14 Coastal wetlands

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14.1 Introduction

It is typical for a portion of the inner, protected margin of an estuary or a low-energy open coast to be covered by a vegetated intertidal environment. If covered with grasses or grasslike vegetation this environment is called a marsh. If covered with woody shrubs and trees typically called mangroves, this environment is a swamp or, more properly, a mangal. These environments may be normal marine in salinity or they may range through brackish toward freshwater. This discussion does not include the freshwater marshes along the rivers that may grade into the estuary. The proportion of the estuary that supports the salt marsh environment ranges widely: from essentially all of the estuary except for tidal channels, to only a border a few meters wide. The proportion of the estuary that is covered by vegetation tends to be an indication of the maturity of the estuary or the degree to which it has been filled in with sediment. For example, some of the estuaries on the Georgia coast have little open water except near the inlet between the barrier islands. A similar situation exists in coastal southwest Florida, where mangroves dominate. Only tidal creeks dissect the extensive vegetated environment in these sedimentologically mature estuaries (Fig. 14.1). By contrast, the German Wadden Sea is bordered by only a

![Fig. 14.1 Aerial overview of a marsh showing only tidal creeks interrupting the marsh vegetation. This condition of little open water landward of a barrier island is common where there is at least a modest tidal range.](image)

narrow marsh and the Bay of Fundy supports a narrow and discontinuous marsh environment where the gradients are steep (Fig. 14.2).

Both salt marshes and mangrove forests are special, vegetated intertidal environments and are discussed in detail. Some comparisons are made to demonstrate important differences between them.

14.2 Salt marshes

14.2.1 Characteristics of a coastal marsh

A marsh is really the portion of only the higher part of the intertidal environment that is covered by vascular plants. Above about neap high tide there is little energy to disturb the sediment substrate and the sediment that accumulates there tends to be relatively fine-grained with a fairly stable sediment surface. These factors provide the type of environment that supports vegetation: an undisturbed place of fine, organic-rich sediment. Various opportunistic and tolerant grasses thrive in this environment.

The marsh environment is commonly divided into the low marsh, which is approximately from neap high tide to mean high tide or slightly above, and the high marsh, which is from that level up to spring high tide.

![Fig. 14.2 Narrow band of marsh vegetation along the margin of the Bay of Fundy in Canada. The steep sides of this bay result in a narrow marsh because of the limitations of marsh growth within the neap to spring high tide zone.](image)
14.2.2 Marsh plants

There are two genera that are particularly prone to establish dense stands on such substrates: *Juncus* (Fig. 14.3) and *Spartina* (Fig. 14.4). Although not the only marsh taxa, these are the most widely distributed in North America.

The specific type of vegetation that develops in marshes depends upon the elevation within the intertidal zone and the latitude; in other words, there is a climatic control. In the middle and southern coasts of North America, *Spartina alterniflora* is the typical low marsh grass (Fig. 14.5), not because of the height of the plants but because of its elevation. It is typically found between neap and spring high tide. In most estuaries this zone has a narrow range in elevation of a few tens of centimeters, but this can be up to a meter or more in estuaries with very large tidal ranges. *Spartina alterniflora* is a coarse grass that grows in very dense populations. Individual plants are generally about knee-high but they display great variability, reaching up to more than 1 m in height depending upon the specific location within the marsh and the availability of nutrients. The highest plants tend to be on the highest elevations: the levees of the channel margins and near spring high tide. The *S. alterniflora* plants at the lowest part of the marsh may be quite small and discontinuous.

The high marsh in these areas is dominated by *Spartina patens*. This species is generally fine and small in contrast to *S. alterniflora*. It grows best on the upper flat surface of the marsh environment. *Juncus* is the high marsh grass in low to mid latitudes and is restricted to the elevation of about spring high tide. *Juncus roemerianus* is the species that is most common in southern North America and *J. gerardii* is most common north of Delaware and New Jersey. It is commonly called the needle...
14.2.3 Global distribution

The worldwide distribution of salt marshes can be organized into nine regions based on the vegetation communities (Fig. 14.7). In the northern high latitudes there is the Arctic region, which includes the northern portions of North America and Russia, along with Greenland, Iceland, and northernmost Scandinavia. Here marshes are fragmentary due to extreme weather conditions. Europe is divided into two regions: one along the north coast, including the Baltic and the coast of Ireland and Great Britain, and the other along the Mediterranean coast.

Another region extends along the Atlantic coast of North America from northeastern Canada through the United States, including the Gulf coast. It is this region that contains the most extensive marshes of North America and that is given the most consideration in this chapter. The south and east coast of South America is another region. The Pacific American region extends along the west coast of both North and South America. Australia and New Zealand comprise a region in the south Pacific. The eastern coast of Asia along with Japan completes the region in the Pacific basin.

The final region is really a special marsh environment that is restricted to high elevations in low-latitude areas that are otherwise dominated by mangroves. This situation exists in Florida and also in parts of Baja California.

14.2.4 Marsh characteristics

The physical environment of the marsh community is influenced by the degree to which it is protected from wave action, the tidal regime, the rate of sea-level rise, the topography of the coastal area, the sediment supply, and the nature of the substrate. The marsh environment is very similar to a river system (Fig. 14.8): (i) it is typically cut by meandering channels; (ii) the channels have point bars; (iii) there are natural levees along the channel banks; (iv) crevasse splay may form in breaches of the levees; and (v) there may be meander cutoffs and oxbow lakes. In addition, the marsh surface tends to be extremely flat and horizontal, just like a floodplain.
Because the zonation of vegetation is so closely tied to the elevation within the intertidal zone, it is practical to zone the marsh in a similar fashion. The most commonly used approach is simply to subdivide the marsh into the low marsh and the high marsh. The low marsh is that part of the marsh from the beginning of vegetation up to at least mean high tide. This is generally dominated by *Spartina alterniflora*. The high marsh extends from about the mean high tide up to the limit of tidal activity. This portion of the marsh is dominated by *Juncus roemerianus* and/or *Salicornia* depending on the overall setting.

There are, however, differences in marsh zonation and profiles depending upon the geographic location. For example, in New England (Fig. 14.9) the lower marsh includes both *Spartina alterniflora* and *S. patens*, with the upper marsh being composed of *Salicornia*, *Distichlis*, and a fringe of *Juncus*. An upland scrub forest typically borders the marsh itself. Further to the south in Georgia and Florida, the typical zonation is a relatively narrow lower marsh of *S. alterniflora* and an extensive high marsh dominated by *Juncus roemerianus* (Fig. 14.10).

### 14.2.5 Marsh classification

A convenient way to consider marsh development is through its maturity. This can most easily be done by considering the relative distribution of the low
and high marsh portions of the total vegetated environment (Fig. 14.11). Without using absolute ages, we can consider young, intermediate, and old marshes to reflect the progressive development of the marsh system, assuming that sea level has not changed substantially.

A young marsh is one that has mostly low marsh vegetation— that is, *Spartina alterniflora*— with perhaps only a fringe of high marsh around the outer edge (Fig. 14.11a). Tidal channels are abundant, providing good drainage and sediment supply. This stage of marsh development lasts until sufficient sediment has been delivered to the upper intertidal area to support a significant upper marsh community.

The intermediate stage of marsh development (Fig. 14.11b) has a near-equal distribution of high and low marsh. The tidal channels are fewer in number than in the young marsh. As the sediment continues to be delivered to the upper part of the intertidal zone, the marsh becomes more mature in its development. Much of the intertidal zone is covered by marsh vegetation, with only a few large tidal creeks interrupting an otherwise continuous marsh environment. Continued sediment accumulation will cause encroachment of land plants into the marsh as the estuary is reduced in overall size.

The end product of this scheme of succession of marsh development is complete infilling of the intertidal zone up to the level of near spring high tide. The marsh is essentially all high marsh, with only a fringe of low marsh, and tidal channels are widely spaced (Fig. 14.11c). Because marshes are sediment sinks, this is their eventual fate unless sea-level changes cause either enlargement of the estuary or abandonment at a high elevation. If this occurs, upland terrestrial vegetation will likely encroach into the highest part of the marsh.

### 14.2.6 Marsh sedimentation

We have noted that a marsh develops above the neap high tide level of the tidal flat, and that as the estuary fills with sediment, the marsh increases in its extent. In addition, there is an increase in the amount of high marsh as the marsh matures through
sediment accumulation with time. How does the marsh grow in this manner and what are the mechanisms for delivering sediment to the marsh or potential marsh environment?

There are various ways for sediment to reach the marsh environment but two are most prominent.

One is the settling lag–scour lag mechanism for building up the tidal flat, discussed in Chapter 13. In this manner the aggradation and progradation of the tidal flat will result in the sediment surface increasing in elevation and thereby providing appropriate conditions for marsh vegetation to colonize.
the tidal flat. This building up of the tidal flat includes both sand that is transported along the substrate as bedload, and mud that is transported by suspension. Each tidal cycle, especially those between mean tide range and spring tide range, brings sediment up to the level where marsh vegetation can become established. This type of accumulation encourages marsh expansion in response to sediment accumulation.

Once marsh vegetation has been established, the primary mode of sediment delivery is via suspended sediment. This sediment is typically mud and is provided from normal high tide flooding of the marsh during near spring conditions and also during storm conditions. Most estuaries have some mud in suspension during each tidal cycle. Each of the high tide phases of the tidal cycles provides a small to modest supply of mud to the marsh. The longer the slack water period at high tide, the more sediment will settle out of suspension.

Storms provide the highest rate of sediment influx into the marsh environment. They do two primary things to help in this activity: (i) the waves and currents generated during storms cause large amounts of fine sediment to be carried in suspension; and (ii) many storms create storm surge or storm tides in the estuaries where the marshes occur. As a consequence, there is a great deal of sediment made available to the marsh environment. This sediment is delivered in two primary ways: (i) through the simple flooding of the marsh by sediment-laden water; and (ii) by breaching of the natural levees and deposition of a crevasse splay type sediment deposit. Both of these mechanisms provide considerable sediment to the marsh surface and both may produce enough sediment during a given storm to temporarily bury the marsh grass (Fig. 14.12). These storm layers may be several tens of centimeters thick. Because marsh grass is very resilient, it will not die when buried but will grow up through the storm layer in weeks to months. This type of high sedimentation rate on the marsh surface results in the eventual elevation of the marsh, rising up to above normal intertidal levels. The result is that the marsh environment disappears in favor of the upland environment.

![Fig. 14.12 Overbank storm deposit (dashed line) covering marsh vegetation. Marshes must have sediment deposited on them to keep up with sea-level rise. Hurricanes and other severe storms flood the marsh with muddy water. The suspended mud is trapped by the marsh grass and some settles to the marsh surface.](image)

![Fig. 14.13 Marsh vegetation showing mud adhering to the blades of the grass and giving an indication of the high tide level. Rain will wash the mud off the grass and onto the underlying sediment surface.](image)

Marsh vegetation tends to be quite dense and provides an excellent sediment trap in two ways. First, the grass slows the flow of tidal waters to permit settling out of fine suspended sediment particles to the floor of the marsh. Second, considerable amounts of fine sediment adhere to the marsh grasses (Fig. 14.13) as the sediment-laden water flows past. Both of these mechanisms provide for accumulation of generally muddy sediment on the marsh. Additional sediment accumulates on the marsh surface as the result of suspension feeders living within the marsh grass producing pellets.
that accumulate within the marsh and contribute to its aggradation. In high latitudes, ice can also be important in transporting sediment onto the marsh surface. This is very common in the New England area of the United States and along parts of the Wadden Sea on the North Sea coast of Europe.

14.2.7 Sediments

The general nature of salt marsh sediment is quite unlike that of other coastal environments, except for the upper part of the intertidal flats. It is commonly a subequal mixture of mud and plant debris, with small amounts of shell material, sand-size terrigenous particles, and large plant fragments. Overall, marshes typically contain the finest sediments of all coastal environments. This is not always true, especially for those marshes developed on washover deposits or flood-tidal deltas associated with barriers; most of these are dominated by sand-size sediments. It is also possible for the particular area to have little mineral-mud sized sediment throughout, thereby making it impossible for mud to be a major component of marshes. The Florida peninsula falls into this category, because marshes there form on sand-dominated substrates.

The coastal marsh accumulates a distinctive combination of sediment, structures, geometry, and biogenic features. Although there is some nearly universal similarity among marsh deposits, there may be striking contrasts. Most marshes accumulate much plant debris and typically develop peat. Numerous benthic invertebrates may live within the marsh. Foremost are infaunal organisms, such as various worms, burrowing crabs, and snails.

As a consequence of all of these burrowing organisms, together with the effects of the roots of the marsh vegetation, many marshes show considerable bioturbation in the substrate (Fig. 14.14).

There are, however, many marshes that do accumulate well bedded marsh sediments (Fig. 14.15).

14.2.8 Sea level and marsh development

It should be apparent from the above discussions that the marsh environment is very delicately balanced with sea level. The entire marsh environment exists within much less than a meter of relief near high tide, except in places with extremely high tidal ranges. The high marsh environment is within only about 10–15 cm of relief. As sediment accumulates on the marsh, the elevation can reach above spring high tide. But this is without considering sea-level change; especially sea-level rise.

In Chapter 4 we discussed the current situation regarding sea-level change and noted, that globally, there is an annual rise of 1.5–2.0 mm. This is modest, but there are indications that the rate is increasing. If we consider the current rate, that means that a coastal salt marsh must accumulate 1.5–2.0 mm of
sediment each year in order to maintain its current elevation relative to sea level. The desired situation is at least a balance between sea-level rise and sediment accumulation. In most coastal settings, this is not a significant problem: such a balance exists. However, if predictions of increased rates of sea-level rise come true, then we will have potential problems, with marshes being drowned by the rise in sea level. There is considerable concern about this scenario becoming a major problem for marsh stability. Because marshes are among the most productive environments of all, this situation could cause major problems for the coastal ecosystem.

Catastrophic conditions currently exist in the extensive marsh environment associated with the Mississippi River delta (Fig. 14.16) on the coast of Louisiana. We can see from the chapters on sea level (Chapter 4) and on deltas (Chapter 16) that this area is experiencing a relative sea-level rise of almost 1 cm each year. While sea-level rise is not a major problem along many coastal environments, it is a very big problem for a marsh. Remember, most of the marsh exists within a very small range in elevation. On the Mississippi delta, an area of less than a meter spring tidal range, the range is only about 10–15 cm.

As a consequence, a sea-level rise of nearly a centimeter may cause much of the marsh to be drowned (Fig. 14.17). If the rate of sediment influx amounts to a centimeter per year, then there is a balance between the rate of sea-level rise and the rate of marsh accretion. In the case of the Mississippi delta area, human interference with the discharge of the river, coupled with the withdrawal of fluids under the delta in the extraction of petroleum has contributed significantly to the high rate of relative sea-level rise. As a consequence, the delta is subsiding and the amount of sediment supply from flooding of the river has been greatly reduced. The bottom line is that much of the coast of Louisiana is drowning. The state is currently losing about 65 km² each year to drowning of coastal salt marshes.

14.2.9 Marsh summary

Although marshes are very diverse in their characteristics and their dominant vegetation, they have many common factors. There are some generalizations that can be made about marshes. Most of these are related to the position along the intertidal zone (Fig. 14.18). It cannot be stressed enough how important the elevation is within the marsh portion of the intertidal zone.

Marshes of all types are among the most important and most productive of all modern environments. They have high concentrations of photosynthetic organisms and they serve as a nursery ground for many animals. Because of their delicate position
within the intertidal zone, their existence is threatened both by human activity and by sea-level rise.

### 14.3 Mangrove coasts

Stands of mangroves, called mangals, are tidal forest ecosystems that exist in protected marine through brackish water to freshwater conditions, as long as there is some tidal influence. Although there are various environmental conditions that influence the nature and extent of mangrove development, the most critical is air temperature: mangroves cannot tolerate a hard freeze. This limits them to lower latitudes. Mangrove mangals are commonly considered as the low-latitude equivalent of coastal marshes. This comparison is not strictly correct in that there are two distinct differences between the two environments: (i) marshes are populated by grasses and mangrove mangals are dominated by trees and shrubs; and (ii) mangroves occupy different positions within the intertidal zone than do marshes. As mentioned in the previous section, there are two areas where mangroves and salt marsh vegetation occur together: parts of Florida and the Baja California coast. In Florida, this is primarily because of temperature. It is warm enough along the shoreline for mangroves to survive because of the water temperature, but even a few hundred meters inland the temperatures are too cold and salt marshes replace them as the wetland vegetation.

In this discussion we consider how mangroves are distributed, both globally and within specific coastal systems. The zonation of mangroves and their influence on coastal processes, especially sediment transport and stability, is also covered.

#### 14.3.1 Mangrove distribution

**Global distribution**

More than 80 species of mangroves are recognized globally. The vast majority of these species are found in Southeast Asia and Oceania, in the Pacific and Indian oceans. This global distribution is controlled by winter temperature: hard freezes are not tolerated by these plants (Fig. 14.7). The Indo-Pacific Zone contains a tremendous variety of mangrove taxa, whereas the Atlantic Zone includes only ten species. As can be seen in the map of the mangrove regions, there is a distinct limitation to the low latitudes. In the United States, for example, only Florida, parts of the Gulf coast, and a little of southern California are home to mangroves.

**Local distribution**

Mangroves are restricted to protected waters where currents are sluggish and waves are small. These are typically associated with rather low-energy estuaries, lagoons, and backbarrier environments. The primary factor in this distribution is the nature of mangrove propagation. Their seeds drop from the trees and float with the currents until they come to rest at the shoreline. It is here that the propagules
Fig. 14.19 (a) Sketch of roots of *Rhizophora mangle*, the red mangrove, and (b) photograph of the species. These prop roots provide outstanding stability for the trees.

Fig. 14.20 (a) Sketch of roots of *Avicennia germinans*, the black mangrove, and (b) photograph of the species. These root systems are pneumatophores and are thought to be primarily for respiration of the mangroves.

root and develop into seedlings. In order for this to take place the seeds must maintain a position for some time. Swift currents and wave action would prohibit this from happening.

**Zonation**

There is a zonation of the prominent mangrove species that is related to their position within the intertidal zone, in a fashion similar to that of the grasses within the marsh environment. The most seaward species is the red mangrove, *Rhizophora mangle* (Fig. 14.19), which commonly extends to below the low tide mark within the low part of the intertidal zone. Above this in elevation but intermixed to some extent is the black mangrove, *Avicennia germinans* (Fig. 14.20). This species is within the intertidal zone. The third typical mangrove of North American mangals is *Laguncularia racemosa*, the white mangrove, which inhabits the highest part of the intertidal zone and may extend up to the supratidal area. The zonation across the intertidal zone in Florida is basically in this same order, with the red mangrove being lowest and the white the highest, just above spring tide (Fig. 14.21). Unlike in marshes, it is common for mangrove species to be somewhat intermixed. There is no sharp boundary between species as there is in the salt marshes.

Mangrove communities have been classified into five types depending on the morphology of the coast, tidal influence, and river influence (Fig. 14.22). This classification is built around three extremes, with river-dominated, tide-dominated, and interior mangals as end members. The differences are as follows. The river-dominated types are those where there is considerable runoff of sediment, nutrients, and organic matter. The tide-dominated mangals are those where bidirectional flux of tidal flow is prominent. The interior mangals are those that are organic-rich and in which sediment sinks.
Of the five types, the riverine, overwash, and fringe mangals are the most extensive. The fringing types occur along the protected open coasts of estuaries (Fig. 14.23) and other coastal bays. Overwash mangals develop on the landward side of barrier islands, where the low-lying overwash deposits accumulate. The riverine mangals line the lower parts of rivers, where they merge with the brackish waters of estuaries.

Basin mangals are generally limited in size and are located in depressions or small basins behind riverine or fringing mangals. They may be served by small tidal creeks. The hammock mangals are in inland tropical locations, where they are isolated by freshwater. The last type, scrub mangals, are located in areas where there is stress due to low water exchange, and therefore insufficient nutrient supply.

### 14.3.2 Mangroves and coastal processes

Mangroves have some influence on coastal processes because of their prominent size and dense network of root structures. Although most of their influence centers on physical processes, some biological processes may also be involved. Some of the mangrove species, especially those of the genus *Rhizophora*, have a significant influence on currents. The primary reason for this influence is the presence of the numerous, closely spaced, and resistant root structures that are possessed by nearly all mangrove species. In sites where open water currents may be as high as 100 cm s⁻¹, the currents within the dense mangrove root system may be as slow as 10% of those of the open water.

As the tide floods and ebbs, the prop roots and pneumatophores, along with substantial burrowing structures at the sediment surface, cause major increases in roughness and friction. This produces a significant decrease in the flow velocity of the tidal currents and thereby greatly affects sediment transport and accumulation. Additional roughness is caused by the algae, barnacles, oysters, and other organisms that may be growing on the root structures (Fig. 14.24). All of these factors have an effect on waves as well. They tend to attenuate wave energy and thereby minimize the role of waves in erosion of the mangrove substrate.

Mangroves also have a significant influence on the effect of storms along coastal environments. Because of their location in low-latitude regions, tropical storms and hurricanes are likely to impinge on mangrove coasts. These storms bring intense winds, large waves, and storm surge. Mangroves are able to withstand these forces very well. The relatively low trees with very dense root systems are adapted to resist such intense conditions. They also help to protect the sediment substrate in the mangal.

A good example of this situation is the passage of Hurricane Andrew across south Florida in August 1992 (Fig. 14.25). Many people are aware of the tremendous destruction that took place in the Miami area. Few people are aware of what happened on the other side of Florida, where mangrove mangals dominate the coastal zone. Here the mangroves
extend essentially to the open coast along this very low energy coast, where mean wave height is only about 15 cm. With large waves developing on a storm surge of 1.5–2.0 m and winds of about 150 km h\(^{-1}\) it would be expected that there would be major erosion on this undeveloped coast. Instead, the shoreline change was minimal: mangrove trees were broken off by the wind but the dense root systems prevented erosion. This is an excellent demonstration of how mangroves are adapted to withstand intense storms and prevent erosion of the coastline.

Another relationship between coastal processes and mangroves involves the dense network of exposed **prop roots** and **pneumatophores** that are associated with the red mangroves and the black mangroves respectively. These structures extend throughout the intertidal zone and below. Prop roots may be
meters high, generally related to tidal range. Pneumatophores are typically 20–30 cm above the sediment surface. The influence that they have on tidal currents has significant effects on sedimentation and erosion. The most obvious of these effects is the interference that the root structures present, causing a slowing of the currents. As a result, sediment that is entrained by these currents is allowed to come to rest due to the baffling effect of the roots. Additionally, the roots prevent sediment from being removed for the same reason. The net effect is that mangrove root systems are sediment traps.

Another aspect of the sediment trap effect of mangroves takes place primarily in the prop roots of the red mangroves. These structures are commonly at least a few centimeters in diameter, and they physically block suspended sediment, which adheres to the surface of these roots. This phenomenon can be important in muddy estuaries, especially those where tidal range is high (Fig. 14.26).

14.4 Summary

Dense vegetation on the intertidal zone represents one of the most important of all coastal environments. These diverse environments provide a tremendous level of productivity in the form of photosynthesis and as a food supply to many types of herbivores. These highly productive environments also provide a home and a place for reproduction for many organisms.

Another major impact of these environments is in the form of coastal protection. Both marshes and mangals are helpful in stabilizing sediment substrates and slowing erosion by waves and currents. This is especially the case for the mangrove mangals, which can withstand direct attack from hurricanes and experience limited erosion. These vegetated environments are also important sediment traps and substrate stabilizers.

Suggested reading