1 Introduction: what is covered in this coastal wetlands book?

Coastal wetlands, including tidal salt marshes and mangrove swamps, are environmentally stressful and variable habitats, and yet are teeming with life. Their biological productivity exceeds that of coral reefs and matches that of tropical rainforests. These wetlands provide resident plants and animals with shelter, food and continuous renewal of nutrients on each tidal cycle. These coastal wetlands are also vital to neighbouring ecological communities and have important values to humans, serving as natural carbon-capture systems, as sources of oceanic 'blue carbon', as filters of sediment or nutrient-loaded flood water and as buffers against storm tides and rising sea levels. Concern about the twentieth-century destruction of many wetlands in North America, Europe, Australia and New Zealand, and the degradation of wetlands worldwide led to the 1971 Ramsar Convention on Wetlands, held on the shore of the Caspian Sea in Iran (see Box 1.1 The Ramsar Convention). The Convention provides foundations for planning of 'wise use' for all wetlands; preservation of wetlands with international importance for ecology, biodiversity or hydrology; and co-operative protection of internationally shared species. Coupled with this landmark environmental agreement, the United Nations designated 2 February as 'World Wetlands Day', bracketing it with programmes to raise awareness of the strong link between global freshwater supplies and wetland resources. These two themes 'Water' and 'Wetlands' highlight global efforts to promote understanding that without coastal wetland conservation, there will not be enough water for sustainable development, human health and, ultimately, the survival of humankind.

This book is a university-level text that covers the major features of coastal salt marshes and mangrove swamps, introducing the reader to their ecology and geology, and showing how natural and man-made changes have impacted the wetlands on time scales of tens to thousands of years. Professionals can also make use of updated climate and sea level change perspectives provided in this multidisciplinary and globally covered book. Although the book takes a global approach (Figure 1.1), many examples are drawn from North American coastal wetlands (Chapter 7) because they are the best known and least altered by pressures of burgeoning coastal human populations. The book is unique in integrating geological and ecological case histories of changes in salt marshes on a global scale and in providing insight to various applications of coastal wetland studies, including laboratory and field experiments with salt marsh mesocosms.

Chapter 2 covers the physical aspects – geological, oceanic and climatic conditions – of coastal wetland formation, morphology and evolution, explaining what marshes do, and the influence of tides, storms and other climate impacts. This chapter defines the specific characteristics of coastal wetlands, which are all marked by some degree of tidal inundation, as opposed to other types of wetlands included in the Ramsar Convention, but not discussed in this book, such as inland salt lakes, freshwater marshlands and peat-moss bogs. The

Box 1.1 The Ramsar Convention: international wetlands conservation

These white storks nesting on the roof of this house in Croatia spent the winter in the Caspian Sea. To protect these iconic birds and other endangered migratory waterfowl, the Ramsar Convention on Wetlands Conservation was signed on 2 February, 1971, at the village of Ramsar on the south shore of the Caspian Sea. This convention is one of the oldest global intergovernmental agreements on the environment and provides a framework for coastal global wetland protection on several levels. The Convention's Mission is 'the conservation and wise use of all [types of] wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world'. The convention is now co-signed by over 150 nations on all continents – where about 300 coastal wetlands sites are identified for protection (Millennium Ecosystems Assessment, 2005). Details of the Convention, the Ramsar definitions of 'wetlands', the ratifying countries and their wetland preserves are given by Mitsch and Gosselink (2007). Maps of the Ramsar wetlands distributions and links to the United Nations initiative on world water resources co-operation can be found at http://www.ramsar.org/pdf/wwd/13/Leaflet.pdf.

Box Figure 1.1

importance of tides is explained further in Chapter 3, which describes how the frequency and depth of saltwater flooding controls the shoreline zonation and the plants that grow in tidal wetlands. This chapter also explains how plants interact with the marsh sediments to shape the development of the marshland and its tidal channels, and how marsh plants are uniquely adapted to the stresses of the constantly shifting marsh environment of variable salinity, oxygen and nutrients. Following these introductory sections, Chapter 4 explores the interaction between marshland animals and plants, the zonations of the animals and their adaptations to stressors. The general ecology of salt marshes and mangroves is given here, emphasizing their immense production and complicated energy flow. Chapter 5

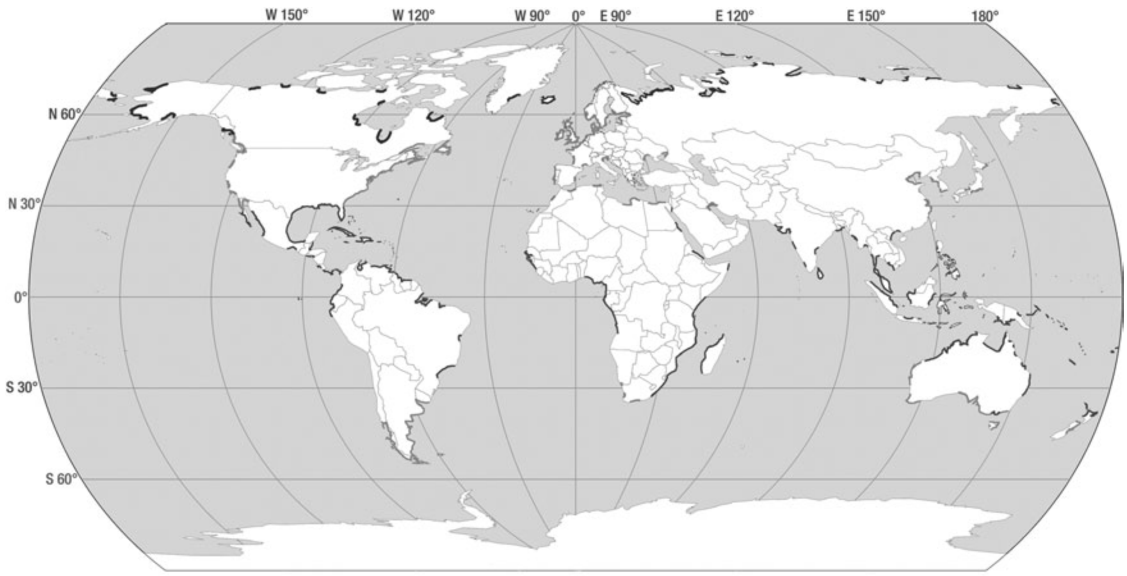

Figure 1.1 World map of coastal wetlands. Green marks areas of temperate climate salt marshes; blue indicates polar marshes; red shows areas of tropical mangroves. See also colour plates section.

introduces the kinds of natural catastrophes that change the wetlands, and it gives examples of the human interventions which affect the natural ocean–atmosphere-controlled systems – often endangering modern coastal communities.

The main focus of this book is the unique perspective it presents for coastal marshes on a global scale, including several (e.g. the Beaufort Sea Arctic coast of Canada, the Tigris–Euphrates Delta in Iraq, and The Gambia in tropical West Africa) that have rarely, if ever, been included in texts on coastal wetlands. Chapter 6 introduces the broad layout of coastal wetland distributions that is governed primarily by the nature of the coastline (including steepness, sediment supply and wave energy), the climate (hence latitudinal zonation and regional variations in marsh vegetation zones) and the ocean circulation, which redistributes heat from tropical to polar regions. The chapter also covers the principles of paleogeography and how this drives wetland biodiversity and is a basis for classifying salt marsh vegetation types for comparison on a global basis.

Following this general introductory outline of global-scale patterns that govern the distribution of all coastal wetlands, various specific features are then illustrated with a selection of regional examples. Chapter 7 presents examples from North America, where the largest and least altered salt marshes and coastal wetlands have survived since European colonization. Chapter 8 gives contrasting examples for the Pacific and Atlantic coasts of Central and South America, where the natural landscape is less conducive to development of extensive coastal wetlands outside of the tropical regions where mangroves dominate. In Chapter 9, we present information for selected marsh and mangrove areas in Africa, where pristine marshes are now being replaced by rapidly growing populations and industrialization. Chapter 10 provides contrasts from Europe and Asia, where little of the coastal wetland has survived centuries to millennia of modification by humans, who have reclaimed the land for agriculture and industrial uses. Chapter 11 covers the coastal marshes of Australia and New Zealand that have some unusual features because of their long geographical isolation and relatively recent colonization by Europeans.

The last section of the book introduces some innovative applications of coastal wetland studies. Chapter 12 describes the use of proxy data (such as microfossils, wood and peat layers) in sediment cores for monitoring earthquakes and the history of past earthquakes and tsunamis, as well as deciphering geological records of climate change, hurricanes and tropical cyclones. This chapter also outlines the importance of these coastal wetland archives for forecasting the potential impact of future climate warming, sea level changes and extreme weather events on coastal communities. Chapter 13 outlines the importance of sustaining salt marsh and mangrove-swamp biological diversity as storehouses of genetic information on physiological adaptations (ionomic databases) for coping with the growing problem of salt stress in modern farmlands which face impending shortages of freshwater for irrigation. Chapter 14 describes what can be learned from wetland mesocosms, which are used to examine, on a small scale, the impacts of various environmental threats and predicted problems. Chapter 15 concludes this book with a summary of the main themes discussed and some directions required for future research and protection of global coastal wetlands.

2 Physical aspects: geological, oceanic and climatic conditions

Key points

Coastal wetlands exist on the edge of all continents except Antarctica; saltwater wetlands are covered by seawater daily or periodically; tidal range and period (once or twice/day) control the amount of submergence and oxygen supply to marsh biota; tidal vegetation includes halophytic salt marshes, mangroves, seagrass beds and brackish water reed-swamps; salt marshes dominate cooler regions (>30° latitude) and mangroves occupy equatorial regions; local variations follow salt gradients measured as parts per mille or dimensionless psu; coastal wetlands develop in wave-sheltered sites: estuaries, deltas, glaciated fiords, barrier lagoons and tectonic down-faults; sediment supply must compensate for erosion by storm tides (cyclones, hurricanes, typhoons); space is also needed for growth on emerging or submerging coasts; global-warming impacts and human population growth are increasing risks of flooding and erosion.

2.1 What are coastal wetlands (saltwater wetlands)?

The Ramsar Convention defines *wetlands* as areas of marsh, fen or peatland with water which is static or flowing, fresh, brackish or salt, including areas of marine water not deeper than 6 m. Coastal wetlands, however, exist only at the interface of the land and sea, occurring on shorelines marked by some degree of tidal inundation, i.e. the tidal marshes and mangrove swamps, as classified in Mitsch and Gosselink (2007), who provide a dictionary of the many terms used to classify wetlands. All saltwater wetlands are characterized by the presence of brackish or saline water derived from the mixing of marine and fresh waters – including salt marshes, mangroves, seagrass beds and brackish water reed-swamps. Of this suite of intertidal habitats, the best known is the salt marsh, which is the most accessible saltwater wetland and the focus of many classical ecological studies which began over 100 years ago, starting in 1903 in North America (Ganong, 1903) and 1917 in Wales (Doody, 2008).

The strict definition of salt marsh is an intertidal area that is influenced largely by marine tidal cycles. The vertical range of a marsh is governed by the tides, which define the exposure time for the marsh vegetation occurring within different elevation ranges between mean sea level and the highest tides (see Box 2.1 Important tidal reference

Cambridge University Press
978-1-107-05601-5 - Coastal Wetlands of the World: Geology, Ecology, Distribution and Applications
David B. Scott, Jennifer Frail-Gauthier and Petra J . Mudie
Excerpt
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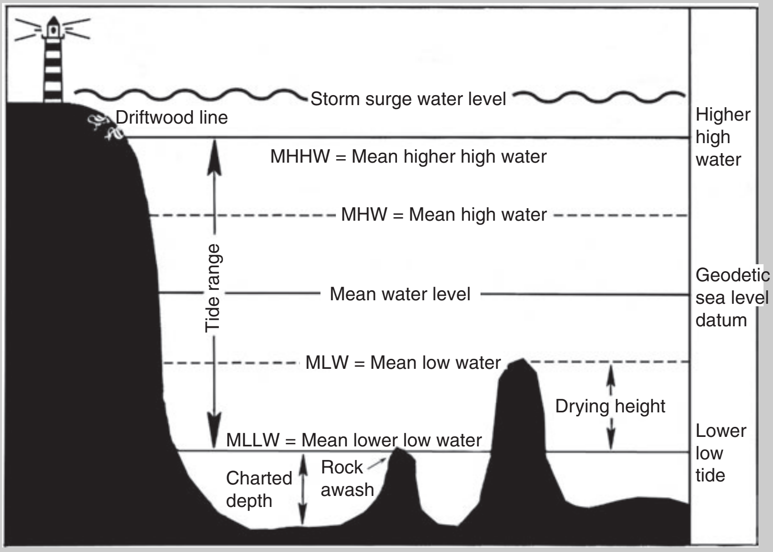
Box 2.1 **Important tidal reference points**

Everyone who has visited the seashore knows that seawater moves up and down with tides. However, the precise meaning of mean sea level (MSL) and its upper and lower limits are not so well known. The graph illustrates the main concepts used to set an official reference level (geodetic datum) for measuring long-term changes in mean seawater level. Note that for navigation (nautical/hydrographic) charts, a different reference (chart datum) is used, which is based on the lower low tide (= low spring tide) as its reference point. This provides maximum safety for boaters in shallow waters, but it requires adjustment if used for mapping of tide levels in coastal wetlands.



Box Figure 2.1 Diagram of Atlantic Geoscience Society, Halifax, Canada.

points). The tidal range is largely controlled by the periodicity and water levels of each marsh area caused by lunar tidal cycles. Ocean tides can range from 30 cm in semi-enclosed microtidal seas such as the Mediterranean, to large inlets or embayments that have macrotidal heights greater than the global average of 2–3 m. Prime examples of macrotidal regimes are found in eastern Canada: the Bay of Fundy in Nova Scotia (see Section 7.3.2), and Ungava Bay in northern Quebec, where the tides are semi-diurnal (two cycles a day) and tidal amplitude is about 16 m on a 12 h cycle. The opposite end of the tidal scale in North America includes the western Arctic Coast (0.5 m microtides) and areas such as Chesapeake Bay and the Gulf of Mexico, where relatively narrow entrances to the open water of the Atlantic Ocean restrict the range to less than 1 m just once a day (diurnal tides). Regardless of the range magnitude and periodicity, all saltwater marshes require tides to supply nutrients for estuarine and nearshore communities and to provide oxygen needed by the aquatic plants and invertebrate organisms living in the wetlands and channels.

2.2 Where are they found?

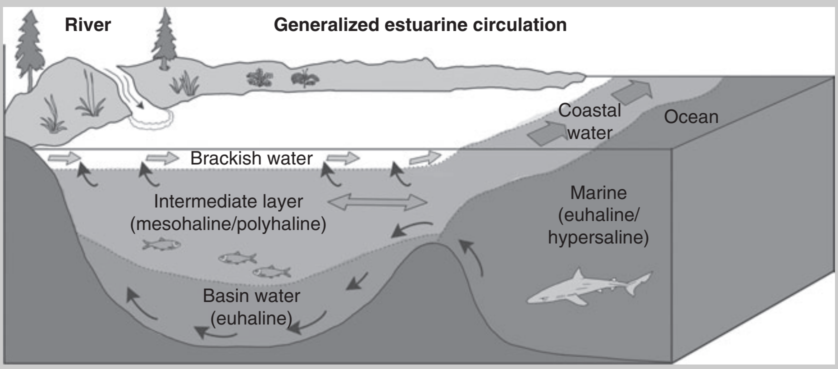
Overall, it is estimated that total area of coastal salt marshes in the world today is ~45 000 km^2 (Greenberg *et al.*, 2006), with about half of that (19 382 km^2) being in Canada and the USA (Mendelsohn and Mckee, 2000) and the other large areas being in China and Korea. The largest area (~50%) of tropical tidal wetlands (mangrove forests/swamps) is found in Southeast Asia, with other large areas being in South America and Africa (Valiela *et al.*, 2009). Mangroves are found in 114 countries, covering a total area of about 181 077 km^2 (Spalding *et al.*, 2010) – more than as much as the salt marshes. The long history of agricultural use of marshland in Eurasia means that there are few, if any, undisturbed coastal salt marshes remaining in Europe, North Africa, the Middle East or eastern Asia. In later sections we will present some case histories outlining the original features of these marshlands and the factors that have led to their present-day reduction to pockets or narrow bands along the coast. It should be noted that although our studies include the sparsely vegetated saltflats around the mean higher high water (spring tide) line, we do not cover salt marshes inland of the coastal zone; some of these inland salt marshes contain the same salt-tolerant (= halophytic) plants as the coastal wetlands, but they are not subject to tidal influences. Interested readers can consult Chapman's (1974) book on salt marshes and salt deserts of the world for the most comprehensive account of salt desert vegetation.

Latitudinal differences in climate are the primary factors governing the distribution of coastal wetlands on a global scale. Details of the importance of geographic location, both past and present, are given in Chapter 6, but here we introduce the broad principles. The vegetation of saltwater wetlands responds to climate by adapting to temperature and salinity fluctuations. Annual rainfall and summer temperatures largely determine the range of salinity within the coastal wetland. In cool temperate regions, soil and water salinities may range from 0 to 20‰ over one tidal cycle (for comparison, the salinity range of open ocean water is about 30−38‰ = 30–38 psu; Box 2.2). In contrast, hypersaline conditions can raise the water salinity to 50–60 psu in hot or cold arid regions. High atmospheric temperatures also cause excess evaporation, which increases salinity, and damages or kills plants less resistant to high salt content. However, most coastal wetland plants are adapted to this harsh and highly variable regime. The most widespread tidal marsh types are the temperate salt marshes, which are dominated by tall, salt-tolerant (halophytic) grasses and herbs with succulent stems or leaves (Figure 2.1). These wetlands predominantly occupy the latitudes 45° N and 45° S, which include the mildest of the global climatic regions. In polar regions, a low diversity of salt marsh grasses, sedges and annual herbs survive the short cool summer growing season and tolerate winter temperatures as low as –50 °C. At the other end of the spectrum are mangrove trees and shrubs, which are largely confined between the tropical latitudes from 25° N to S because they cannot tolerate winter temperatures below 16 °C or more than three continuous days of frost.

Some of the largest continents, which occur in both Northern and Southern Hemispheres, have the most extensive mangroves because they straddle the tropical

Box 2.2 Measuring and defining saltiness

Salinity in seawater and soil is measured by the amount of dissolved salt present relative to the weight of the water. During most of the twentieth century, salinity was usually reported as either the amount of salt in a kilogram of water (as mg/kg) or as parts per mille, denoted as ‰. This per mille notation, ‰, is most commonly used by geologists. However, today, by oceanographic convention, salinity is measured as the electrical conductivity of a sample relative to a standard solution of potassium chloride. This number is a ratio, so it has no units of dimension and is expressed as psu, meaning practical salinity unit. Estuaries are often classified by the salinity of the water, which depends on the amount of freshwater river discharge relative to seawater inflow, as depicted in the sketch below. Where river flow is high, the estuary is either vertically stratified, with brackish water (5—25 psu) at the surface and marine water (>30 psu below), or horizontally stratified with oligohaline (0.5—<5 psu) water at the inner end, mesohaline or polyhaline (>5–18 psu) water in the centre, and euhaline (>30—40 psu) water at the entrance.



Box Figure 2.2

latitudes: South America (mainly east coast), the Latin American Caribbean and Mexican coasts, Africa, India, Malaysia, Indonesia, Australia (east and west coasts above 10° S). Southern Australia has the most southerly mangroves at ~40° S. The Caribbean Islands, including Cuba, also have extensive marshes and some mangroves, but these are isolated from each other by expanses of ocean. Bermuda and the Japanese island of Okinawa have the most northerly mangroves. There is a small, isolated tidal marshland on the most northeastern part of Hokkaido Island (Japan) – this is the only salt marsh in either Hokkaido or the main island of Honshu.

2.3 How are salt marshes formed?

Salt marshes occur on low-energy shorelines in temperate and high latitudes. The survival of a salt marsh depends primarily on the rate of sea level rise and changes in the tidal range

Figure 2.1 Range of coastal wetland vegetation. Left: temperate region *Spartina* grass-dominated salt marsh, southeastern Canada (photo by P. J. Mudie). Right: tropical riverine mangrove *Rhizophora* in Belize (photo by Helen Pease).

relative to movement of the shoreline, which can be stable, submerging or emerging (Scott *et al*., 2001; McFadden *et al*., 2007; Barnhardt, 2009). Figure 2.2 illustrates the changes in shorelines that are expected to accompany long-term changes in sea level associated with glacial and interglacial cycles. When the sea level rise is sudden and large, as associated with tectonic subsidence, then the salt marshes will be rapidly drowned and buried by wave-transported or flood sediments, as discussed later in Chapter 12. Commonly, shorelines with the largest salt marshes consist of mudflats or sand flats (known also as tidal flats), which are sustained primarily by sediment deposits from inflowing rivers and streams. Where sediment supply is sufficient, then accommodation space for horizontal growth of the marsh along the shore becomes the determining factor for salt marsh survival and growth.

Salt marshes typically occur in wave-sheltered environments, such as estuaries, large fiords (= glaciated valleys) and protected bays, areas behind the embankments (levees) of delta tributary channels, and on the leeward side of barrier islands and sand spits (Doody, 2008; Figure 2.3). Less commonly, salt marshes occur on the sheltered shores of submerged tectonic down-faults, such as the Bay of Fundy and San Francisco Bay. On wave-exposed rocky or gravelly shorelines, salt marshes are usually restricted to a few deep-rooted plants near the high tide line, as commonly seen on the wave-swept, glaciated shores of southern Alaska. In the tropics and subtropics, the salt marshes are largely replaced by salt-tolerant mangrove trees (= mangal vegetation) that shade out the low-growing salt marsh herbs and small shrubs.

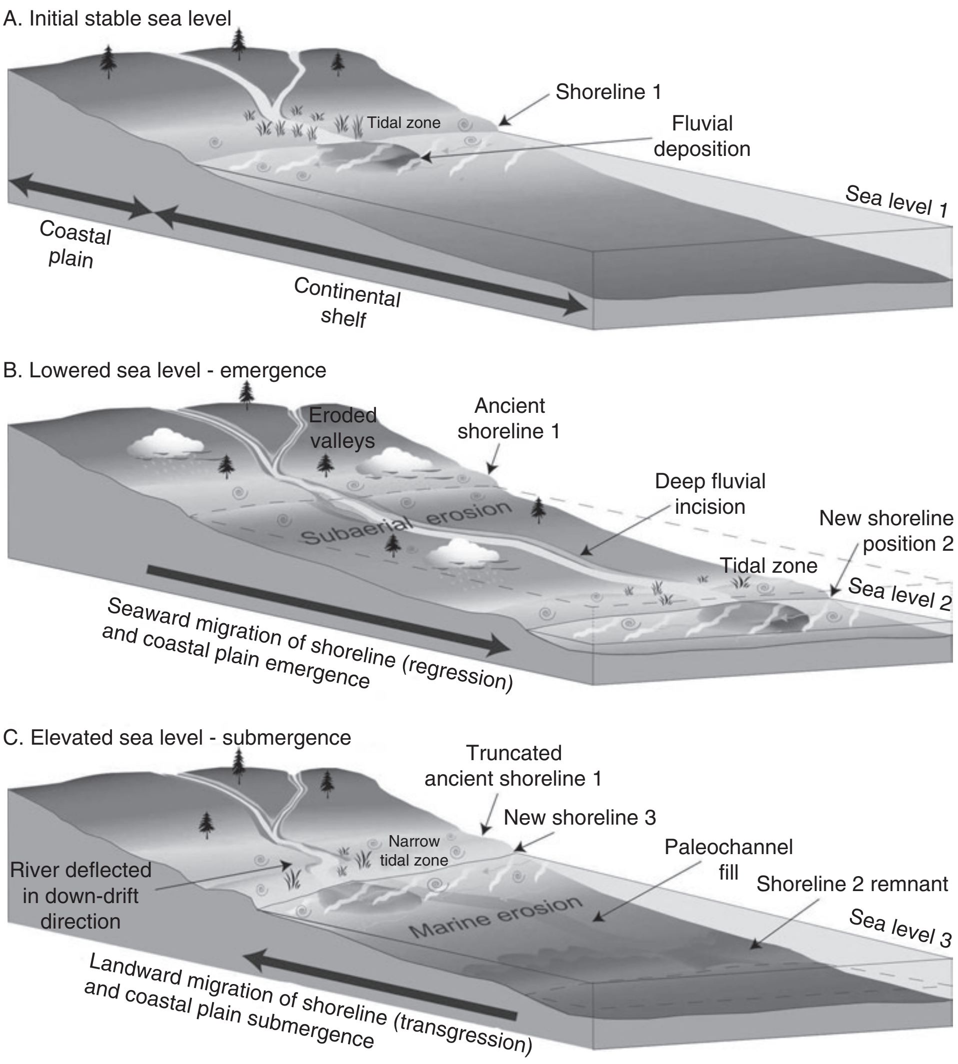


Figure 2.2 Emergent versus submergent coastline features. A: Salt marsh formed on a stable coastline with no major sea level change; B: Salt marsh retreats seaward on an emerging coastline associated with a falling sea level (= regression), leaving behind saline coastal plain soils and marine shell deposits that are eroded by rain and/or wind; C: Narrow salt marshes form on submerging shores where sea level is continually rising during a marine transgression (modified from Barnhardt, 2009, Fig. 3.8).

Most natural salt marshes occupy extensive areas of low coastal topography, which are preferred areas for human settlement and the reason many salt marshes have been degraded and lost. Deltaic marshes are associated with large rivers such as the Nile Delta, the Danube Delta in Romania and Ukraine, the Mississippi Delta in the USA, the Ganges and Mekong Deltas in Southeast Asia, and the Yangtze and Yellow Deltas in China. These large