each other with regard to their functioning in the landscape, whereas both are important system engineers. Various projects, for example at the coasts of Florida, Caribbean Islands, Australia, Thailand, and Egypt, are working in restoration of coral reefs. These include research and monitoring, genetic analyses, coral gene banking efforts, cultivation and reproduction of corals and other species, ecological engineering, species reintroduction into natural habitats, and education. Especially the development of coral nurseries and cultivation of endangered coral species such as *Acropora* species seem to prove successful efforts (Precht 2006; Yeemin et al. 2006; Rinkevich 2008; Ammar 2009; Sen and Yousif 2016; O'Donnell et al. 2018).

5.2 Restoration of Mangroves

Mangrove forest restoration often focuses on restoring the environmental conditions as planting of mangrove tree species often fails. Combining planting with increasing the water quality by measurements elsewhere (e.g. erosion prevention in river delta's or limiting nearby aquaculture) has more effect. The best practise to restore mangrove systems, however, is to create entirely new habitats. This is very costly and hard to achieve over large areas, but as the necessity for resilient and durable coastal protection grows, mangroves restoration may present a good option for the long-term (Lewis III et al. 2005).

5.3 Restoration Projects of Saltmarshes and Tidal Flats

The Wadden Sea at the coasts of the Netherlands, Germany and Denmark is the largest tidal flat system in the world. These three countries therefore have an important international responsibility to protect these habitats. A large part of this area belongs to national parks and most habitat types are additionally protected by the European Habitats Directive and additional (national) regulations. However, despite regulations and measures for nature protection the Wadden Sea is highly impacted by waste, pollution and eutrophication, dumping of dredge spoil, shipping, fishery, residential and commercial development, energy production (oil and gas extraction, wind parks), coastal defence measures, tourism, and diverse other anthropogenic influences (e.g. Tougaard and Ovesen 1981; Goetting et al. 1988; Hobohm 1992, 1993; Lasserre 1994; Hughes and Paramor 2004; Kirwan and Megonigal 2013; Gu et al. 2018). Many pollutants and debris wash ashore after it has been lost by ships. For example, in 2019, the cargo vessel MSC Zoe lost over 200 transport containers in the North Sea near the German coast. Within days, the beaches of the Wadden isles were covered with chemicals, micro plastics and plastic pallets which are likely to enter the food web of the dunes. Additionally, on the long-term land subsidence, insufficient sediment supply and the rising sea level may impact parts of the Wadden Sea (Baptist et al. 2019).

For the Wadden Sea saltmarshes, the following five targets have been formulated in the trilateral Wadden Sea plan of The Netherlands, Germany and Denmark (Esselink et al. 2017):

1. maintaining the full range of variety of saltmarshes typical for the Wadden Sea landscape;
2. achieving an increased area of saltmarshes with natural dynamics;
3. achieving an increased natural morphology and dynamics, including natural drainage of mainland saltmarshes, under the condition that the present surface area is not reduced;
4. maintaining a saltmarsh vegetation diversity reflecting the geomorphological conditions of the habitat with variation in vegetation structure;

5. maintaining or to achieve favourable conditions for all typical species.

Restoration projects comprise e.g. the recovery of Eel Grass (*Zostera marina*) and mussel beds (*Mytilus edulis* and *Ostrea edulis*), and ecological restoration of saltmarshes include de-embankment of summer polders and re-develop former geomorphology and drainage systems. Restoration the widespread occurrence of *Zostera marina* in the Netherlands is a real challenge, as the population at all locations of restoration substantially decreased due to reduced seed production (van Duren et al. 2013, 2014). Most likely, the water conditions, i.e. chemistry and/or light are not adequate. Moreover, a fungus is threatening eel grasses. The establishment of mussel beds (de Paoli et al. 2015) is a challenge too. Currently, the possibility of using bio-degradable artificial reefs for mussel bank settlement is studied in the Wadden Sea area. In contrary, restoration measures in saltmarshes face higher success (Bernhardt and Koch 2003; Esselink et al. 2017). Salt marsh restoration by habitat increase can be achieved via e.g. large scale de-embankment (Wolters 2006). However, it can be assumed that restoration projects might become more successful if major impacts, i.e. artificial limitation of natural dynamics, the amount of nutrients and pollutants, will be reduced on regional or even global scale in the future.

5.4 Restoration Projects of Coastal Dunes

Active dunes and wet dune slacks in general represent areas of positive sedimentation rates. Under natural conditions unvegetated dunes are migrating due to erosion at one side and sedimentation at the other. Later succession stages of dunes show more or less dense vegetation cover, i.e. pioneer vegetation, vegetation dominated by grasses and herbs, dune shrubs, and finally forest if the airborne content of salt is low enough.

Lithgow et al. (2013) defined and assessed variables influencing the success of restoration measures in dune areas. They used different criteria and subcriteria such as degree of degradation, system fragmentation, stress factors, factors that facilitate restoration, and 38 indicators such as visitor pressure, infrastructure affecting sediment dynamics, and so on.

Restoration of coastal dunes and beaches including wet dune slacks has many goals, facets, and mechanisms. Correspondingly, the natural heterogeneity of dune systems and the special conditions including human influences of each site needs to be assessed. Numerous restoration projects showed that anthropogenic influences cannot completely be compensated with respect to natural conditions including hydrology, biodiversity and aeolian transport of sand, for example. Thus, also the re-introduction of traditional management technics such as mowing, grazing, sod removal and non-traditional construction of artificial habitats such as wet dune slacks might be tested and evaluated (Grootjans et al. 2002).

However, one comprising target is the re-establishment of the natural dynamic. Thus, national and regional authorities should give space to natural dynamics and free movement of dunes in coastal areas as much as possible.

The dynamic nature of dunes (Figs. 3 and 4) was, and sometimes still is, considered as a challenge. Through history, human settlements near coastal dunes were threatened by the moving sands. There are many examples of villages which even disappeared underneath the sands. Examples of lost villages are Sier on the wadden isle of Ameland, Berkheide near The Hague, a town called Onze Lieve Vrouwe op Zee on Duiveland, Kenfig in Wales and Shoyna in Russia (Williams and Davies 2001; Stulp 2011; Raffaele and Bruno 2019). As we have seen before, people tried to decrease the dynamics of the sand by fixing the dunes through the plantation of either Marram grass (and other sand-binding grasses) and pine trees. However, by reducing the natural dynamics, the functioning of the ecosystem is affected. Vegetation succession and encroachment of shrubs and trees are accelerated, whereas invasive species may enter and degrade the system. Species such as Japanese rose (*Rosa rugosa*) in temperate coastal regions of Europe or Sour fig (*Carpobrotus edulis*) in many warm coastal regions worldwide are often concentrated in areas with limited natural dynamics. At the Baltic and North Sea coasts, the Japanese rose is often removed mechanically because the species richness is lower in plots where this species occurs (Isermann 2008; Novoa et al. 2013).

In the past, at North and Baltic Sea coasts, rabbits were—at a large scale—able to keep the dune landscape open, through grazing and the digging of holes, but there populations have been decimated by (sometimes deliberately introduced) viruses, like VHS and Myxomatosis. Nowadays, intensive management is often necessary to maintain an open dune landscape. One common practice is the introduction of large grazers into the dunes, but their effect is often insufficient. Cattle and horses are often not able to keep up with the encroachment of woody plants. In some cases, they even increase encroachment by concentrating nutrients and compacting the soil, preventing aeolian processes resetting the system. Meanwhile, nitrogen deposits from heavy industries, often located near harbours, increase the rate of encroachment. One specific victim of human influence in the dune system is the Northern wheatear (*Oenanthe oenanthe*), a passerine bird that nests in abandoned rabbit holes in dune grasslands. As the vegetation closes, the small ground orientated bird loses habitat and nesting opportunities. Moreover, heavy metal industries and nearby marine transports are causing an increased deposition of toxins in dune areas. Dioxin levels in the eggs of the Norther wheatears in the Dutch dune system are that high that a large amount of the embryos die before hatching (Van Oosten 2015).

Sand dunes of shorelines are natural defence systems against forces of the sea. However, in many regions the dynamic of coastal dunes is part of the controversy between nature and coastal protection. For example, dunes in the Wadden Sea area to a great extent are artificially stabilized by plantations of *Ammophila arenaria* or *Ammocalamogrostis x baltica*, also in areas where the sedimentation rate is positive. In contrary to natural unvegetated and vegetated dunes such plantations are species-poor, and normally do not offer space for rare, endemic or threatened species. Fences are used across all dune areas in Europe to control the stream of visitors, with the

effect that no plants can grow where the visitor impact on sandy ground is high. On the other side, behind the fence dense and often shrubby vegetation occurs. The natural sequence of succession stages cannot be observed under such circumstances. In some dune areas, it is a successful policy to tolerate trespassing fences.

Recent approaches along European dune systems focus on returning the natural dynamics and homogeneity in the landscape (Grootjans et al. 2002; Provoost et al. 2011). Artificial blow outs are created, or even entire dunes are removed to open up the coast line. In some cases, on islands, the opening of dunes facilitates wash-overs to occur, sea water flowing through the dunes into the saltmarshes on the other side of the dune system, increasing a potential for nature. Where sand was once fixed, it is now mobile and can reach weaker dune complexes through natural processes, increasing the overall resilience of the dunes. Artificial blow-outs may provide new sources of sand to rejuvenate coastal grasslands and provide space for flora and fauna that need open areas (Aggenbach et al. 2018). In suitable areas, new dunes or new sand flats are being created on the coastline, sometime referred to as sand engines. In other cases, sand is added to the beach. This so-called sand suppletion functions as a source of sand for natural dune areas and provide new space for beach communities.

Although many coastal dune restoration projects have been evaluated as successful with respect to target species, target communities, elimination of anthropogenic residues and elimination of exotic species or woody plants (e.g. Petersen 1999; Grootjans et al. 2002; Ruz et al. 2005; Nygaard et al. 2011; Martínez et al. 2013; Lithgow et al. 2013; Eischeid et al. 2018), it is still unclear and debatable how effective the various measurements in dune systems at the long term might be. This could apply to the introduction of large grazers and the creation of blowouts. It is quite possible that the re-introduction of extensive traditional management techniques, such as mowing, grazing, sod removal and rewetting dune slacks, will be necessary in the long term (Grootjans et al. 2002). The difficulty lies in the elemental drivers of the dune system: water and wind. These drivers seem to be part of a much larger system subject to climate variables and weather conditions. There are indications of large cyclic events that affect atmospheric and oceanic currents (for instance El Niño, or the North Atlantic Oscillation), having an effect on local and regional aeolian processes in dune systems. Artificial measurements that intend to restore the fundamental dynamics of dunes should take the complex interactions in consideration (González-Villanueva et al. 2013; Van Rooijen et al. 2018).

5.5   Restoration Projects of Rocky Shores

Rocky shores are generally no subject for habitat restoration, as they simply perform just as they are, as long as their existence is guaranteed. An interesting item, however, with respect to the 'restoration' of rocky shores and their species, is the construction of artificial structures, which may facilitate a high biodiversity. As an example, a remarkable project is that of the Afsluitdijk in the north of the

Netherlands. The Afsluitdijk is a dam created to protect the low-lying county from flooding. By establishing the dam in 1932, the Zuiderzee bay was cut off from the North Sea and Wadden Sea creating the fresh water lake IJsselmeer. The dam was constructed of basalt stone on the Wadden Sea side. After 80 years, remarkable plant species established on this artificial rocky slope, like Wild Cabbage (*Brassica oleracea var. oleracea*), Sea Kale (*Crambe maritima*) and Sea Beet (*Beta vulgaris subsp. maritima*), species that are rare in this area. Wild Cabbage is endemic to coastal regions of western Europe and only a limited number wild populations are known (Gustafsson and Lannér-Herrera 1997). As the Afsluitdijk needs to be renovated to current standards for coastal protection, the entire dam is being renovated. Therefore, the basalt will be replaced by concrete, and the entire vegetation cover will be removed. To protect the various plant species, the seeds are collected before building starts to ensure the preservation of the plant genetic diversity. The new concrete substrate is designed in such a way that it is fitted with small cracks and spaces for the establishment of vegetation (and coastal fauna). The seeds (or carefully bred offspring) will then be reintroduced on the renovated habitat.

5.6 Restoration Projects of Inland Saline Habitats

The ecological meaning and environmental conditions of salt lakes, inland salt steppe, and continental alkali marshes including brackish reeds and halophytic shrubland has been studied, mapped and assessed in many countries and regions. In general, the uniqueness including endemic, rare and threatened plant and animal species has often been proved during the last years or decades. According to Flora Iberica (Castroviejo et al. 1993), for example different *Limonium* species such as *L. album*, *L. aragonense*, *L. dichotomum, L. erectum*, *L. hibericum*, *L. longebracteatum*, *L. paui*, *L. ruizii*, *L. soboliferum*, *L. squarrosum*, *L. stenophyllum*, *L. toletanum*, *L. viciosoi*, and some more are Iberian endemics which are confined to inland saline or alkaline depressions and borders of lakes (Castroviejo et al. 1993). However, also critically endangered species such as Sociable Lapwing (*Vanellus gregarius*) which has a relatively large range across Northern Eurasia, Northeast Africa and India depend on or profit from the existence of inland saline habitats. However, the breeding ground of this bird is much smaller than the range of occurrence (IUCN 2019).

Moderate grazing, in some cases also mowing, removal of sod, and/or limitation of strong visitor impact are identified as adequate instruments of nature conservation policies. However, in many cases it is useful and cost-efficient to simply keep the habitats untouched (e.g. Allen et al. 1997, Pardo et al. 2003, Ministerium für Landwirtschaft, Naturschutz und Umwelt Thüringen 2005, Šefferová et al. 2008, Balázs et al. 2014, Janssen et al. 2016 incl. fact sheet E 6.1 on Mediterranean inland salt steppe).

6   Challenges and Future Perspectives in the Light of Land Use and Climate Change

Reliable planning of future potential nature-based protection of coastal habitats depends on ideally precise scientific models of expected relative sea-level rise at regional to global scales, a good knowledge on the geomorphology of the landscape, a broad understanding of the dynamics and ecology of coastal habitats and their major threats in the region, the availability of reliable socio-economic data, and a further development of improved models integrating these major components to calculate best possible future scenarios. Regarding the implementation of scientific results, Spalding et al. (2014) additionally highlight the need of tools and decision support systems helping communities to understand coastal hazards in their region and finding nature-based solutions for future protection of the coast. Provided that research-driven, nature-based development of strategies for coastal protection is given, we assume that for many communities which are exposed to flood risk or other problematic factors, one can obtain a decreased vulnerability.

The climate changed dramatically during the last 30,000 years and the global sea-level arose by 120–140 m since last glacial maximum. Thus, coastal habitats had to migrate vertically and horizontally—on occasion up to hundreds of kilometres—in relation to the shifting climate zones (Ray and Adams 2001). Likewise in recent times, the coastal systems are subdue to many factors, making it hard to forecast the available area for coastal habits in the future. Geomorphological aspects such as horizontal and vertical movements of the earth' crust) also reflect parts of the current ongoing change of coastal landscapes. This includes the regional land-upheaval caused by glacial rebound, which for instance can be observed in Scandinavia (Hill and Wallström 2008). Opposite in character is coastal subsidence, as can be seen in certain delta areas such as the Huanghe Delta, New Orleans. Some of the towns, cities and habitats at the coast are sinking faster than the sea level is rising. Subsidence drivers are both natural and anthropogenic processes (Meckel et al. 2006; Syvitski et al. 2009; Strozzi et al. 2013; Auerbach et al. 2015).

Such geological processes, also including erosion and sedimentation, and human activities such as the creation of artificial islands caused an increase in coastal area of 13600 km^2 between 1985 and 2015 (Donchyts et al. 2016). However, the increased area of coastal land does not, in any means, guarantee the quality and quantity of natural coastal habitats in the future.

Different processes and land use change will have different effects to humans and biodiversity. Although climate-related extremes such as floods and hurricanes imply a much higher risk for humans and human buildings at the coast than for natural habitats, which evolved under dynamic conditions and are adopted to strong coastal wind and water dynamics (Nishida et al. 2017), natural resilience of coastal habitats is now often impaired by anthropogenic factors, and climate extremes have become a growing threat to these systems.

Combined factors of massive land-use and climate change add new challenges to the future of coastal landscapes and may ultimately result in small and rather isolated

strips of coastal vegetation lacking fully functionality. Current land-use change adversely affects quality and quantity of coastal habitats through pollution, reduced sediment availability, suppressed natural dynamics, among others. These may ultimately result in just small and rather isolated strips of still well-functioning habitats. These negative changes are connected to a strong intensification of industry and a rapidly increasing building development (settlements, tourism, coastal defence). Moreover, regional and global shifts in climatic conditions and relative sea-level rise, although difficult to predict, may strengthen the effects of other human impacts.

Consequently, the natural dynamic and the capacity of coastal habitats to migrate inland and to build up vertically is reduced. At regional level, serious damages have been recorded already for coastal habitats in shallow waters. Regarding small islands, atolls and other vulnerable places, solutions are required. Thus, we are in urgent need to think about and act with long-term, resilient and cost-efficient protection measures.

Conventional coastal engineering is getting increasingly costly due to the need of adjusting the rigid constructions to prevent the growing risk of flooding. It additionally facilitates land subsidence and adversely effects sediment availability owed to the disruption of natural coastal dynamics (Temmerman et al. 2013). Sediment availability is further reduced by sediment compaction from the removal of oil, gas, salt and water from underlying sediments (Syvitski et al. 2009). We therefore need to focus on and implement nature-based solutions. Already now, well-functioning coastal habitats, such as mangroves, saltmarshes, seagrass beds and coral reefs, contribute to the protection of our coastlines across all biogeographical regions of the world. And so, their capacity to attenuate flood waves and storm surges, to decrease erosion, to accumulate sediments (e.g. Spalding et al. 2014) and thus, their capability to grow vertically in relation to sea-level rise (Kirwan and Megonigal 2013) makes them a serious alternative or addition to artificial coastal defence. Studies investigating the capacity of intertidal habitats to function as coastal protection show promising concepts and encouraging results. Still, we need to understand more about the response of coastal habitats to sea-level rise and increasingly unpredictable flooding events on regional as well as on global scales. For example, judging the extent of coastal habitats attenuating storm surges differs between studies (Fonseca and Cahalan 1992; Mcivor et al. 2012; Möller et al. 1999), because of its dependence on frictional effects, wind speed and duration (Resio and Westerink 2008). Restrictions in coastal protection are given in relation to large-scale erosion and enormous tsunami waves (Gedan et al. 2011).

To enable nature-based coastal protection, the conservation and restoration of coastal habitats aiming to build a natural, interconnected and fully functional coastal landscape is required. The functionality of coastal habitats relies on an unhindered spatial and temporal dynamic, which includes horizontal movements, suitable sediment availability (enabling vertical accretion) and a complete species pool. For example, the functional breakdown of coastal habitats owing to sea-level rise may be related to the constraints in horizontal migration of habitats and its successional stages (called coastal squeeze; Feagin et al. 2005), due to the natural geomorphology of the landscape or by socio-economic barriers. Reducing these barriers where

possible, may contribute to the enlargement of coastal habitats (e.g. Schuerch et al. 2018).

Additionally, due to building development and artificial coastal defence, the natural dynamic and the capacity of coastal habitats to migrate inland and to build up vertically is reduced. Also, the ecological processes and dynamics of coastal habitats are highly entangled (Duarte et al. 2008; Barbier et al. 2011) and their sound ecosystem functioning partially depends on their positive synergetic relationships (Barbier et al. 2011). For giving an example, offshore seagrass beds and reefs facilitate the sediment availability of nearby saltmarshes or mangroves, which in turn decrease sea-water pollution by functioning as filter for polluted river- or groundwater.

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