

# Tidal flats

Coastal Ecosystems Series (Volume 5)

Sriyanie Miththapala





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# Introduction

Coastal ecosystems contribute to supporting human well-being because of their immense biological resources and the varied, often life-supporting, services they provide (WRI, 2001; UNISDR/UDNP, 2012).

Yet, as Duarte et al (2008) note, although there is an increase in scientific knowledge of many coastal ecosystems (including coral reefs, mangrove forests, seagrass meadows, and salt marshes), these ecosystems are vanishing fast. Coastal ecosystems across the world face a wide range of anthropogenic threats — overexploitation, habitat destruction and pollution. A dense and increasing human population centred on coastlines underlies many of these threats; the threats from unplanned coastal development and the overarching threat of climate change are considerable (WRI, 2001).

An understanding has now emerged that recognises these coastal ecosystems are interconnected and interdependent (Duarte et al., 2008). This understanding now directs management of these ecosystems.

Research on coastal ecosystems has been skewed towards the more 'charismatic' systems such as mangroves and coral reefs (Duarte et al., 2008). Further, public awareness and communication of scientific research are also biased towards the above-mentioned ecosystems (Duarte et al., 2008). Because effective management must recognise that a coastline comprises a mosaic of interconnected ecosystems, but manage them as a whole within a wider landscape (NSAP, 2009), research and awareness about the lesser known ecosystems is essential (Duarte et al., 2008).



A note is necessary at this point, with reference to Sri Lanka. Decades of research and understanding have led to a recent re-classification of Sri Lanka's coastal ecosystems, into seven inter-related categories: coastal marine zones, bays, beaches, dunes, estuaries, lagoons and tidal flats (NSAP, 2009).

It is now considered that 'mangroves, seagrasses, coral reefs and soft mud bottoms are habitats situated within these seven parent ecosystems' (NSAP, 2009). It should be noted clearly, that this terminology is applied to Sri Lanka where, 'excepting the coastal marine zones, [coastal ecosystems] are relatively small in size in their micro-tidal setting (difference between high and low tide never exceeds one metre)' (NSAP, 2009). In other countries, mangroves, coral reefs, seagrasses and salt marshes are referred to as coastal ecosystems (Duarte et al., 2009).

Although there has been previous research reported on salt marshes in Sri Lanka, it should be clarified that these areas are, in fact, now considered tidal flats. In the more landward areas of tidal flats, small, herbaceous, salt-tolerant plants grow (NSAP, 2009). Salt marshes are found along temperate shorelines and are considered to be the temperate counterparts of mangroves, which are not found in temperate areas (Chandrasekera, 1996; Survey Dept., 2007; Zedler, 1997 in litt. NSAP, 2009).

This booklet uses the NSAP classification and presents a general overview of tidal flats to create awareness about this little known ecosystem.

# What are tidal flats?

Tidal flats are found on coastlines and on the shores of lagoons and estuaries in intertidal areas (areas that are flooded at high tide and exposed at low tides) ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)). They are sandwiched between marine, freshwater and land environments and are found in areas where there are low slopes and regular flooding occurs (MacKinnon et al., 2012). Tidal flats are areas where sediments from river runoff, or inflow from tides, deposit mud or sand (<https://en.wikipedia.org/wiki/Mudflat>). If the energy of waves beating on these shores is low, then small-grained sediment — or mud — is deposited in the upper reaches of the area. In this instance, these areas are called mud flats ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)). When there is a higher energy in the waves and the sediment is coarse-grained and lighter, then sand is deposited in the lower reaches of the area. Then, these areas are called sand flats ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)). Tidal flats are always exposed to air during low tide.

There are three zones in a tidal flat: 1) the supratidal zone, located above high tide mark; 2) the intertidal zone, located between high and low tide marks; and 3) the subtidal zone which occurs below low tide mark and is rarely exposed ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)).

On the surface, the mud in a mud flat is usually brown and contains oxygen, because it is on the surface, but below the surface, the mud is black and lacks oxygen. Microorganisms that live in this oxygen-deficient (hypoxic) or oxygen-depleted (anoxic) mud can function without oxygen but they often release gases such as hydrogen sulphide, methane and/or ammonia, with the result that, often, mud flats can be smelly ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)).

## Comparison of mud flats and sand flats

|                        | Sand flats | Mud flats |
|------------------------|------------|-----------|
| Wave energy            | Low        | Low       |
| Grain size             | Med        | Fine      |
| Slope                  | Low        | Low       |
| Stability              | Med        | High      |
| Availability of oxygen | High       | Low       |

(Source: [www.uvm.edu/~mbeekey/WFB279/Soft\\_substrate.../Soft\\_substrate.ppt](http://www.uvm.edu/~mbeekey/WFB279/Soft_substrate.../Soft_substrate.ppt))

## Where are tidal flats found in the world?

Tidal flats are found along coastlines all over the world, in intertidal areas, where there are low-sloped shorelines, and where the energy of the beating waves is low, resulting in the accumulation of sediment ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)).

- The extent of tidal flats worldwide has not been mapped.
- The Wadden Sea, a UNESCO World Heritage Site, combining the Dutch Wadden Sea Conservation Area and the German Wadden Sea National Parks of Lower Saxony and Schleswig-Holstein, is the largest area of connected tidal flats in the world, extending over a length of some 500 km and an area of 10,000 km<sup>2</sup> (<http://whc.unesco.org/en/list/1314>).
- Along the entire west coast of Korea there is a stretch of tidal flat as much as 10 km wide, extending over 2850 km<sup>2</sup>, which are part of a tidal flats found along the southeastern banks of the Yellow Sea (<http://whc.unesco.org/en/tentativelists/5482/>).
- According to a survey carried out in 2002, there were 23,800 ha of tidal flats (formerly called salt marshes) in Sri Lanka, with extensive tracts from Mantai to Vankalai, on the northwestern coastline, and patches in sedimented areas of lagoons and estuaries such as Hambantota, Puttalam, Kalpitiya and Mundel (Dela, 2009).



# The biodiversity of tidal flats

Even though tidal flats — largely devoid of vegetation — initially look as if they had no life, they are teeming with organisms.

Lying on the surface there can be diatoms (algae that contain silica), which can produce their own food.

In the Wadden Sea, these diatoms can be densely packed on the surface of the mud, reaching densities of three million diatoms per square centimetre, comprising 40 different species (<http://www.lighthouse-foundation.org/index.php?id=71&L=1>).

The most important autotrophs<sup>1</sup> in tidal flats are microscopic blue-green organisms called cyanobacteria that often form a velvety mat — called 'lab lab' — visible on the surface of tidal flats (<http://www.cbbep.org/projects/molliebeattie/lifeonflats.htm>). These cyanobacteria were formerly called blue green algae, and are still commonly referred to in this way. They harness energy from the sun and, like plants, convert it into food that can be used by other organisms (<http://www.cbbep.org/projects/molliebeattie/lifeonflats.htm>). Seemingly innocuous, this mat of cyanobacteria plays a major role in shaping tidal flat communities, because it is in this mat that the food for the rest of the food web is produced.

Nearly four-fifths of the total food production in the Wadden Sea can be attributed to this layer of cyanobacteria (<http://www.ecomare.nl/en/ecomare-encyclopedie/animals-and-plants/plants/flora-on-tidal-flats/>).

Some single-celled organisms live deeper down in the mud, up to nearly half a metre deep, and can survive in these oxygen-deficient areas for several years.

In Sri Lanka, on the landward edges of tidal flats, are narrow strips of small, herbaceous, salt-tolerant plants such as glassworts (*Salicornia*) and seablites (*Suaeda*).

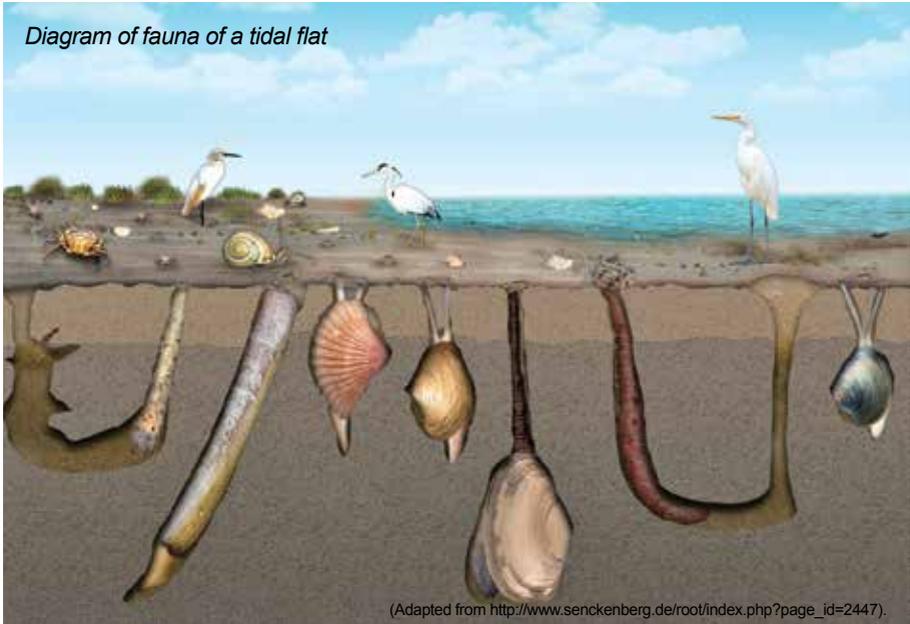
<sup>1</sup> **Autotrophs** (self-feeding from the Greek) are organisms which include higher plants, macro-algae, micro-algae and some bacteria, which are able to manufacture their own food from simple chemical compounds. They do so by the process of photosynthesis which involves harnessing the sun's energy through the green pigment chlorophyll that they possess and using this energy to combine carbon dioxide and water to form simple sugars.



Many of the fauna of tidal flats are benthic organisms, i.e., organisms that live on or in the bottom of aquatic environments. There are several groups of benthic organisms. Epibenthic organisms or **epifauna** live on the mud. Epifauna include crabs and other crustaceans, cockles, mussels and other shellfish ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)) — as well as wading birds and shore birds.

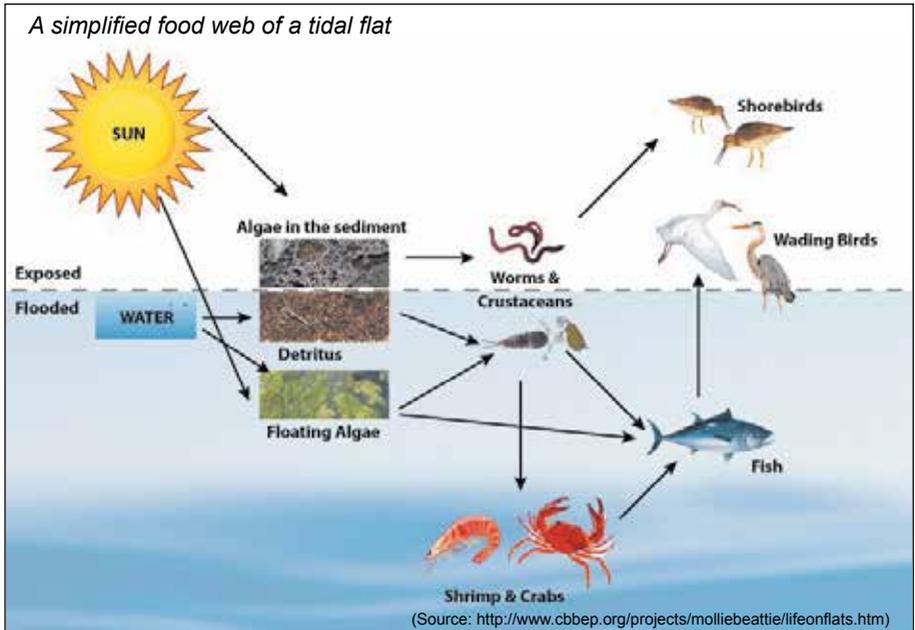
Yet another group of benthic animals include multicellular organisms which are less than 1 mm in length — such as tiny crustaceans, flatworms and roundworms — which live in the thin layer of water found between particles of mud. These organisms form a vital link in the food chain of tidal flats by feeding on microscopic organisms such as diatoms and bacteria, while they themselves serve as food for other organisms ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)).

**Infauna** burrow into the mud and are sometimes called ecosystem engineers because they alter the microenvironment around them ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)). Infauna in tidal flats include molluscs, worms, crustaceans, echinoderms<sup>2</sup> and acorn worms ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)). These organisms serve as food for wading birds.



<sup>2</sup> Sea stars, sea urchins and sea cucumbers belong to the group Echinodermata.

*A simplified food web of a tidal flat*



- In the Korean tidal flats, there may be as many as 100 different species of invertebrates in a given area and as many as 85,000 individual water birds in a given area on a given day (<http://www.docstoc.com/docs/122498471/Korean-Tidal-Flats-The-West-Pacific-Mirror-of-the-European-Wadden>).
- Many birds breed in temperate countries but migrate along specific pathways — called flyways — to feed, during the winter months, in the tropics. One of these migratory flyways is in Asia's eastern coastline — East Asian-Australasian Flyway. Twenty-four species of globally Threatened or Near Threatened water birds that use this Flyway are heavily dependent on the intertidal zone in the region (MacKinnon et al, 2012).
- The tidal flats of the Wadden Sea in Europe are visited by 10-12 million birds each year (Reise et al., 2010).
- Migrant birds arrive in Sri Lanka during late August and return in April each year mainly from the Central Asian Flyway (Kotagama, person.comm.; Kotagama and Ratnavira, 2010). Many of these birds use tidal flats along the coastline of the island, as stopovers or sites for feeding.

## Special adaptations of plants, animals and other organisms for survival in tidal flats

There are daily and seasonal fluctuations in the salinity of tidal flats. This salinity is highly variable because freshwater enters from rivers and watersheds, increasing in quantity during rainy periods, while salt water enters with the tides. Salinity increases when temperatures and evaporation increase. When evaporation is high, salinity can be greater than that of seawater, i.e., the water can be hypersaline.

In addition, the daily flooding and exposure leaves organisms living in tidal flats vulnerable to desiccation.

When the soil is periodically flooded, it becomes oxygen deficient.

Therefore, organisms living in tidal flats have to cope with daily changes in

- Salinity;
- Evaporation; and
- Dissolved oxygen in the soil.

### Adaptations to cope with changes in salinity

There are very few plants in tidal flats and these are found landwards. Plants adapt to changes in salinity by developing **xeromorphic** and **halophytic** characteristics. Xeromorphic characteristics — such as leathery, waxy leaves and sunken breathing pores or stomata, both of which minimise water loss — are adaptations that enable plants to conserve water. Another xeromorphic characteristic is the storage of water within leaves or stems, so that they become succulent. Yet another adaptation is the minimisation of the leaves themselves (Pennings and Bertness, 2001). Glassworts (such as *Salicornia*) and seablites (*Suaeda*) have succulent stems and reduced, scale-like leaves (<http://en.wikipedia.org/wiki/Salicornia>).

Halophytic characteristics — including salt glands that excrete salt — are adaptations that enable plants to live in salty environmental conditions (Kathiresan and Bingham, 2001).

Animals — such as fish — cope with changes in salinity by sensing the salinity in their surrounds and either eliminating excess fresh water or excess salt from blood (de Silva, person. comm). These fish are called **euryhaline** as they are able to tolerate a wide range of salinities ([http://oceanservice.noaa.gov/education/kits/estuaries/estuaries07\\_adaptations.html](http://oceanservice.noaa.gov/education/kits/estuaries/estuaries07_adaptations.html)).



Other animal species — such as many oysters and their relatives — adapt their behaviour to changing salinity. When salinity is low, they close their shells and stop feeding; and open their shells and feed only when the salinity increases; or they burrow into the mud ([http://oceanservice.noaa.gov/education/kits/estuaries/estuaries07\\_adaptations.html](http://oceanservice.noaa.gov/education/kits/estuaries/estuaries07_adaptations.html)) .

Another mechanism of coping — exhibited by some worms and molluscs — is to cover their bodies with slime. This behaviour protects them from changes in salinity (<http://suite101.com/article/species-adaptations-to-estuarine-conditions-a104317>).

### **Adaptations to withstand desiccation**

Avoiding desiccation when the tide is low, barnacles and bivalves (two-shelled molluscs) shut their shells keeping water inside and their breathing organs (gills) moist. Mudskippers can be seen completely exposed to the air at some times, while at other times, are completely submerged in water. They cope because their gills are housed within an enlarged cavity that contains both air and water. These gills can absorb oxygen from the air — functioning like a lung — if the air is moist (Kathiresan and Bingham, 2001).

Some plants cope exhibit xeromorphic characteristics which enable them to cope with desiccation. (See section above.)

### **Adaptations to cope with changes in oxygen content**

When the oxygen content in the water is low, many animals — such as fish — either move away to an area with more oxygen or move less, decreasing the need for oxygen (<http://www.hawaii.edu/gk-12/evo/erinb.streams.factors.htm>). Others — such as fiddler crabs — burrow into the mud, encapsulating themselves in a bubble of air that lasts till the period of flooding is over.

# What is the importance of tidal flats?

## Provisioning services

### Tidal flats provide goods for human use.

Tidal flats support a large number of invertebrates, such as mussels, bivalves and other molluscs, which are harvested as food. It is reported that food provision in tidal flats is 10-20 times higher than in deeper coastal waters.

The subtidal area of tidal flats are prime sites for filter feeders<sup>3</sup> such as mussels and oysters which are harvested for food (Reise et al., 2010).



<sup>3</sup> Filter feeders are animals that strain water and filter off suspended matter and food matter as a means of feeding.

- In the Puttalam district in northwestern Sri Lanka, the fry of Milkfish (*Chanos chanos*), commercially important, are collected in large numbers from tidal flats (IUCN 2011a).
- On the tidal flats of the Korean coast of the Yellow Sea about 50,000~90,000 tons of clams, more than 1,000 tons of mud octopus and 500 tons of polychaetes are caught annually (Jong-Geel Je et al., undated).

## Supporting services

### **Tidal flats are highly productive systems.**

Although species richness may be low in tidal flats, they are highly productive areas because they support a high biomass<sup>4</sup> of microorganisms (both autotrophic and heterotrophic<sup>5</sup>). These, in turn, support invertebrates, fish and ultimately large numbers of shore birds and wading birds ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)). The daily inflow of freshwater runoff and tidal influxes brings in nutrients that promote high levels of photosynthesis by algae found in these tidal flats.

### **Tidal flats enrich nutrients in coastal waters.**

The cyanobacteria in tidal flats have the capacity to trap atmospheric nitrogen into a form that other organisms found in these areas can use. Much of this escapes in the surrounds and the daily ebb and flow of the tides takes these nutrients into coastal waters (<http://www.cbbep.org/projects/molliebeattie/flatlinksvaluable.htm>).

### **Tidal flats support coastal biodiversity.**

While tidal flats may look bare, they support very large numbers of microorganisms — bacteria and cyanobacteria (in the form of mats) — that contribute to the diets of many invertebrates — such as commercially important shellfish (crabs, shrimps and molluscs) as well as fish. Therefore, there is usually an abundance of invertebrates in these coastal ecosystems and these serve as food for larger fish and a wealth of shore birds and water birds.

<sup>4</sup> The total mass of living matter within a given unit of habitat (<http://www.thefreedictionary.com/biomass>).

<sup>5</sup> Heterotrophs cannot manufacture their own food and feed on autotrophic organisms.



Along with mangroves and seagrasses, tidal flats provide refuges (for spawning and as nurseries) for many species of commercially important fish and crustaceans (Yusoff et al. 2006 in litt. MacKinnon et al, 2012).

- These species include the Banana prawn (*Fenneropenaeus merguensis*) and Tiger prawns (*Penaeus monodon*), as well as fish such as the Yellowfin bream (*Acanthopagrus australis*), important in recreational fishing in Australia (<http://www.wetlandinfo.derm.qld.gov.au/resources/static/pdf/profiles/p01719aa.pdf>).
- In tidal flats of Corpus Christi Bay, Texas, USA, the most common species are sheepshead minnows (*Cyprinodon variegatus*), various shrimp species and blue crab (*Portunus pelagicus*) are the most common invertebrates (CCBNEP, 1998).

Among the most important functions that tidal flats perform is to provide feeding grounds to migrant birds, most of which use tidal flats during stopovers while they are migrating ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)).

- The Seguwantivu tidal flat of the Puttalam Lagoon area has been declared one of the 111 Important Bird Areas of Sri Lanka, because of its importance for bird life, especially migrant birds. Other, numerous, similar tidal flats are found around the Lagoon. These also support a large number of migrant birds. Here, the Lesser Sand Plover (*Charadrius mongolus*) can be seen in flocks of 350-600 birds (IUCN, 2011a).
- About 300,000 migrating birds used to stop over annually in the Saemangeum tidal flat area of the Yellow Sea (<https://en.wikipedia.org/wiki/Mudflat>).
- The tidal flats of Corpus Christi Bay, Texas US, serve as a feeding ground for federally or state-listed threatened species such as Piping and Snowy Plovers (*Charadrius melodus*, *C. alexandrinus*), Reddish Egret (*Egretta rufescens*), White-tailed Hawk (*Buteo albicaudatus*), and Peregrine Falcon (*Falco peregrinus*) (CCBNEP, 1998).



## **Tidal flats and salt marshes are carbon sinks.**

Carbon sinks absorb (sequester) more carbon dioxide than they release into the atmosphere. In today's world, when the impacts of climate change can be dangerous, carbon sinks have become very important.

Studies in tidal flats have shown that there is rapid sequestration of carbon in tidal flats and much of the carbon lies below ground (Thom et al., 2001).

Given that tidal flats are home to microorganisms — such as cyanobacteria — that have high rates of primary production, it is not surprising that there is rapid carbon sequestration. However, the amount of carbon stored in tidal flats does not approximate those of salt marshes in temperate countries, which have very high rates (World Bank, IUCN, ESA and PWA, 2010).

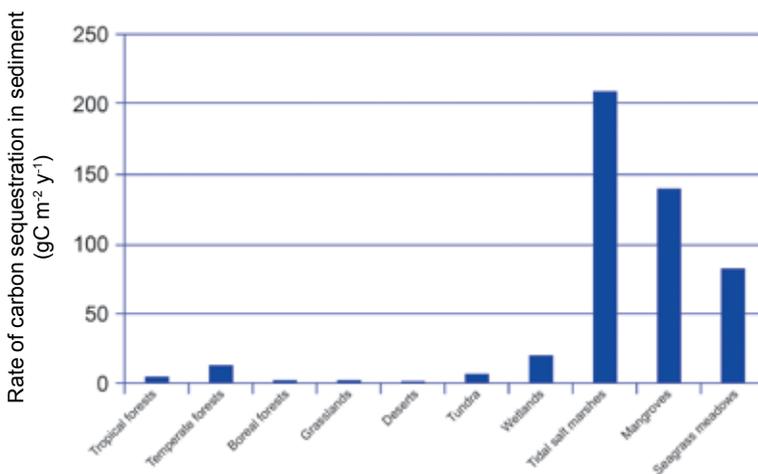
In addition, the sulphates produced by cyanobacteria in tidal flats prevent the production of methane (which is a far more potent greenhouse gas than carbon dioxide) and which is normally produced in wetlands that contain decaying material (Chmura, 2009).



It has been estimated that the amount of carbon sequestered in the sediments of many coastal ecosystems is as much as 50 times higher than carbon stored in land sinks (Conservation International in litt. <http://www.earthtimes.org/climate/blue-carbon/2021/>). In many of these ecosystems, these sediments have been building for many thousand years (World Bank, IUCN, ESA and PWA, 2010). Although some coastal ecosystems emit methane and others may be carbon sources (giving out more carbon that they absorb), coastal wetlands are net sinks for greenhouse gases (World Bank, IUCN, ESA and PWA, 2010).

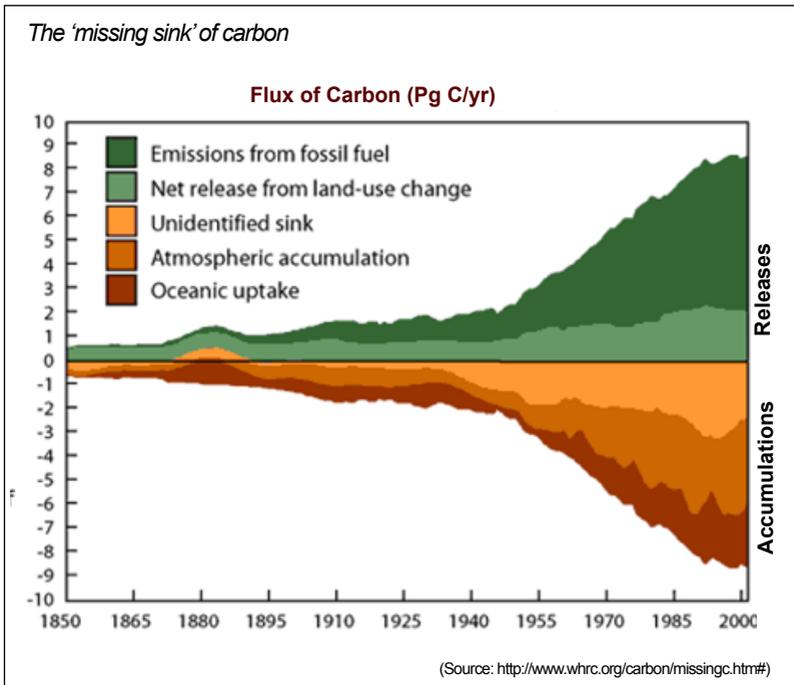
The dramatic difference between carbon absorption in coastal marine and terrestrial ecosystems is the capacity in coastal ecosystems for long-term carbon sequestration in their sediments.

*Comparison of carbon sequestration in among terrestrial and coastal ecosystems*



(Source: <http://www.earthtimes.org/climateblue-carbon2021> adapted from Lavooley and Grimsditch, 2009)

Each year, eight billion tons of carbon are emitted. About 30% of this is absorbed by oceans and 40% accumulates in the atmosphere, leaving yet another 30% unaccounted for. For about three decades, scientists have been trying to find this 'missing sink of carbon' (<http://www.enviroliteracy.org/article.php/1339.html>).



Studies have shown that tropical forests absorb carbon at a much higher rate than earlier believed, which could account for the 'missing' carbon. However, in recent years the topic of blue carbon — carbon stored in coastal, marine and aquatic carbon sinks — has gained prominence (World Bank, IUCN, ESA and PWA, 2010).

A study by Guarani et al. (2008) of the primary production in benthic organisms in intertidal ecosystems, suggests that there is considerable carbon storage that may account for the carbon which remains unaccounted for.

## Regulating services

### Tidal flats provide protection from floods.

Tidal flats, together with mangroves, lagoons and estuaries (collectively called coastal wetlands) serve as water retention basins, therefore, providing a natural flood control mechanism by soaking up and storing flood water (<http://www.dnr.state.oh.us/portals/9/PDF/pub397.pdf>). The soft mud in many of these ecosystems and habitats has enormous water-carrying capacity. After the peak of the flood is over, it slowly releases the stored water.

- It is estimated that an acre of wetland can usually store about three-acre feet of water, or 3,786 m<sup>3</sup> of water. An acre-foot is one acre of land, covered one foot deep in water. Three acre-feet is one acre, covered by three feet of water (<http://water.epa.gov/type/wetlands/outreach/upload/EconomicBenefits.pdf>).

### Tidal flats absorb storm energy.

Like other coastal wetlands, tidal flats also act as natural physical buffers absorbing some of the impact of storms.

### Tidal flats trap sediments and filter water.

'Wetlands have been called the kidneys of the landscape, because they can filter out sediments from surface water runoff and absorb surplus chemicals' (<http://www.dnr.state.oh.us/portals/9/PDF/pub397.pdf>).

When water enters a tidal flat, the speed of flow is retarded by the mud. The sediment in the water then settles to the floor of these ecosystems; the pollutants are adsorbed<sup>6</sup> on to mud particles. The net result is that excess nutrients and pollutants from inland runoff are trapped and effectively removed from the system (<http://water.epa.gov/type/wetlands/outreach/upload/EconomicBenefits.pdf>; ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)).

<sup>6</sup> Held as a thin film on the surface.

## **Tidal flats prevent erosion.**

By increasing sedimentation tidal flats bind the soil and prevent erosion (<http://www.ecomare.nl/en/ecomare-encyclopedie/animals-and-plants/plants/flora-on-tidal-flats/>).

The cyanobacteria on the surface of a mud flat secrete substances that make particles of mud stick, preventing erosion (<http://www.ecomare.nl/en/ecomare-encyclopedie/animals-and-plants/plants/flora-on-tidal-flats/>).

## **Cultural services**

Tidal flats, with their abundance of shore birds and water birds, are popular sites for bird watching (Laffoley and Grimsditch, 2009).

In many Asian countries, tidal flats were, and still are, areas for traditional fishing.

Historically, mullet caught in the mudflats of Muan County in the South Jeolla Province of South Korea was considered a delicacy and served to royalty between the 14<sup>th</sup> and early 20<sup>th</sup> centuries (Woo-young, 2013).

## **What are the threats to tidal flats?**

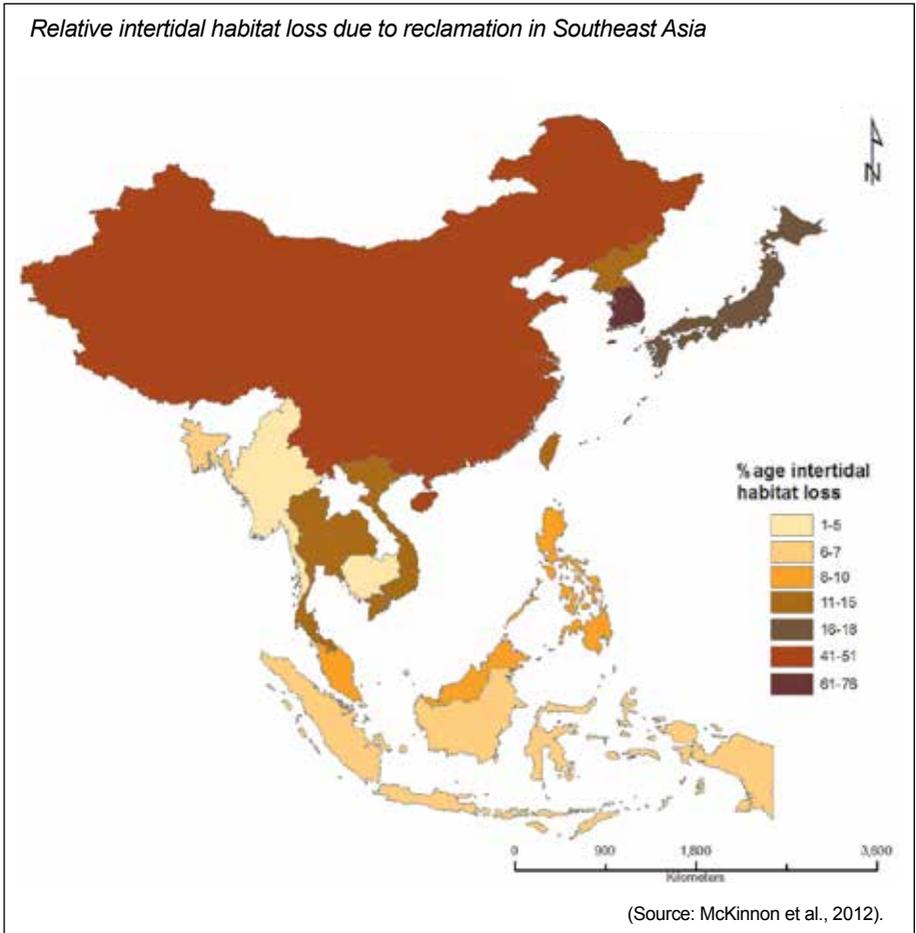
The underlying drivers of change in many ecosystems all over the world are increased human population and its associated pressures, such as unplanned and uncontrolled development (Duarte et al., 2008). This is especially true of the coastal zone, where, often, there is a denser concentration of human habitation and infrastructure (Duarte et al., 2008). In fact, one of the most populous coastal populations in the world is in the Bay of Bengal, which is home to around 450 million people, who are critically dependent on coastal and marine ecosystems for their livelihoods (BOBLME, 2012).

The coastal area of Sri Lanka represents about 24% of the island's land area and is home to 25% of Sri Lanka's population (CZMP, 2006).

## **Habitat destruction and fragmentation**

Among the direct drivers of coastal ecosystem loss, is habitat loss and fragmentation. Coastal ecosystems are threatened by increasing urbanisation and heavy pressure from human populations that tend to congregate near coastlines, with the result that they are often reclaimed, dredged and filled (Bromberg et al., 2009; Valiela et al., 2009).

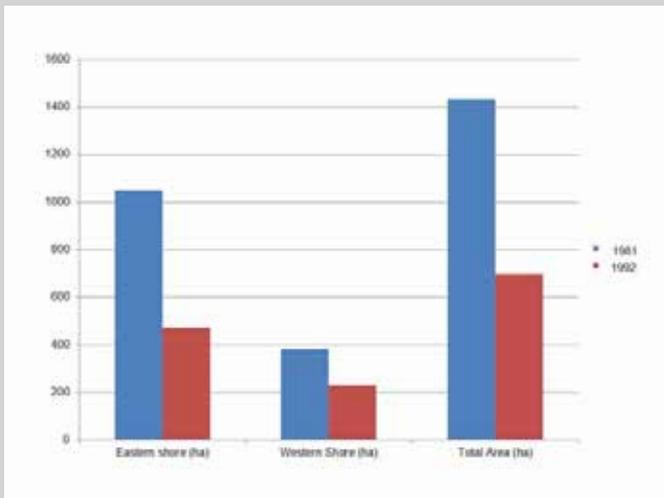
*Relative intertidal habitat loss due to reclamation in Southeast Asia*



Although the global rate of loss for tidal flats does not appear to have been calculated, it is known that tidal flat areas in Asia are popular as sites for aquaculture and other urban development (McKinnon et al., 2012).

Tidal flats are also reclaimed for salt production.

- Tidal flats in Japan are found on Kyushu and Okinawa islands, on the Pacific coast. Historically, they were important fishing grounds. The extent of tidal flats decreased by 35% in 33 years, between 1945 and 1978 (Akiko and Okamoto, 2008).
- During the past few decades, about 25% of the tidal flats in Korea have been lost (Jong-Geel Je et al., undated).
- About 1.19 million ha of coastal tidal flats in China have been reclaimed for urban development or mining. This represents 51% of all China's coastal wetlands (McKinnon et al., 2012).
- Land reclamation in the Wadden Sea, has decreased the extent of tidal flats to one-third of the extent compared to 1500 AD (Reise et al., 2010).
- In Sri Lanka, there has been a 20% reduction in the extent of tidal flats<sup>7</sup> over a period of 16 years (CZMP, 2003 in litt. Joseph, 2003).
- In the Puttalam District on the northwestern coastline of Sri Lanka, more than 85% of the extent of tidal flats<sup>7</sup> was lost between 1986 (3,461 ha) and 2002 (499 ha) (Joseph, 2003). The following graph shows the extent of loss within a decade, around the Puttalam Lagoon (Pathirana et al., 2008).



- In Sri Lanka, major threats to intertidal areas in the Puttalam lagoon, in the northwestern coastline, are encroachment for housing, habitat destruction clearing for salt production, shrimp culture and agricultural expansion (IUCN, 2011a).

<sup>7</sup> These were listed formerly as salt marshes.

A hugely detrimental consequence of the loss of tidal flats is the threat to migratory water birds. Several studies have shown a clear link between the loss of these habitats and the decline of water bird populations.

Saemangeum, a mud flat at the mouths of the Dongjin and Mangyeong Rivers on the coast of the Yellow Sea, South Korea, was an important stop over for some over 200,000 migratory birds including the Endangered Spotted Greenshank (*Tringa guttifer*) and the Critically Endangered Spoon-billed Sandpiper (*Eurynorhynchus pygmeus*). The estuary was dammed by the Saemangeum seawall project in 2006 and completed in 2010. The reclaimed land is expected to be used for development and agriculture. Immediately after the estuary was closed, millions of molluscs living in the mud flats died and there was a dramatic decline in the number of visiting shore birds. Bird counts revealed that there were population declines in 19 species of shore birds visiting the mudflats (McKinnon et al., 2012).

## Pollution:

Tidal flats, like the other habitats of the coastal mosaic to which they belong, are also affected by point-source pollution<sup>8</sup> and non point-source pollution<sup>9</sup>.

Although they are known to trap and bury various pollutants in their sediments, these coastal ecosystems are vulnerable to changes in the dynamics of the natural processes that form them ([http://www.sms.si.edu/irlspec/Tidal\\_Flats.htm](http://www.sms.si.edu/irlspec/Tidal_Flats.htm)). Changes could result in the release of the buried pollutants.

**Point-source pollution** includes effluents from shrimp farms — such as artificial feeds with chemical additives (including chlorine) and insecticides (organochlorides — which persist in the environment), as well as antibiotics that are added to prevent shrimp disease. These effluents also carry suspended solids. In Sri Lanka, most shrimp farms have no effective effluent treatment procedures and discharge their usually untreated effluent into surrounding land and/or downstream waterways (IUCN, 2011a).

In tidal flats on the Nagaipattinam and Karaikal, on the western coast of India, there is an average of 45 species and 400 individual birds per tidal flat, but only nine species and 80 individuals in similar-sized areas next to shrimp farms (Nagarajan and Krishinamoorthy, 2006).

<sup>8</sup> Point source pollution is a contamination that occurs at a particular location, immediately at or near the source of the pollution.

<sup>9</sup> Non-point source pollution, as its name implies, enters these ecosystems not from a single or a couple of clearly-defined locations, but in a diffuse way through an infinity of small sources spatially distributed in the environment.



**Non-point source pollution** enters in a diffuse way through many sources distributed in the environment, not from one or two clearly-defined locations. Agrochemicals (pesticides, fertilisers, herbicides and fungicides), as well as waste from livestock, domestic and urban waste (for example, sewage and plastics), and industrial runoff (that may include heavy metals) are all examples of non-point source pollution (Loage and Corwin, 2005).

## Hydrological alteration

Both freshwater coming in and tides flushing salt water in and out are critical for the maintenance of tidal flats. The microbial and other fauna of tidal flats are adapted to flooding, as well as fluctuating salinities and oxygen. Changes in the natural ebb and flow in intertidal coastal ecosystems have profound effects on these coastal ecosystems and are common worldwide (Kennish, 2002).

## Changes to fresh water inflows

The most common change in fresh water inflows is through dams, channels and diversions upstream. These significantly affect the quantity and timing of water reaching coastal ecosystems downstream. Dams across rivers regulate water flows: during floods, flood water is routed through reservoirs, so that very high flows are prevented from flowing into estuaries; in contrast, during dry seasons, the water is released into rivers, increasing flows. Either way, the natural seasonal changes in salinity are altered.

If freshwater inflow decreases, then salt-water tolerant species proliferate, changing species composition. The converse occurs when freshwater inflow increases — freshwater species thrive.

As a consequence of upstream damming, sediments along the Haihe River in China have reduced from an average of  $0.75 \text{ kg/m}^3$  to  $0.1 \text{ kg/m}^3$ . The reduction in the amount of sediments reaching the coast has resulted in a loss of accretion<sup>10</sup> and the eastern coastline in China is now eroding at a rate of 5 m per year (McKinnon et al., 2012).

<sup>10</sup> The process of growth or increase, typically by the gradual accumulation of additional layers or matter.

## Changes to tidal flows

Just as freshwater inflows are critical in intertidal coastal ecosystems, the ebb and flow of tides are also vital to the well-being of these systems. When the mouths of lagoons or estuaries through which the tides ebb and flow are closed by the development of structures that impede this tidal movement in and out, then vast changes occur in the ecosystems and habitats found within such lagoons and estuaries — such as tidal flats and mangroves.

When the tidal influence is reduced, flora and fauna more adapted to freshwater proliferate, changing species composition (Bromberg et al., 2009). Coastal infrastructure development — the construction of dykes, piers, ramps, groynes, ports, harbours and jetties — often impedes tidal flows in intertidal coastal ecosystems.

The reclaiming of land by filling lagoons also reduces the tidal flow in and out of the lagoon with consequent impacts on both sedimentation and water quality.

In Bangladesh 1.2 million hectares of land were ‘protected’ with embankments from inundation at high tide and thus converting the intertidal area and reclaiming it for permanent settlement and agriculture. The reduction of tidal volumes has had serious, unanticipated consequences that have resulted in drainage congestion over a significant area. (CEIP, 2013).

## Changes in sedimentation

Intertidal coastal ecosystems receive sediments carried in by rivers and freshwater runoff (Samarakoon and Samarawickrama, 2012).

Tidal flats are dynamic ecosystems, which rely on a fine balance of natural accretion and erosion. These processes are affected when sedimentation increases or decreases. The flow from inland of sediments stabilises the fringes of coastal wetlands, strengthening substrates for salt marshes, tidal flats and mangroves (Olsen et al., undated).

Anthropogenic activities can either increase or decrease the natural sediment loads in intertidal coastal ecosystems.

A study of the eastern coast of the USA showed that decreasing sediment loads resulting from damming and river dredging, triggered erosion in tidal flats (Mariottia and Fagherazzia, 2013).

Mining for river sand is a major threat in Asian countries. In the normal dynamics of beach structure and function, sand is always lost offshore, but is replaced continually by sediment that is brought from rivers. When rivers are mined, then the amount of sand being washed to coastal stretches reduces, resulting in coastal erosion (CZMP, 2006).

The Coastal Zone Management Plan for Sri Lanka (2006) states that 'overall sand mining in rivers at current rates to meet the requirements of the construction industry is clearly unsustainable, and could lead to . . . a further decrease in the supply of sand to the coast in time to come.

It notes that there has been a dramatic increase in river sand mining in the Deduru Oya, Maha Oya Kelani Ganga, Kalu Ganga, Gin Ganga and Nilwala Ganga (in the northwestern, western and southern provinces of the island) — from 1.2 million m<sup>3</sup> in 1984 to 5.5 million m<sup>3</sup> in 2001 (CZMP, 2006).



When sedimentation decreases, the consequence is erosion. Coastal wetlands such as tidal flats, salt marshes and mangroves that require replenishment of sediments start eroding at the edges, in turn, affecting the flora and fauna that live in them (Olsen et al., undated).

In Sri Lanka, the main source of increased sedimentation is from earthworks, where large areas are cleared of protective vegetation for infrastructure and road development, as well as housing, and bare sloping surfaces are left open to the elements (Ranjit Galappatti, person. comm.). With the first rains, massive quantities of mud are washed into rivers and carried into estuaries and lagoons (IUCN, 2011b). Activities — such as building construction and road development — are particularly prone to the release of large quantities of sediment into the waterways, as well as increasing impermeable surfaces that enhance overland flow of water and sediment into the coastal zone following rainfall. Another major source of increased sedimentation is deforestation in catchment areas, where, again, tracts of bare earth are left to the elements, unprotected (IUCN, 2011b).

## Overexploitation

Tidal flats are areas that can be reached easily during low tide and, therefore, the potential for exploiting resources is high.

- Peanut worms (*Sipunculus nudus*) are harvested by local communities from tidal flats in the northeastern coast of Vietnam for use as a valued food in domestic and international markets. Although this harvest brings in considerable income for local communities, the yield and size of worms collected is decreasing over time (Nguyen et al., 2007).
- The European flat oyster (*Ostrea edulis*) has now nearly disappeared from the tidal flats of the Wadden Sea, as a result of a combination of factors, including overexploitation (Reise et al., 2010).

## Invasive alien species

There are few data on alien invasions in Asian tidal flats, but research in temperate countries has shown that invasive alien species (IAS) have changed the species composition of benthic organisms in tidal flats (Reise et al., 2010).

It is reported that about 60 IAS have been accidentally introduced into the Wadden Sea. The Pacific oyster (*Crassostrea gigas*) has spread considerably among mussel beds and appears to benefit from warming temperatures. Near the low-tide line the epifauna are dominated by IAS and the species composition has changed (Reise et al., 2010).

## Climate change

Climate change is an over-arching and often dangerous consequence of anthropogenic activities — notably excessive greenhouse gas emissions (mainly carbon dioxide and methane) from industry, transport, agriculture and other economic sectors. These emissions have warmed the Earth, 30°C warmer than it should have been (WMO, 2013). The temperature of the Earth has risen by 0.6°C in the 20<sup>th</sup> century (WMO, 2013). The warmest year ever to be recorded is estimated to have been 2010 and the decade of 2001-2010 was the warmest on record (WMO, 2013).

Currently, there are 390.9 parts per million of carbon dioxide (CO<sub>2</sub>) and 1,813 parts per billion of methane, in the atmosphere, a 140% and or 259% increase respectively, of pre-industrial levels (WMO, 2013).

As a consequence of global warming, it is predicted that there will be

- *Sea level rise*: associated with the melting of polar and continental glaciers, as well as the expansion of water with increasing temperature (<http://www.grida.no/publications/planetin-peril/page/1321.aspx>). The rate of mean sea level rise in the decade of 2001-2010 was about 3.2 mm per year, double that of the 20<sup>th</sup> century rise of 1.6 mm per year (WMO, 2013).

Tidal flats are known to accrete when sea levels rise, but it has been shown that there is a threshold of sea level rise, beyond which tidal flats will erode (Mariottia and Fagherazzia, 2013).

In addition, inundation as a result of sea-level rise could simply convert tidal flats into areas that are submerged all the time.

On developed coastlines, ecosystems such as tidal flats are subject to a 'coastal squeeze' as a result of already rising sea levels on the seaward side, and development on the landward side (Chmura, 2009).

- It has been predicted that sea level rise will result in a loss of 8,000 to 10,000 ha of intertidal flats in England between 1993 and 2013 (<http://strategy.sebiodiversity.org.uk/pages/coastal-mudflats.html>).
- A modelling study of tidal flats in southern San Francisco Bay, USA shows that more than half of the current tidal flats could be lost by 2100 at the current rate of sea-level rise, while the Bolivar flats of Texas will completely disappear (Galbraith et al., 2005).

- *Changes in temperature*: Increases in temperatures could increase desiccation and exceed the normal adaptive capacities of fauna and flora of tidal flats. This is likely to have impacts on species composition of both flora and fauna.
- *Changes in rainfall patterns*: This is likely to increase freshwater inflows and increase sedimentation. The increase of freshwater will change the existing composition of species, favouring species that thrive in less saline water, in turn affecting the species that feed on them. Increased sedimentation will have the impacts discussed under the section on Changes in sedimentation.
- *Increase in extreme weather events* such as cyclones and floods ([http://unfccc.int/files/press/backgrounders/application/pdf/press\\_factsh\\_science.pdf](http://unfccc.int/files/press/backgrounders/application/pdf/press_factsh_science.pdf)): Although tidal flats serve to buffer the impacts of storm surges, cyclones and floods, they are affected by these events, although these effects are largely transient (Ranjit Galappatti, person.comm.). The major impact is likely to be an inter-annual alteration in sedimentation (Bromberg et al., 2009).

## **Lack of knowledge about these ecosystems**

One of the major indirect threats to tidal flats is the lack of knowledge — both scientific and public — about these ecosystems. ‘The public image of tidal flats as barren wastelands contributing nothing aesthetically, economically, or ecologically’ (CCBNP, 1998). The public is not aware of the important services these ecosystems provide, nor is it aware that the ‘barren’ mud is teeming with organisms.

In the scientific world too, there is a dearth of research related to tidal flats as compared to other coastal ecosystems such as mangroves and coral reefs (Duarte et al., 2008).

A study by Duarte et al. (2008), examined published articles in the media — both as general interest articles and reports of scientific publications — and found that although research related to coastal ecosystems has doubled in the last decade, it still compares unfavourably with research on terrestrial ecosystems (1/3<sup>rd</sup> of the research carried out on terrestrial ecosystems) (Duarte et al., 2008).

## At a glance: services provided by and threats to tidal flats

| Ecosystem service               | Description   | Threats  |
|---------------------------------|---|--|
| Provisioning services (Goods)   |   |  |
| Sustaining coastal fisheries    | Mussels, bivalves and other molluscs, found in tidal flats are harvested as food.   | Habitat destruction; pollution; hydrological alteration; changes in sedimentation; some over-exploitation; invasive alien species; climate change and lack of knowledge.   |
| Supporting services             |   |  |
| Primary production              | Tidal flats are highly productive, supporting a high biomass of microorganisms, in turn, supporting invertebrates, fish and, ultimately large numbers of shore birds and wading birds.  | Point and non-point source pollution.  |
| Enriching coastal nutrients     | Cyanobacteria in tidal flats have the capacity to trap atmospheric nitrogen into a form that other organisms found in these areas can use. Much of this escapes in the surrounds and the daily ebb and flow of the tides takes these nutrients into coastal waters.               | Point and non-point source pollution; hydrological alteration.   |
| Supporting coastal biodiversity | Tidal flats support very large numbers of microorganisms that contribute to the diets of many species. Therefore, there is usually an abundance of invertebrates in these coastal ecosystems and these serve as food for larger fish and a wealth of shore birds and water birds. | Changes in sedimentation: This changes the composition of species and could result in a cascade of changes.<br><br>Hydrologic alteration triggers change in sedimentation.<br><br>Climate change will exacerbate these existing threats. |

| Ecosystem service  | Description  | Threats   |
|--|--|---|
| <b>Regulating services</b>   |  |   |
| Absorbing storm energy and providing flood protection and drainage | <p>Tidal flats act as natural physical buffers, absorbing some of the impact of storms.</p> <p>Tidal flats serve as water retention basins, soaking up and storing flood water.</p>  | <p>Habitat destruction: This loss leaves the coast vulnerable to the full force of physical impact of weather events.</p> <p>Climate change will exacerbate these existing threats.</p> |
| Trapping sediments and filtering water                             | Tidal flats serve as mud and pollutant 'catchers'.   | Changes in sedimentation and hydrologic alteration.   |
| Preventing erosion   | By increasing sedimentation, tidal flats bind the soil and contribute to accretion and thereby help prevent erosion.   | Same as above.  |
| Functioning as carbon sinks  | <p>The sulphates produced by cyanobacteria in tidal flats prevent the production of methane.</p> <p>Studies in tidal flats have shown that there is rapid sequestration of carbon in tidal flats and much of the carbon lies below ground.</p> | Habitat loss.   |
| <b>Cultural services</b>   |  |   |
| Important for recreation   | <p>Tidal flats are popular for recreational fishing.</p> <p>Tidal flats are important sites for bird watching.</p>   | All of the above threats.   |

References as in text.

## What is being done to conserve tidal flats?

In Sri Lanka, very little is being done to conserve tidal flats *per se*, as individual ecosystems. This is evident in the dearth of scientific papers specific to these ecosystems, although much research has been carried out on other coastal habitats such as mangroves, and the status of coral reefs in the Indian Ocean was reviewed after the Indian Ocean tsunami of 2004 (Wilkinson et al., 2006).

Although threats to coastal ecosystems were already being addressed by the Coast Conservation and Coastal Resources Management Department, under the aegis of various coastal zone management plans, the tsunami of 2004 served to highlight these problems and much more effort and financial investments were focused subsequently on the plight of charismatic coastal ecosystems such as mangroves and coral reefs. With this general focus came the understanding that '*all seven classes of coastal ecosystems are interconnected*' (NSAP, 2009). There is hope for ecosystems such as tidal flats because of this shift in thinking.



## Increasing general awareness

Duarte et al. (2008) recommend that there is a switch from conventional knowledge-based products to effective communication-based products as shown in the following figure. They note that 'only increased public understanding can ultimately inform and motivate effective management of these ecologically important coastal ecosystems'.



Increasing general awareness about the value of tidal flats for human well-being is very important all over the world, but is particularly necessary in Sri Lanka, where there has been a recent re-classification of coastal ecosystems.

This booklet is an attempt to redress the lack of general knowledge about tidal flats and created awareness about their importance and the current threats facing these little known ecosystems.

## **Shifting to a holistic approach to management**

A holistic approach to the management of coastal ecosystems, although difficult, is the ideal, and must be the goal towards which all coastal managers work. Holistic management has two elements that must be included: ensuring all geographic areas that have a bearing on the coastal stretch be managed and that all relevant players are included in the process of planning and management.

## **Shifting to a landscape approach**

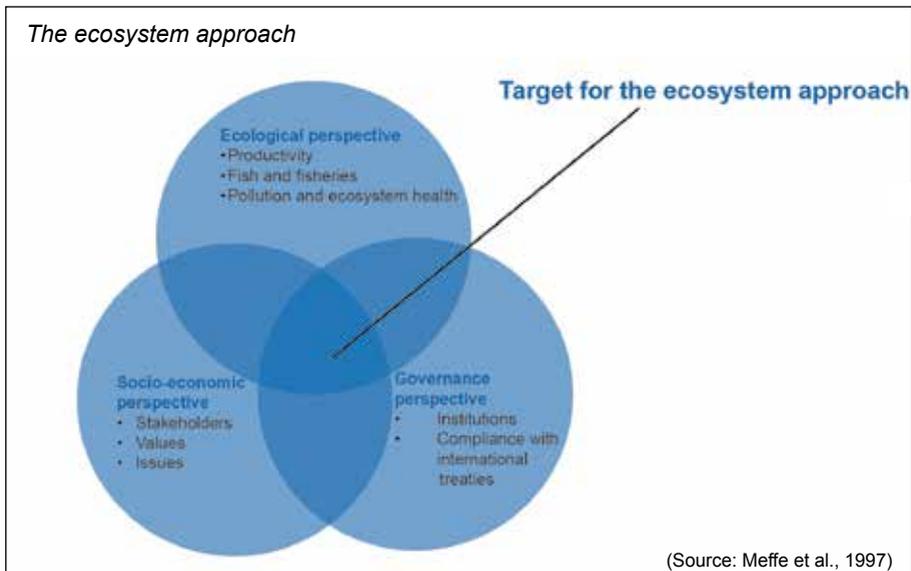
Coastal ecosystems are severely affected by human activities carried out inland. (See under section on 'What are the threats to tidal flats?'). From a single action inland, there could be a cascade of impacts in the coast. For example, mining for river sand upland could result in decreased sediment loads in rivers, in turn, eroding habitats such as mangroves, which rely on this inflow of sediments to stabilise their fringes. The loss of these habitats — which are nursery grounds for commercially important fish and shellfish — affects fisheries. The loss of mangroves and tidal flats, as a consequence of erosion, affects the protective services provided by these ecosystems of serving as physical buffers for extreme weather events.

Therefore, when conservation measures are taken on the coast, without any action being taken at the source of the problem, these measures fail. This is analogous to a doctor treating a symptom and not the cause: the result is merely palliative. It is essential that the entire landscape of impact is reviewed: this is called a landscape approach to conservation (Meffe et al., 1997).

## Shifting to an ecosystem approach

One of the main problems relating to the coastline of Sri Lanka is erosion. In the past, interventions to prevent erosion were comprised of hard engineering solutions, such as groynes and piers, constructed by engineers. In contrast, the management of fisheries lies within the jurisdiction of the Fisheries Department. The protection and conservation of mangroves, which are found on the coast, is the responsibility of the Forest Department; while there are also sanctuaries and national parks on the coast, managed by the Department of Wildlife Conservation. Each of these institutions often works in isolation of the others. The users of the coastal zone — communities, developers and others are rarely included in management.

‘The ecosystem approach integrates ecological, socioeconomic and institutional perspectives, applied within a geographic framework defined primarily by natural ecological boundaries’. The ecosystem approach recognises that long term sustainability cannot be achieved if an ecological focus overshadowed human welfare and vice versa (Meffe et al., 1997).



## Integrated coastal zone management (ICZM)

The ultimate aim in the coastal zone is integrated coastal zone management. Even though the concept of Integrated Coastal Zone Management predates the ecosystem approach, the central theme of ICZM is fundamentally an ecosystem approach viewed through the lens of a coastal zone. Like the ecosystem approach, the process of ICZM starts with an awareness of the geographic spread of issues of concern, identifies all key stakeholders — not only all relevant organisations from different sectors but also communities and other users, ensures information collection across the geographic range, and promotes dialogue, cooperation leading to joint decision-making and coordinated management and implementation (European Communities, 1999).

- Local communities in the Muan tidal flat in Korea, currently manage tidal flats. Days and hours for harvesting in the mud are set by communities. In addition, routes into the tidal flats are also set, so that unnecessary damage is prevented (Woo-young, 2013).

## Taking innovative approaches

On many occasions, lateral thinking in conservation has resulted in remarkable, positive impacts.

The usual response to IAS is to try to eradicate or control them by traditional clean-up methods. A unique effort in Denmark has turned a situation potentially damaging to tidal flats into a profitable enterprise.

The Pacific oyster was identified in the Wadden Sea for the first time in 1998 and has spread extensively in tidal flats. Normal methods of control or eradication — such as bringing tractors or backhoe for collecting them — are not possible in this sensitive environment. Now, Denmark's Jutland peninsula promotes oyster safaris, where people are encouraged to walk on the mud and collect oysters one by one, taking back as much as they can carry. People can carry back a load of 9-18 kilogrammes from one safari, and in seven years, visitors have harvested more than 100 tons of this IAS (Serafin, 2012).

## Establishing protected areas

Globally, there are now 168 contracting parties and 2,161 Wetlands of International Importance (Ramsar sites)<sup>10</sup> extending over 2,056,812 km<sup>2</sup>. Among these sites, 411 sites, extending over 326,732.7 km<sup>2</sup> contain tidal flats ([http://www.ramsar.org/cda/en/ramsar-sept13-homeindex/main/ramsar/1%5E26292\\_4000\\_0\\_\\_](http://www.ramsar.org/cda/en/ramsar-sept13-homeindex/main/ramsar/1%5E26292_4000_0__)).

- Among 18 designated Ramsar sites in the Republic of Korea, five or 27.78% are tidal flats. These sites provide roosting sites for Globally Threatened species such as the Oriental white stork (*Ciconia boyciana*), the Saunders' gull (*Larus saundersi*), the Spoon-billed sandpiper (*Eurynorhynchus pygmeus*) and the Spotted Greenshank (*Tringa guttifer*).
- In Sri Lanka, Vankalai in the Mannar district in northwestern Sri Lanka is a Ramsar site with tidal flats. Vankalai is home to more the 20,000 migratory shore birds, including the Northern Pintail (*Anas acuta*), Greater Flamingo (*Phoenicopterus roseus*) and the Eurasian Wigeon (*Anas penelope*).

<sup>10</sup> The Convention on Wetlands of International Importance, called the Ramsar Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. Wetlands of International Importance, commonly called Ramsar sites, are designated and afforded protection.



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## Photocredits

| Page  | Caption   | Credit  |
|-------|---|---|
| iii   | Tidal flat, Puttalam lagoon, northwestern Sri Lanka.  | © Ranjit Galappatti                                       |
| iv    | Common Redshank ( <i>Tringa totanus</i> ) a migrant, on a submerged tidal flat, Mannar Island, northwestern Sri Lanka.  | © Sriyanie Miththapala                                    |
| 2     | Tidal flat, Mannar Island, northwestern Sri Lanka.  | © Niroshan Mirando  |
| 5     | Tidal flat, Mannar Island, northwestern Sri Lanka, showing salt-tolerant plants and a flock of egrets in the background.  | © Niroshan Mirando  |
| 7     | Top: Mat of cyanobacteria;bottom: Salt-tolerant plants growing at the landward edge of tidal flats.   | Top: © Sriyanie Miththapala; Bottom: © Dilup Chandranimal |
| 11    | Top: <i>Salicornia</i> ; bottom: <i>Suaeda</i> , both salt tolerant plants that grow on the landward edge of tidal flats, Puttalam, northwestern Sri Lanka.   | © Niroshan Mirando  |
| 13    | Women collecting molluscs from tidal flats in Puttalam lagoon, northwestern Sri Lanka.  | © Dilup Chandranimal                                      |
| 15    | Top: Dead molluscs piled up at the edge of a tidal flat, Puttalam, northwestern Sri Lanka; bottom; Wild donkeys on a tidal flat, Mannar Island, northwestern Sri Lanka.   | © Sriyanie Miththapala                                    |
| 17    | Top: Migrant Black-headed Gulls ( <i>Chroicocephalus ridibundus</i> ) on a submerged tidal flat, Kayts Island, Northern Province, Sri Lanka; Caspian terns ( <i>Hydroprogne caspia</i> ), winter migrants on a tidal flat, Mannar Island, northwestern Sri Lanka. | Top: © Luxshmanan Nadaraja; bottom: Niroshan Mirando      |
| 18    | Tidal flat, Puttalam lagoon, northwestern Sri Lanka.  | © Ranjit Galappatti                                       |
| 26    | Top: Shrimp farm; bottom: Salt production, Puttalam lagoon, northwestern Sri Lanka.   | © Dilup Chandranimal                                      |
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| 35    | A flock of migrant Black-tailed Godwits ( <i>Limosa limosa</i> ) in Vankalai Sanctuary, northwestern Sri Lanka.   | © Niroshan Mirando  |
| 40    | A pair of migrant Northern Pintails ( <i>Anas acuta</i> ) in Vankalai Sanctuary, northwestern Sri Lanka.  | © Niroshan Mirando  |
| 46-47 | A flock of unidentified birds, on a submerged tidal flat, Mannar Island at sunset.  | © Niroshan Mirando  |



## Mangroves for the Future

Mangroves for the Future (MFF) is a unique partner-led initiative to promote investment in coastal ecosystem conservation for sustainable development. It provides a collaborative platform among the many different agencies, sectors and countries who are addressing challenges to coastal ecosystem and livelihood issues, to work towards a common goal.

MFF builds on a history of coastal management interventions before and after the 2004 Indian Ocean tsunami, especially the call to continue the momentum and partnerships generated by the immediate post-tsunami response. It initially focused on the countries worst-affected by the tsunami; India, Indonesia, Maldives, Seychelles, Sri Lanka, and Thailand. MFF has expanded to include Bangladesh, Cambodia, Pakistan and Viet Nam. MFF will continue to reach out other countries of the region that face similar issues, with an overall aim to promote an integrated ocean wide approach to coastal zone management.

The initiative uses mangroves as a flagship ecosystem, but MFF is inclusive of all coastal ecosystems, including coral reefs, estuaries, lagoons, sandy beaches, sea grasses and wetlands. Its long-term management strategy is based on identified needs and priorities for long-term sustainable coastal ecosystem management. These priorities emerged from extensive consultations with over 200 individuals and 160 institutions involved in coastal management.

MFF seeks to achieve demonstrable results in influencing regional cooperation, national programme support, private sector engagement and community action. This will be achieved using a strategy of generating knowledge, empowering institutions and individuals to promote good governance in coastal ecosystem management.

Learn more at: [www.mangrovesforthefuture.org](http://www.mangrovesforthefuture.org)