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INVESTING IN COASTAL ECOSYSTEMS

Lagoons and Estuaries

Coastal Ecosystems Series (Volume 4)

Sriyanie Miththapala

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Contents

Introduction

Coastal ecosystems, located along the margins of continents and oceanic islands, are areas of high productivity. They play vital roles in supporting human wellbeing because of their immense biological resources and the life-supporting services they provide (WRI, 2001; UNISDR/UDNP, 2012). Nearly 500 million people (including nearly 30 million poor people) depend directly and indirectly on coral reefs for their livelihoods, food and other resources (Wilkinson, 2004). Further, it is estimated that up to 80% of the global fish catch is directly or indirectly dependent on mangroves (Sullivan, 2005).

Within the coast, there is a range of coastal ecosystems, ranging from the familiar coral reefs to seagrass meadows, sand dunes, mangroves, salt marshes, tidal flats, lagoons and estuaries. Each of these ecosystems harbours a wealth of species and provides an array of ecosystem services vital to humans. What emerged after the Indian Ocean tsunami, and an immediate and intense focus on coastlines, was the recognition that each of these ecosystems is interconnected and interdependent on others and that together they form a mosaic of interconnected environments (Kallesøe et al., 2008). No less important is the emergent knowledge that ecosystems across landscapes are interconnected. Thus, the impacts of a development scheme upstream can have detrimental effects on an ecosystem downstream on a coast.

Healthy ecosystems not only provide an array of goods (water, shelter, food, fuel, fibre, raw materials, medicine, genetic materials) but also a multitude of services (such as protecting the coastline against extreme weather events, absorbing carbon and filtering pollutants) that people critically depend on for their survival and existence (Krishnan and Soni, 2011).

Yet, these coastal ecosystems are facing a gamut of human-induced threats ranging from over-exploitation to habitat degradation and destruction as well as pollution. A burgeoning human population concentrated on coastlines is exacerbating many of these threats and the threat from unplanned coastal development is considerable (WRI, 2001). The overarching threat of climate change remains a sword of Damocles.

There is little information available to the general public regarding the threats to specific ecosystems, particularly the lesser known ones (Duarte et al., 2008). In an attempt to address this issue, the Ecosystems and Livelihoods Group, IUCN, with financial support from the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), published three booklets on Coastal Ecosystems (Coral Reefs: Vol. 1; Mangroves: Vol 2; Seagrasses and sand dunes: Vol 3). This booklet is the fourth of this series. It is produced by the IUCN Sri Lanka Country Office and Mangroves for the Future with the financial support of Danida, Norad and Sida.

Coastal lagoons and estuaries represent coastal water bodies that formed during rises in sea level, which was particularly high during the early Holocene (12,000-8,000 years ago) and slowed down some 6,000 years ago (Kjerfve, 1994). Many authors call them 'ephemeral' (de Wit, 2011; Kennish and Paerl, 2010; and Kjerfve, 1994) as they are continuously changing with the passing of time.

There are many definitions for the words lagoon and estuary, and many people use these words interchangeably. This booklet reviews these definitions and attempts to clarify the distinctions between lagoons and estuaries.

What are lagoons?

Lagoons are classified commonly as coastal or oceanic/atoll lagoons.

A **coastal lagoon** is a shallow, coastal body of water, separated from the ocean by a barrier, (Kennish and Paerl, 2010; Kjerfve, 1986 &1994; http://www.sms.si.edu/IRLSpec/Whatsa_lagoon.htm). This barrier can be formed by a coral reef, barrier islands, a sand bar or spit, shingle, or, less frequently, rocks (Kjerfve, 1994; http://www.sms.si.edu/IRLSpec/Whatsa_lagoon.htm; http://education.nationalgeographic.com/education/encyclopedia/lagoon).

The word lagoon is derived from the Italian word *laguna* for a shallow body of water, in turn, derived from the Latin word *lacuna*, meaning pool, hollow or gap (http://www.thefreedictionary.com/lagoon).

An oceanic or atoll lagoon is a circular coral reef or string of coral islands surrounding a lagoon. Atoll lagoons are much deeper than coastal lagoons, sometimes about 20 m deep. (http://www.thefreedictionary.com/atoll). Huvadhu Atoll in the Maldives has a land area of only 38.5 km^2 surrounding 3113.5 km^2 of lagoon.

This booklet only refers to coastal lagoons and therefore, the word lagoon will be used to refer to coastal lagoons.

There is a great range in size of coastal lagoons, with the smallest being about a hectare in size and the largest, in Lagoa dos Patos, Brazil, more than 10,000 km^2 (Bird 1994 in litt. Kennish and Paerl, 2010).

Lagoons are usually located parallel to the shoreline, and are often longer than they are wide (Kennish and Paerl, 2010).

Lagoons usually do not have large rivers flowing into them. In very large lagoons, however, sometimes, there are rivers flowing in. For example, the Curonian Lagoon straddling Russia and Lithunia on the Baltic coast has the Neman River flowing into it.

The depth of a lagoon seldom exceeds a few metres (Kjerfve, 1994). Because of this shallowness, lagoons are highly susceptible to changes in precipitation, evaporation and wind (http://www.sms.si.edu/IRLSpec/Whatsa_lagoon.htm). This results in varied changes in salinity and temperature in lagoons (http://www.sms.si.edu/IRLSpec/Whatsa_lagoon.htm).The tidal exchange and freshwater inflows also alter salinity. Therefore, different lagoons could have water ranging from fresh to brackish to hypersaline (Kjerfve, 1994).

'Salinity is the saltiness or dissolved salt content (such as sodium chloride, magnesium and calcium sulphates, and bicarbonates) of a body of water.' Salinity is an extremely important ecological factor that influences the types of organisms that live in a body of water (http://en.wikipedia.org/wiki/Salinity).

There is a range of salinity in lagoons: some lagoons have near freshwater, others have brackish water which is saltier than freshwater, but less salty than sea water; then there is salt water found in the sea; and concentrated salt water which is hypersaline and called brine.

Salinity is expressed in parts per thousand (‰), which is approximately grams of salt per kilogramme of solution.

Unit	Water salinity			
	Fresh water	Brackish water	Saline water	Brine (Hypersaline)
Parts per 100	< 0.05%	0.05 – 3%	3 – 5%	> 5%
Parts per 1000	< 0.5 ‰	0.5 – 30 ‰	30 – 50 ‰	> 50 ‰

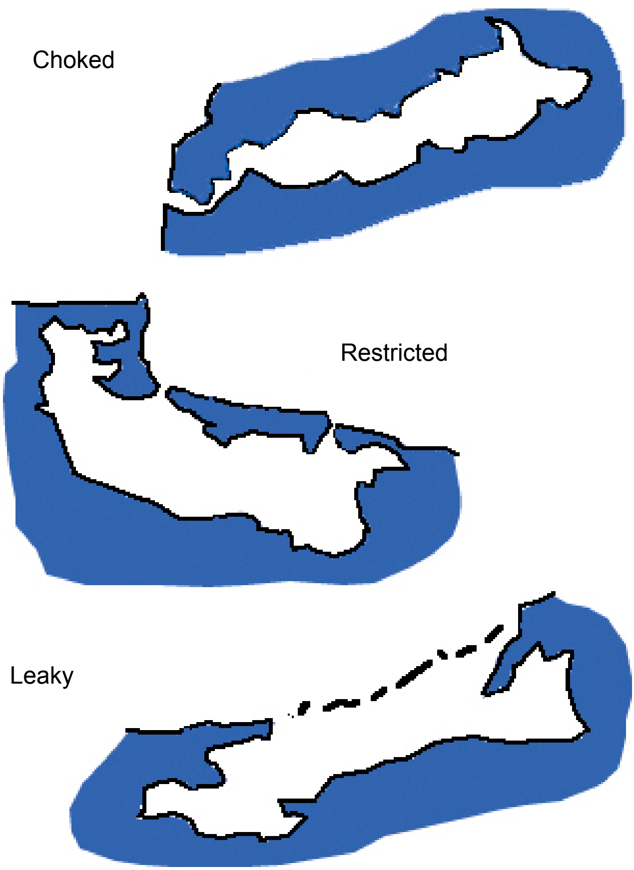
Examples of lagoons with different salinities		
Fresh water	Brackish water	Hypersaline
Murray mouth Lagoon, Australia. Kalametiya lagoon, southern Sri Lanka.	Chilika Lake, Orissa India. Jubho Lagoon, Sindh, Pakistan. Bundala lagoon.	Mundel Lagoon, Sri Lanka. Coorong, South Australia. Laguna Madre, USA.

Many coastal lagoons show strong variations of salinity during the year. For example in temperate and Mediterranean climates, salinities are typically low during the cold wet seasons, while salinities are high during the warm dry periods. Similarly, in tropical climes, salinity increases during dry seasons, when evaporation is high, and decreases during the monsoons.

Depending on the size of the barrier which impedes the flow of water in and out of the lagoon, coastal lagoons may be partially or entirely enclosed (Kennish and Paerl, 2010).

Lagoons can be classified into three types according to how water is exchanged with the ocean.

Coastal Lagoons



(Source: Kjerfve, 1994)

The amount of time required to exchange the fresh water in an estuary or lagoon for new fresh water is called the flushing time (Weiss and Duffy, 2008).

Choked lagoons

Choked lagoons usually have a narrow channel to the sea and form in areas where the energy of waves in the sea is high (Kjerfve, 1994). The narrow inlet mostly prevents the tides from entering, and also prevents much mixing of water (Kjerfve, 1994). In arid areas, high evaporation rates and reduced tidal inflow result in this type of lagoon becoming temporarily or permanently hypersaline (Kjerfve, 1994). Mundel Lagoon and Rekawa Lagoon in Sri Lanka, the Songkhla Lake in Thailand and the Lagoa dos Patos, Brazil are examples of choked lagoons (Jayasiri and Rajapaksha, 2000; Kjerfve, 1994).

Restricted lagoons

Restricted lagoons have more than one channel to the sea, temporarily 'restricting' water exchange, but in reality there is good water exchange, and a net transport of water to the sea (http://www.sms.si.edu/IRLSpec/Whatsa_lagoon.htm; Kjerfve, 1994). Wind plays a role in restricted lagoons, as surface currents can develop because of the wind and result in mixing of water (http://www.sms.si.edu/IRLSpec/Whatsa_lagoon.htm; Kjerfve, 1994). The flushing time is very much shorter than in choked lagoons. Uppar Lagoon, in eastern Sri Lanka and the Laguna de Terminos, Mexico are example of restricted lagoons (Kjerfve, 1994).

Leaky lagoons

Leaky lagoons have wide channel(s) to the sea, unhindered interchange of water and fast water currents. As Kjerfve (1994) says, 'leaky lagoons occupy the opposite end of the spectrum from choked lagoons'. The Mississippi Sound, USA is an example of a leaky lagoon (Kjerfve, 1994).

What are estuaries?

An estuary is the point at which a river and the sea meet. Estuaries are, therefore, dynamic ecosystems where seawater is brought in by the tides but is diluted by freshwater flowing in from rivers and streams (http://en.wikipedia.org/wiki/Estuary).

Like lagoons, they can be partially enclosed by a barrier that protects them from the elements. Estuaries are areas of transition from land to sea, as well as from freshwater to saltwater (http://www.epa.gov/owow_keep/estuaries/kids/about/what.htm).

> The word estuary is derived from the Latin word *aestuarium* meaning tidal inlet of the sea, which, in turn is derived from the term *aestus*, meaning tide (http://www.thefreedictionary.com/estuary).

There is much overlap in the usage of the terms coastal lagoon and estuary, and in some cases, it very difficult to distinguish one from another because coastal drift and other influences can change a typically funnel-shaped estuary in a lagoon with a sand bar, lying parallel to the coast (de Wit, personal communication). At the end of this section there is a diagram that shows these differences.

The main difference between lagoons and estuaries is in the flow dynamics of the water bodies: in estuaries, the water flows fast and strong, while in lagoons the water is more shallow and flows sluggishly.

Estuaries are usually deeper than lagoons (Kjerfve, 1986). Generally, there are three zones in an estuary: the first is where the river begins to meet the saltwater — more freshwater than saltwater is found in this zone; the next zone, towards the sea, is where there is about an equal mix of fresh and saltwater; the last zone is the area where the water flows into the ocean and this zone is mostly saltwater (http://www.nhptv.org/natureworks/nwep6a.htm).

In estuaries, there is a characteristic pattern of how water circulates. Less dense and, therefore, lighter water flows out to the sea from near the surface, while the denser, heavier saline water flows into the estuary from the sea from near the bottom. The amount of time required to exchange the fresh water in an estuary for new fresh water is called the **flushing time** (Weiss and Duffy, 2008).

There are several different ways of classifying estuaries, based on water balance, geomorphology (the formation of land after interaction with the elements), water stratification and hydrodynamics (the forces acting on water). Shown in the tables below and in the following pages are the first three classifications.

Classification based on water balance

Classification based on water balance	Characteristics	Examples
Positive	Fresh water input exceeds evaporation and there is a net outflow to the ocean; water density increases seawards.	'Typical estuaries'.
Inverse	Here evaporation exceeds freshwater input. There is little or no river discharge into these estuaries. The salinity gradient is opposite to that of positive estuaries, so the water density gradient increases landwards. Flushing is sluggish in these estuaries.	Puttalam lagoon (technically an estuary), northwestern Sri Lanka (Laguna Madre, Texas, USA.
Low-inflow	Evaporation is still high, but there is a small fresh water discharge into the estuary. During the hot and dry season, high evaporation results in a zone where salinity is very high, called a salt plug. Towards the sea from this salt plug, water density decreases, as in an inverse estuary. Conversely, landwards from this plug, water density decreases as in a positive estuary. The salt plug prevents flushing out and inward flow of sea water.	Tomales Bay, California USA. Puttalam Lagoon, northwestern Sri Lanka (http://www.ce.ufl.edu/~arnoldo/ocp6050/notes_pdf/estuaries.pdf).

(Source: extracted directly from Valle-levinson, 2010)

Classification based on geomorphology

Classification based on geomorphology	Characteristics	Examples
Coastal plains or drowned river valleys	These are formed as a result of increasing sea levels during the Pleistocene era. These were once rivers, and are wide and shallow.	Chesapeake Bay in the eastern US.

Classification based on geomorphology contd.	Characteristics	Examples
Barrier-built estuaries/Basin estuaries (also called Bar-built estuaries)*	These estuaries were originally small bays, which have become partly enclosed because sand and sediments drift and deposit themselves as a sandbar or spit between the coast and the ocean.	Batticaloa lagoon (technically an estuary), eastern Sri Lanka, Puttalam lagoon northwestern Sri Lanka (Samarakoon and Samarawickrama, 2012).
Tectonic estuaries	These are formed by formed by earthquakes or by fractures of the Earth's crust. Faults cause part of the crust to sink, forming a hollow basin. An estuary is formed when the basin is filled by the ocean.	Guaymas Bay in Mexico.

(Source: extracted directly from Valle-levinson, 2010)

* It is particularly difficult to distinguish a coastal lagoon from an estuary in the case of bar-built estuaries. Coastal drift may contribute to the growth, in one direction of a sand bar or spit. This changes the form from a typical funnel-shaped estuary to a larger water body, oriented morphology parallel to the coastline. (This has been observed in the Bassin d'Arcachon in southwest France.) (de Wit, personal communication.)

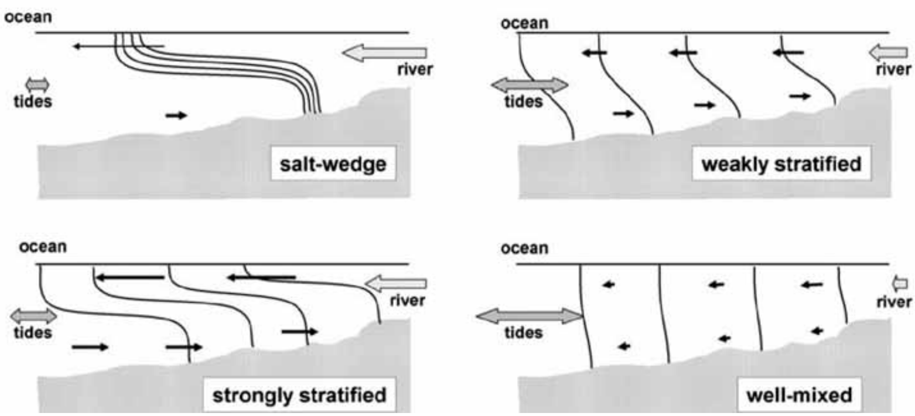
Classification based on stratification

Classification based on stratification	Characteristics	Examples
Salt wedge	Here there are large freshwater inputs and weak tides. During high tides, salt water forces itself in at the bottom in a wedge shape. The average mixing pattern is weak mixing between fresh water and saltwater.	Vellar, India.
Strongly stratified	In these estuaries there is moderate to large freshwater discharge and weak to moderate tides. There is clear stratification of fresh and salt water. The flow of freshwater is stronger than the inflow of saltwater.	Kelani Ganga Estuary in Sri Lanka (Ranjit Galappatti, pers.comm.).

Classification based on stratification contd.	Characteristics	Examples
Weakly stratified or partially mixed estuaries	Here there are moderate to strong tides and weak to moderate freshwater discharge. There is adequate mixing of fresh and seawater.	Chesapeake Bay in the eastern US.
Vertically mixed	In these estuaries there are strong tides and weak freshwater discharge. Freshwater and saltwater are completely mixed.	Estuaries in Bangladesh, with a high (3-5m) tidal range (Ranjit Galappatti, pers.comm.).

(Source: extracted directly from Valle-levinson, 2010)

Classification of estuaries based on stratification



(Source: Valle-Levinson, 2010)

Some estuaries may change from one form to another at different times. For example, the Hudson River, in the eastern United States, changes from a highly stratified estuary during neap tides[1] to weakly stratified during spring tides[2] (Valle-levinson, 2010).

[1] A tide in which the difference between high and low tide is the least. Neap tides occur twice a month when the Sun and Moon are at right angles to the Earth. When this is the case, their total gravitational pull on the Earth's water is weakened because it comes from two different directions' (http://www.thefreedictionary.com/neap+tide).

[2] 'Either of the two tides that occur at or just after new moon and full moon when the tide-generating force of the sun acts in the same direction as that of the moon, reinforcing it and causing the greatest rise and fall in tidal level'c (http://www.thefreedictionary.com/neap+tide).

‘Lagoons and estuaries are water-dominated ecosystems formed at the interface between the land and the sea. Hence, the attributes of water determine the life or death of estuaries and lagoons . . .

Each estuary or lagoon is unique based on geology . . . the ongoing processes that influence its [physical] form, the quantity of water from land drainage flowing through it and the volume of sea water flowing into it with the tides.’

Discharges from rivers and tidal inflow from the sea are essential for these ecosystems and they are, therefore, vulnerable to changes in these flows (Samarakoon and Samarawickrama, 2012).

Rivers carry sediment from inland to the sea. The flow of the river slows as it widens into an estuary near its mouth and the coarser, larger grains of sediment fall to the river bed. The finer, smaller grains are carried to the mouth and deposited as fine sand, silt or clay particles. When rivers deposit material faster than it can be removed, and this alluvium accumulates, deltas form as islands, out of the water and extend out to sea (http://www.scribd.com/doc/33734709/Delta-and-Estuaries).

Many river deltas have a triangular shape, because typically, heavily silt laden rivers tend to branch out (with islands forming in between the branches) hence their common name. (The Greek letter Delta is triangle-shaped.) (http://education.nationalgeographic.com/education/encyclopedia/delta/?ar_a=)

The largest delta in the world is the Ganges-Brahmaputra delta in India and Bangladesh, which empties into the Bay of Bengal. Much of Bangladesh lies within this delta (http://education.nationalgeographic.com/education/encyclopedia/delta/?ar_a=). Coastal Bangladesh lies on top of a 20 km layer of silt, sand, clay and peat, still consolidating under its own weight in addition to the effects of tectonic movements, on account of its proximity to a major plate boundary (Ranjit Galappatti, personal communication).

(Source: http://en.wikipedia.org/wiki/Dhaka)

Estuaries and lagoon are highly dynamic ecosystems that are very vulnerable both to natural and anthropogenic disturbances. Natural disturbances are caused by the forces of nature and include winds, tidal currents and waves.

Barrier built estuaries and lagoons are separated from the ocean by a barrier island, sand bar or spit. This entrance barrier forms and breaks down depending on the movement and redistribution of sand and sediments by waves, upland runoff, tidal water exchanges and winds. During the monsoons, or heavy rains, when there is much water flowing from inland into lagoons or estuaries, the water level within them rises, spills over the barrier and sometimes breaks down. While this is happening, the inlet remains open. Large lagoons, where the natural tidal exchange is large, can remain open even without upstream runoff. While the lagoon mouth is open, the tidal exchanges affect the lagoon ecosystem. Tidal impacts are less when there are large upstream discharges running through the lagoon.

In contrast, the movement of sand across the lagoon mouth (called littoral drift) has the effect of closing the lagoon outlet. At this time, lagoons or estuaries are not flushed and remain closed to the sea.

This process of opening and closing is an irregular but natural cycle. However, structures built on the adjacent coastline that impede littoral drift of sand can keep lagoon mouths open for longer periods. Similarly reduction of upstream flows (by dam building/diversions etc.) could have the opposite effect. (http://www.dpi.nsw.gov.au/fisheries/habitat/aquatic-habitats/wetland/coastal-wetlands/management-of-coastal-lakes-and-lagoons-in-nsw).

Differences between lagoons and estuaries at a glance

	Lagoons	Estuaries
Depth	Shallow.	Usually deeper than lagoons.
Rivers flowing into it	Usually no large rivers.	Always has inflow of freshwater water from a river.
Flow dynamics	Flow of water sluggish and slow.	Flow of water fast and strong.
Flushing time	Long in choked lagoons, less in restricted lagoons and fast in leaky lagoons.	Varies widely. Flushing time is dependent on the tide and/or upstream freshwater inflows.

Where are lagoons found in the world?

Lagoons are found along low-lying coasts all over the world, on every continent except Antarctica, in tropical as well as temperate areas, along 13% of the world's coastline (Isla, 2009).


(Source: After Thomas et al., 2009)

In tropical humid areas, rainfall exceeds evaporation; in tropical dry areas, the converse occurs with evaporation exceeding precipitation (Isla, 2009). In temperate coastal lagoons, temperatures are warm and the rainfall is moderate. At high latitudes, freeze-thaw cycles control the hydrology[3] of lagoons (Isla, 2009).

Lagoons form in areas where the tidal range is small, as a shallow basin near the shore, which gradually erodes, allowing the ocean to seep in between the barrier and the basin (Isla, 2009).

- Lagoons are most extensive along the coasts of Africa, extending over nearly 18% of the continent's coastline.
- The extent of the coastline occupied by lagoons in other continents are as follows:
    - In North America, 17.6%;
    - In South America, 12.22%;
    - In Asia, 13.8%;
    - In Australia, 11.4%; and
    - In Europe, 5.3%.
- The longest stretch of coastal lagoons in the world (about 2,800 km of the coastline) is found along the Atlantic and Gulf coasts of the USA (Nichols and Boon 1994 in litt Kennish and Paerl, 2010).

(Source: Barnes, 1980 in litt. Kennish and Paerl, 2010)

[3] The study of the properties, distribution, and effects of water on the earth's surface (http://www.thefreedictionary.com/hydrology).

Where are estuaries found in the world?

Estuaries form wherever rivers flow into the sea.

(Source: After http://www.euratlas.net/geography/world/rivers/index.html)

Estuaries are areas of heavy human settlement and is it reported that of the 32 largest cities in the world, 22 are located on estuaries (http://oceanservice.noaa.gov/facts estuary.html).

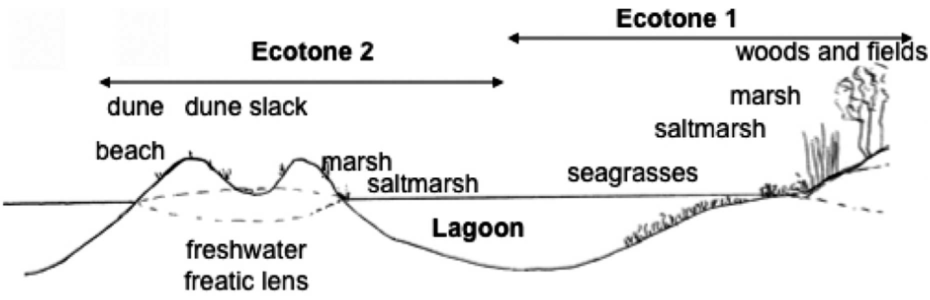
The biodiversity of lagoons and estuaries

Lagoons and estuaries contain ecotones

Lagoons and estuaries, lying at the boundary between the ocean and land, house a unique mosaic of habitats from sea to land. Apart from the habitats of lagoons and estuaries, there may be barrier islands, spits, beaches, sand dunes, salt marshes, seagrasses within lagoons and estuaries, as well as mangroves fringing their shores (de Wit, 2011). This high ecosystem diversity within the immediate landscape of lagoons and estuaries, gives rise not only to high species diversity but also to the creation of ecotones — areas of transition between two habitats.

One ecotone — from inland terrestrial vegetation, mangroves, salt marshes and submerged vegetation such as seagrasses — runs perpendicular from the inland area to the inner shoreline (de Wit, 2011). A second ecotone — salt marsh vegetation, sand dunes, beach and open ocean — runs from the lagoon or estuary to the ocean shoreline (de Wit, 2011). (See figure on opposite page.)

Ecotones in lagoons



(Source: de Wit, 2011)

A third ecotone exists within the water body — along a salinity gradient from freshwater inland, to brackish water in the lagoon or estuary, to saltwater at the mouth of the sea (de Wit, 2011).

Because an ecotone is a boundary where two habitats — each with its own ecological community — meet, an ecotone will contain animals and plants of both communities, as well as organisms that are found only in the ecotone. Therefore, ecotones have a higher number of species than each habitat on either side (http://www.eoearth.org/article/Ecotone?topic=58074). Ecotones often have a larger number of species and larger population densities than the communities on either side. This effect is called the edge effect (http://www.eoearth.org/article/Ecotone?topic=58074).

Therefore, lagoons and estuaries — through the diverse habitats they house — support a high level of biodiversity (de Wit, 2011; Kennish and Paerl, 2010).

The Chilka lagoon in Orissa, India is home to

- about 150 species of water birds, including 100 migrants, one of which is the threatened Siberian Crane (*Leucogeranus leucogeranus*);
- about 100 species of fish, including commercially important Mullets, Hilsa, Catfish (*Mystus*), Perches (*Lates)*, Drums and Croakers (Sciaenids) and Cichlids (*Etroplus*);
- commercially important shrimps such as the Indian white prawn (*Penaeus indicus*) and the Giant tiger prawn (*Penaeus monodon*);
- commercially important crabs such as Mud crabs (*Scylla serrata*);
- over 60 species of phytoplankton and 170 species of zooplankton; and
- 120 species of benthic organisms.

(Source: Sudarshana, 1999)

Lagoons and estuaries have a flourishing benthic zone

The benthic zone is the lowest level of a water body such as a lagoon, estuary or ocean (http://en.wikipedia.org/wiki/Benthic_zone). Organisms that live in this layer are called benthic organisms, and are, therefore, associated with mud, rock or sand, found at the bottom of the water body (http://en.wikipedia.org/wiki/Benthic_zone). Lagoons have many benthic plants and animals (Kennish and Paerl, 2010).

A fundamental difference between lagoons and estuaries is their depth (Kennish and Paerl, 2010; Kjerfve, 1986 & 1994). Because lagoons are shallower, light can penetrate right to the bottom, allowing benthic plants — such as algae and seagrasses — to thrive (Kennish and Paerl, 2010).

Lagoons and estuaries are safe habitats

Lagoons and some estuaries are protected by some form of barrier (barrier islands, coral reefs, spits or sandbars) and this barrier protects the ecosystem from the elements, except in cases of extreme weather events (de Wit, 2011). Because of this, lagoons and estuaries and their associated habitats — such as mangroves and seagrasses — provide safe refuges as nurseries and feeding grounds for many commercially important species such as shellfish and finfish (Heck et al., 2003; Kathiresan and Bingham, 2001; Kennish and Paerl, 2010). Many fish species have adapted to spawn in marine coastal waters, while juveniles migrate into estuaries or lagoons to feed and grow in their shelter (de Wit, 2011).

The Level Fin Eel (*Anguilla bicolor*) is a catadromous species that normally inhabits fresh water habitats and spawns at sea. (Catadromus species living in fresh water, but migrate to marine waters to breed.) This fish is found in fresh water bodies in Kala Oya and Mi Oya in Sri Lanka and enters Puttalam estuary (commonly called the Puttalam Lagoon) to migrate to the sea to breed. The shallow Puttalam estuary, which has dense seagrass meadows, is an ideal environment where incoming juvenile eels hide and protect themselves from predators. Therefore, the Puttalam estuary plays a major role in sustaining Level Fin Eel populations within these two major river systems in the dry zone of Sri Lanka.

(Source: IUCN, 2011).

Special adaptations of animals and plants in lagoons and estuaries

There are daily and seasonal fluctuations of salinity in lagoons and estuaries. Salinity is highly variable because freshwater enters from rivers and watersheds, increasing in quantity during rainy periods. Salt water enters with the tides, and the salinity increases when temperatures increase, with a concurrent increase in evaporation (http://www.sms.si.edu/irlspec/Saltmarsh.htm). When evaporation is high, salinity can be greater than that of seawater, i.e., the water can be hypersaline (http://www.crd.bc.ca/watersheds/ecosystems/saltmarshes.htm).

In addition, the daily ebb and flow of the tides in estuaries result in an instability of the floor bed of the estuary. In addition, organisms that live in estuaries may be exposed daily to the air and submersed in water.

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

All the above conditions make reproduction difficult.

Therefore, organisms living in lagoons and estuaries have to cope with changes in

- Salinity;
- Instability of the floor bed;
- Evaporation; and
- Dissolved oxygen in the soil.

Adaptations to cope with changes in salinity

The primary adaptation that both animals and plants of lagoons and estuaries have is the ability to cope with seasonal or daily changes in salinity. This is particularly true of plants and animals in estuaries, where there are daily fluctuations in salinity.

Animals and plants that can tolerate only small changes in salinity are called stenohaline (Sumich, 1996 in litt. http://oceanservice.noaa.gov/education/kits/estuaries/estuaries07_adaptations.html). Organisms that live only in freshwater or saltwater are known as stenohaline.

In contrast, plants and animals that are able to tolerate a wide range of salinities are called euryhaline (http://oceanservice.noaa.gov/education/kits/estuaries/estuaries07_adaptations.html).

Half-beaks (*Hemiramphus* spp.) and Milkfish (*Chanos chanos*) are euryhaline species. Many crab, shrimp, oyster, clam, mussel and snail species living in lagoons and estuaries are euryhaline.

Freshwater fish eliminate excess water and saltwater fish get rid of excess salt from their blood. Euryhaline fish are able to do both by sensing the salinity in their surrounds (de Silva, person. comm).

Other animal species — such as water monitors and crocodiles — have salt glands that excrete excess salt (Hutchins and Saenger, 1987).

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).

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).

Plants cope with changing salinity by exhibiting both xeromorphic and halophytic characteristics. Xeromorphic characteristics — such as leathery, waxy leaves and sunken breathing pores (stomata) — are adaptations that enable plants to conserve water.

Halophytic characteristics — including salt glands that excrete salt — are adaptations that enable plants to live in salty environmental conditions (Kathiresan and Bingham, 2001). Mangroves plants — supremely adapted to changeable salinities — have a range of adaptations. Species such as Grey Mangroves (*Avicennia*) and Mangrove Holly (*Acanthus*) have specialised salt glands in leaves. Yet other such as Mangrove (Rhizophora), Oriental Mangrove (*Bruguiera*), and Yellow Mangrove (*Ceriops*) have the capability of selectively absorbing water from the soil, through their roots, while leaving behind salt (Kathiresan and Bingham, 2001). This process is called ultrafiltration.

Seagrasses, found in lagoons and estuaries, can tolerate high concentrations of salt in their tissues — up to 36 parts per thousand (Short, personal communication).

Adaptations to cope with changes in tides and the action of currents/ turbulence in water

The ebb and flow of tides in estuaries result in i) an instability of the floor bed and ii) daily exposure to air and submersion in water of organisms.

To cope with the instability in the substrate, plants — such as Mangrove (*Rhizophora*) — have stilt roots that extend sideways to provide support to the main stem (Kathiresan and Bingham, 2001).

Seagrasses, found in lagoons and estuaries, use their extensive underground horizontal stems (rhizomes) to anchor themselves in many places to the lagoon or estuary bed (Dawes, 1981). Rhizomes are firmly attached to sediment and this prevents plants becoming uprooted or the sediment eroding. These rhizomes can remain alive for long periods of time until the conditions are conducive to the production of new leaves. In addition, the leaves of seagrasses are usually flat, ribbon-shaped and flexible; the stems are also flexible, allowing the leaves to bend with the currents and not break (Short et al., 2007).


Animals cope differently with this shifting mud. Mussels and barnacles — which do not move from one place to another — anchor themselves onto something to prevent themselves from being washed away by the tide. Crabs climb up tree trunks during high tide and descend during low tide (Kathiresan and Bingham, 2001). Other species burrow into the mud to prevent being washed away (Kathiresan and Bingham, 2001).

Adaptations to avoid desiccation

To avoid desiccation when the tide is low, barnacles and bivalves (two-shelled molluscs) shut their shells to keep water inside and their breathing organs (gills) moist. Mudskippers can be seen completely exposed to the air at some times, while at others 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 with desiccation by exhibiting xeromorphic characteristics. (See previous section.)

Adaptations to cope with low oxygen content

The mud in lagoons and estuaries is water-logged, so that sufficient oxygen is not readily available to the roots of plants in these water bodies. Mangroves have special breathing roots (pneumatophores) that are above ground (aerial), and these roots are adapted to absorb oxygen from the air and transport it underground.

In some estuaries, when the tidal changes are small, and there is only a little mixing of water, oxygen renewal may also be low. In these instances, animals must adapt to cope with deficiencies in dissolved oxygen.

In lagoons and estuaries, the roots of seagrasses lie in oxygen-deficient sediments. An extensive system of air channels in the leaves transports oxygen to the buried rhizomes and roots (Turner and Schwarz, 1990).

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 their need for oxygen (http://www.co.bell.tx.us/bellnet/bellnetweb/web/adaptati.htm_).

Adaptations to cope with unfavourable conditions for sexual reproduction and dispersal

Mangrove plants have developed vivipary to cope with the unfavourable conditions in lagoons and estuaries for sexual reproduction and seed dispersal. Fertilised seeds do not drop from the tree but develop directly into seedlings while still on the parent tree. Once they have germinated, these seedlings grow to form a propagule that can disperse. Once these propagules fall into the water, they float until they reach a place where they can root and grow successfully (Kathiresan and Bingham, 2001).

In seagrasses, the reproductive parts of flowers extend well above the petals and so allow for easy movement of pollen in the water. Pollen grains are oval-shaped or joined together to become elongated and so move easily in the water (http://hypnea.botany.uwc.ac.za/marbot/seagrasses/seagrassadaptations4.htm).

Seagrasses also reproduce asexually. They produce new shoots from underground stems (rhizomes) (Short et al., 2007). Remarkably, seagrasses can grow asexually for thousands of years, extending over many hectares (Bjork et al., 2008).

What is the importance of lagoons and estuaries?

Lagoons and estuaries are ecologically and economically important ecosystems because they provide many ecosystem services.

Provisioning services

Lagoons and estuaries provide goods for human use.

Lagoons and estuaries are extremely important in the sustenance of coastal fisheries. Many edible shell fish and fish are found in lagoons, estuaries and their associated habitats such as mangroves and seagrasses. The relatively calm habitats of lagoons allow for the practice of traditional and artisanal fisheries (Bjork et al., 2008).

Nixon (1982) reported that 'the yield of lagoon fisheries per unit area is commonly as high as or higher than that from the most productive coastal and offshore fisheries.'

- Lagoons and estuaries found along the 1,340 km coastline of Sri Lanka support the livelihoods of some 500,000 people (2% of the population of Sri Lanka) and the income from fisheries from these lagoons and estuaries is estimated to be more than five billion rupees (39.6 million USD) (Samarakoon and Samarawickrama, 2012).
- With a surface area/water area of 32,700 ha, and famous for good quality fish, the Puttalam Estuary or Puttalam Lagoon, as it is commonly but mistakenly called, harbours many marine, brackish and freshwater species, (Dayaratne et al., 1997). It is reported that a total of 69 species of finfish (belonging to 27 families dominated by the mackerel and scad family, herring, shad and sardine family and the snapper family are harvested from here (Weragodatenna, 2010). There are about 165,000 people directly or indirectly dependent on the Puttalam Lagoon, including nearly 15,000 active fishers, and 5,938 fishing directly in the estuary. There are 88 fishing villages around the estuary and 12,680 households engage in fisheries (Department of Census and Statistics, 2009; Fernando, 2010). (All of the above in litt. IUCN, 2011.)
- It is estimated that the average yield of estuarine fish production in India is 45-75 kg/ha (Jhingran, 1991; Sugunan, 2010 in litt. Bijoy Nandan et al., 2012).
- Estuaries in Kerala, South India are home to over 200 resident and migratory finfish and shellfish. These estuaries support the livelihoods of some 200,000 fishermen (Bijoy Nandan, 2008 in litt. Bijoy Nandan et al., 2012).

In addition, lagoons and estuaries serve as breeding and nursery grounds for many important fin and shellfish (Amarasinghe, 1997; Beck et al., 2001; Samarakoon and Samarawickrama, 2012).

Many finfish and shellfish actually breed in the sea, where salinities are more constant than in lagoons and estuaries, as larvae often have no capacity to adapt to changes in salinity. Juveniles enter lagoons and estuaries where conditions and calmer, and they are have refuge as well as food. Finally, the adults leave the lagoon before starting their reproduction.

They also provide places for coastal fishermen to anchor their boats (Samarakoon and Samarawickrama, 2012). Many old cities are sited by estuaries because they provided safe ports for boats and small ships.

Supporting services

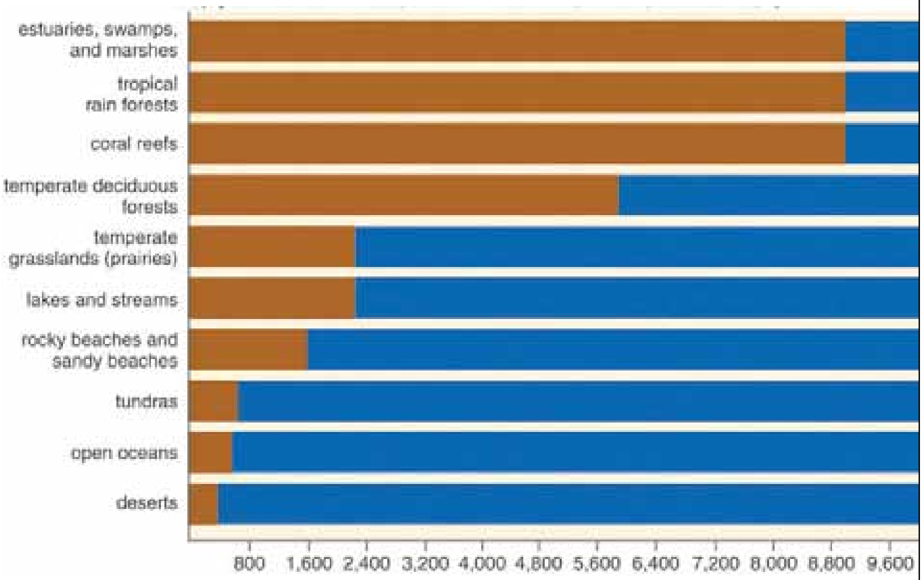
Lagoons and estuaries are highly productive systems.

Through the process of photosynthesis, green plants and some other organisms such as green algae and phytoplankton[4], absorb inorganic substances such as carbon dioxide and water from air or water to produce organic compounds — sugars — that can be used as energy for living organisms (http://en.wikipedia.org/wiki/Primary_production). The rate at which this organic matter (food) is created is called primary productivity. Once this primary productivity is calculated for an ecosystem it is possible to compare primary productivity across ecosystems, as a measure of the potential of each ecosystem as a means of food production for supporting biodiversity.

- Primary producers in lagoons are phytoplankton, benthic algae, aquatic plants or a combination of the above (Vazquez-Botello et al., undated). In shallow lagoons, benthic organisms can dominate primary production (Kennish and Paerl, 2010).
- In estuaries, the main primary producers are phytoplankton (http://en.wikipedia.org/wiki/Estuary).

[4] Plankton are small and microscopic organisms drifting or floating on surface of bodies of water, comprising one celled organisms, algae, bacteria, small crustaceans, and the eggs and larval stages of larger animals (http://en.wikipedia.org/wiki/Plankton). Phytoplankton are plankton that are able to photosynthesise.

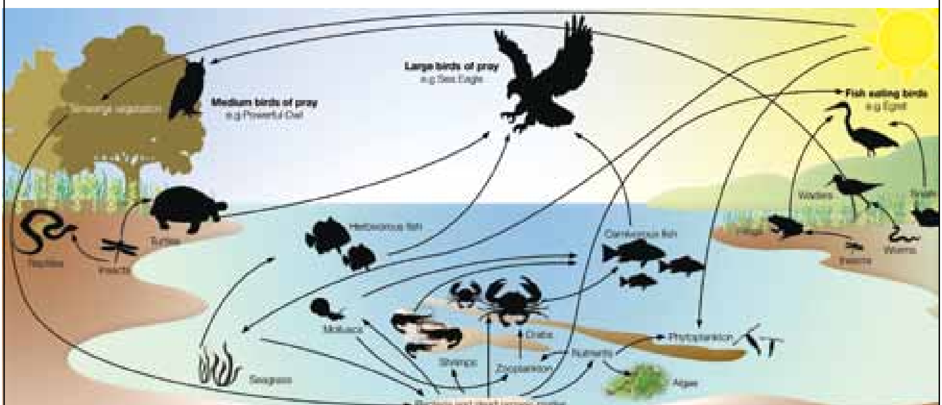
Average Net Primary Productivity (kcal/m²/yr)



(Source: McGraw-Hill; Campbell, et al, 1999)

The diagram above compares primary productivity across selected ecosystems, and shows that the mouths of estuaries, where rivers meet the sea, are areas of high productivity. The primary productivity of estuaries matches that of tropical rain forests and coral reefs. This high primary productivity supports coastal food webs.

A simplified food web of a lagoon



(Source: http://tripleontour.blogspot.com/2010/04)

Lagoons and estuaries cycle nutrient efficiently.

Autotrophic (self-feeding from the Greek) organisms which include higher plants, macro-algae, micro-algae and some bacteria in the phytoplankton and benthos, are able to synthesise organic matter (i.e., manufacture their own food) from simple chemical compounds. They do so by the process of photosynthesis which involves the harnessing of 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. These sugars are later combined in the cells of the autotrophs through chemical reactions with inorganic nitrogen, phosphorous and sulphur N, P and S, taken up from their environment. The complex organic compounds thus synthesised contribute to the growth and functioning of these organisms.

These autotrophic organisms form the basis of food webs as they serve as a source of food for organisms that cannot manufacture their own food, (**heterotrophs**). These heterotrophs include herbivores (plant-eaters) who, in turn, are fed upon by carnivores (meat-eaters) and omnivores (which feed both on plants and on heterotrophs). When the heterotrophic organisms consume food they assimilate a minor percentage (typically about 10%) while the rest is used for the generation of energy and excreted in a degraded form into the environment. When organisms die, they are decomposed by a suite of other heterotrophs — organisms that feed both on dead and excreted organic matter: **detritivores** and **decomposers**. The activities of this suite of detritivores and decomposers (fungi and bacteria), result ultimately in the complete breakdown of the organic matter and as a result, the inorganic forms of carbon, nitrogen, phosphorous and sulphur are recycled into the environment.

In lagoons and estuaries, nutrients come in and are cycled within and are exchanged with the open ocean (Kennish and Paerl, 2010). The rate at which water enters, circulates and exits is called the flushing rate (Spaulding, 1994 in litt. Anthony et al., 2009). This flushing rate depends on many physical features of a lagoon, but in general flushing rates for lagoons are low and nutrients being brought in can be cycled many times before they are flushed out to the ocean, resulting in the high primary productivity discussed in the previous section (Kennish and Paerl, 2010).

Lagoons and estuaries support coastal biodiversity.

Because of their high primary production and efficient nutrient cycling, lagoons and estuaries support coastal biodiversity.

Within the landscape of a lagoon or estuary, there is a mosaic of habitats — seagrass meadows, tidal flats, mangroves — giving rise to rich ecosystem diversity and, from this ecosystem diversity, species diversity.

Diagram of the mosaic of habitats found in a lagoon/estuary

(Source: http://www.igert.org/system/content_item_assets/images/119/original/0504103_2008_Figure_1.jpg?1241577701)



The five lagoons of the Bundala wetland in southern Sri Lanka are important internationally as homes to large populations of migratory birds that visit from regions as far away as Siberia. Resident and migratory birds include the Greater flamingo (*Phoenicopterus ruber*), the Spot-billed pelican (*Pelecanus philippensis*), the Lesser adjutant (*Leptoptilos javanicus*) and the Black-necked stork (*Xenorhynchus asiaticus)* (http://www.iwmi.cgiar.org/About_IWMI/Strategic_Documents/Annual_Reports/1998/Bundala.pdf).

Regulating services

Lagoons and estuaries absorb storm energy and provide flood protection and drainage.

Found at the interface between land and sea, the water bodies of lagoons and estuaries function like buffer zones, protecting coastal communities from the full force of weather related events, such as storm surges, floods and cyclones, by damping wave action, dissipating river discharge and temporarily storing water (http://oceanservice.noaa.gov/education/kits/estuaries/estuaries03_ecosystem.html). When there is flooding, lagoons and estuaries function like gigantic sponges to absorb excess water and drain this water to the sea (http://oceanservice.noaa.gov/education/kits/estuaries/estuaries03_ecosystem.html). These interfaces also protect rivers from erosion from water and wind (http://oceanservice.noaa.gov/education/kits/estuaries/estuaries03_ecosystem.html).

Lagoons and estuaries trap sediments and filter water.

The mosaic of habitats found in lagoons and estuaries (such as mangroves, salt marshes and seagrass meadows) function as large filters to extract pollutants, excess nutrients and sediments carried from municipal and industrial wastewater inland and storm water runoff (http://oceanservice.noaa.gov/education/kits/estuaries/estuaries03_ecosystem.html). The high rate of nutrient cycling that occurs within these water bodies quickly absorbs nutrients and pollutants and degrades organic matter into inorganic matter. Nitrogen and phosphorus — found in excess nutrients — and pollutants such as heavy metals often accumulate in the sediments of the lagoon and do not, therefore, enter the coastal sea. The flushing of water in lagoons and estuaries dilutes pollutants originating from land (Samarakoon and Samarawickrama, 2012).

Cultural services

Lagoons and estuaries are historically significant.

Through the course of history, it is along the banks of rivers and near estuaries (where nutrient-rich, easily-cultivable soils are found) that humans have lived (http://omp.gso.uri.edu/ompweb/doee/science/descript/whats.htm). The earliest fossils of human ancestors (found on the banks of the Awash River in Ethiopia) and the earliest civilisations (along the banks of the Euphrates, Tigris, Nile, Indus and the Yellow River) were all sited near banks of rivers (http://www.internationalrivers.org/a-short-history-of-rivers-0).

Lagoons and estuaries are important for recreation.

People all over the world use lagoons and estuaries for recreation: for sailing and boating, fishing, swimming, other water sports such as jet skiing and kite surfing, as well as bird watching.

Lagoons and estuaries are places where traditional fishing is practised.

Traditional fishing — fencing and amassing fish — has been practised in lagoons and estuaries since the 1st century BC oysters when were cultivated in Rome, Italy (http://en.wikipedia.org/wiki/Oyster_farming). Since prehistoric times, lagoons in Hawaii were used for rearing mullet (Kjerfve, 1994).

A common practice in South and Southeast Asia is brush pile fishery (Kjerfve, 1994). Here branches from nearby mangroves are planted as a fence on the floor of the lagoon and left overnight, when shrimps gather in these fenced areas and are caught easily by hand held nets.

What are the threats to lagoons and estuaries?

'Lagoons and estuaries are water-dominated ecosystems formed at the interface between the land and the sea. Hence, the attributes of water determine the life or death of estuaries and lagoons . . . '(Samarakoon and Samarawickrama, 2012). Many human-induced activities are threatening these diverse and complex ecosystems. According to Kennish and Paerl (2010) lagoons 'may now rank among the most heavily impacted aquatic ecosystems on Earth'. Lagoons and estuaries are affected by anthropogenic activities adjoining or in these water bodies as well as activities inland (Kennish and Paerl, 2010).

The underlying drivers of change in these coastal ecosystems are over-population and unplanned and uncontrolled development in the watersheds of rivers (Kennish, 2002). The coastal population of the Bay of Bengal is one of one of the most populous in the world and is home to around 450 million people who are critically dependent on coastal and marine ecosystems for their livelihoods (BOBLME, 2012).

Many of the impacts of over-population in coastal areas and unplanned development inland are subtle and build up gradually, over time (Kennish and Paerl, 2010), to result, in the end, in chronic disasters (Samarakoon and Samarawickrama, 2012). In addition, extreme weather events — such as floods and cyclones — turn into major disasters when coupled with over-population and unplanned development (Ranjit Galappatti, personal communication).

Changes in water quality:

Pollution:

The characteristics that make shallow lagoons and estuaries highly productive — long water residence times, the cycling of nutrients several times before they are flushed to the sea — also makes them very vulnerable to over-enrichment by nutrients and its attendant consequences (Keenish and Paerl, 2010). One of the main threats facing lagoons and estuaries is point and non-point source pollution.

Point source pollution is a contamination that occurs at a particular location, immediately at or near the source of the pollution. A toxic waste spill site at a location is point source pollution (Loage and Corwin, 2005).

In the Bolgoda Lake estuary, south of the capital Colombo, Sri Lanka, organic pollution of chemicals and pesticides from the Ratmalana industrial zone and effluents from the garment industry, both close by, has resulted in a decrease in fish catches, skin lacerations in some species, and a smell of kerosene which makes fish unfit for sale (Dassanayake, et al., 1991 in litt. Joseph, 2003).

Shrimp farms discharge polluting effluents, rich in both nutrients and sediments, into the environment. Shrimp farms take in water from, and discharge effluents to, the same water source. In order to grow as much shrimp as possible, shrimp farmers add artificial feeds with chemical additives (including chlorine) and insecticides (organochlorides — which persist in the environment), as well as antibiotics to prevent shrimp disease. 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. This negatively impacts on water quality and aquatic life (IUCN, 2011).

Shrimp farms also release effluents with high suspended solids (200-600 mg/l) and high BOD[5] levels (60-180 mg/l) (Dayaratne et al., 1997). Suspended solids in water can obstruct the respiration of aquatic organisms and smother the eggs of aquatic fish species. In addition, suspended solids become deposited as silt and this can affect seagrass meadows.

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. Examples of non-point pollution are agricultural, urban and industrial runoff from inland that is carried along rivers into estuaries or with surface run off to lagoons (Loage and Corwin, 2005). Agricultural runoff includes excess agrochemicals (pesticides, fertilisers, herbicides and fungicides) as well as waste from livestock (http://en.wikipedia.org/wiki/Estuary). Urban runoff includes domestic waste including sewage and plastics, and industrial waste can contain contaminants such as heavy metals (http://en.wikipedia.org/wiki/Estuary). (See table on page 39.)

Large quantities of nitrogen and phosphorous are added through non-point source pollution with agricultural runoff, which leads to eutrophication (Gamito et al, 2005). Eutrophication is a process of nutrient over-enrichment of water, where excess nutrients result in rapid growth and increase of phytoplankton and macro-algae in the water.

[5] Biological Oxygen Demand Biological Oxygen Demand is the amount of dissolved oxygen needed by oxygen breathing biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. It is used to assess organic pollution (i.e., from sewage) in a water body.

This rapid increase can form such high biomass[6] that it may even appear as a mat on the surface of the water, thus blocking sunlight from reaching the lower layers of water, preventing plants below the surface from photosynthesising and producing oxygen as a by-product. The submerged plants remain in darkness, while animals in the water body continue to use up oxygen while respiring. The water then becomes depleted in oxygen affecting marine animals such as fish, which die.

Eutrophication is most severe in shallow systems which take long to flush (Kennish, 2002).

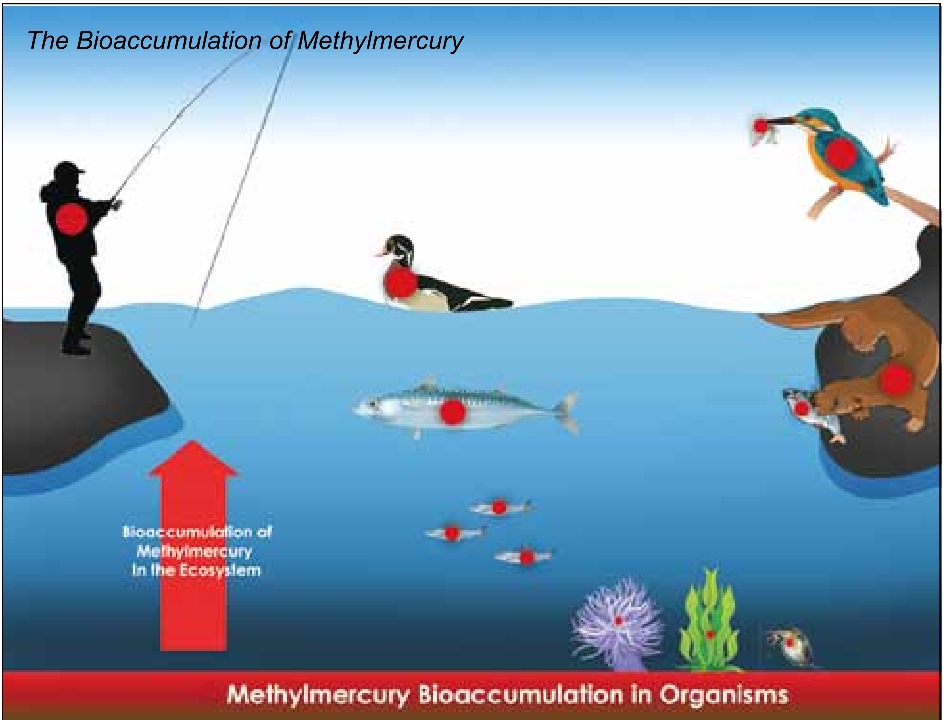
Sometimes, the increase in phytoplankton is so rapid it is called an algal bloom. Some species of phytoplankton species that form such blooms contain toxins and become a danger to animal and human health. This kind of algal bloom is called a harmful algal bloom (HAB)(http://oceanservice.noaa.gov/hazards/hab/). These HABs are usually coloured. Harmful algal blooms cause mass deaths of fin fish and shellfish and have been known to cause mortality in humans who eat these contaminated organisms (http://oceanservice.noaa.gov/hazards/hab/).

The South China Sea is surrounded by Malaysia, Thailand, Vietnam, Brunei, Indonesia, Philippines, and China. On the coastline of this sea, live about 300 million people. The Pearl or Zhu Jiang River flows into to the South China Sea. In two months in 1998, HABs in Pearly River estuary caused mass mortality of fish, resulting in financial losses in excess of 45 million USD (Wang et al., 2007).

Heavy metals (such as lead and mercury), organochlorides (many of which are persistent, that is, they last in the environment for decades) and polycyclic aromatic hydrocarbons (PAH — found in processed fossil fuels) are contaminants from industries that reach coastal waters (Kennish, 2002). The main problem that arises from these chemicals is bioaccumulation and biomagnification.

Bioaccumulation is the process by which an environmental contaminant increases in concentration when it moves from the environment into an organism. Biomagnification is the process by which the concentration of a contaminant steadily increases as it passes along the levels of a food chain (http://www.marietta.edu/~biol/102/2bioma95.html). Ultimately, these processes are dangerous for human health as humans suffer poisoning from ingested fish or seafood that has been contaminated by these chemicals (Kennish, 2002).

[6] The total mass of living matter within a given unit of environmental area (www.thefreedictionary.com/biomass).



(Source: http://www.ec.gc.ca/mercure-mercury/D721AC1F-4446-4E44-A13E-3845A7FAF7D7/i-f-bom-e.jpg)

The runoff from four main rivers in Thailand end up in the Gulf of Thailand. The Chao Phraya estuary is highly polluted and studies have revealed the accumulation of heavy metals — cadmium, copper, chromium and lead (Polprasert, 1982). These metals are harmful to human health.

The Ta chin, another river flowing into the Gulf of Thailand is polluted by development in the capital city and ensuing industrial waste. The Mae Klong was polluted but is now being managed to reduce pollution at the mouth of the river. The Bang Pakong may be affected in the future by the installation of a thermal power plant near the estuary (Menasveta, 2001).

Solid waste pollution is also an increasing problem, unpleasant to the sight. In addition, aquatic organisms may eat this debris or become entangled in it, resulting in their deaths (Shaw and Day, 1994 in litt. Kennish, 2002).

Sources	Common pollutant categories	Main impacts
Point sources		
Municipal sewage	Bacteria, nutrients, ammonia, toxic chemicals.	Mainly eutrophication, and depleted oxygen.
Industries	Toxic chemicals.	Contamination with heavy metals, bioaccumulation, biomagnification, depleted oxygen.
Sewer overflows	Bacteria, nutrients, turbidity, total dissolved solids, ammonia, toxic chemicals.	Depleted oxygen, eutrophication, the spread of pathogens.
Non-point sources		
Agricultural runoff	Nutrients, turbidity, total dissolved solids, toxic chemicals.	Eutrophication, depleted oxygen.
Urban runoff	Turbidity, bacteria, nutrients, total dissolved solids, toxic chemicals.	Sedimentation, bioaccumulation, biomagnification, depleted oxygen.
Construction runoff	Turbidity, nutrients, toxic chemicals.	Sedimentation, bioaccumulation, biomagnification, depleted oxygen.
Mining runoff	Turbidity, acids, toxic chemicals.	Sedimentation, bioaccumulation, biomagnification, depleted oxygen.
Septic systems	Bacteria, nutrients.	Depleted oxygen, eutrophication, the spread of pathogens.
Landfills/spills	Toxic chemicals, miscellaneous substances.	Sedimentation, bioaccumulation, biomagnification, depleted oxygen.
Run off from forestry	Nutrients, turbidity, toxic chemicals.	Eutrophication, depleted oxygen.

(Source: Extracted and adapted from Kennish, 2002)

Decreased or increased sedimentation

In many Asian countries, there is usually a sustained effort to improve living standards and promote economic development. This customarily entails vast changes in land use that destroys natural habitats and increases built infrastructure. Both the process of changing land use and the end result of built infrastructure can change sedimentation.

Both lagoons and estuaries receive sediments from inland: estuaries from the catchment of rivers that flow into them and lagoons from surface runoff. Hence, coastal lagoons have a tendency to become filled in with sediments and thus disappear, in time, from the coastal landscape. As Samarakoon and Samarawickrama (2012) note, these water bodies 'are destined to die [eventually] through sediment entrapment'.

The flow from inland of sediments stabilises the fringes of these water bodies, strengthening substrates for habitats such as salt marshes, tidal flats and mangroves (Olsen et al., undated). These sediments are also vital in providing material for the formation of the barrier islands, barriers, spits and beaches, and hence, replenishes erosion on the coastline (Olsen et al., undated).

Human actions can change this natural sedimentation process — either increasing the amount of sedimentation or decreasing it.

The greatest source of increased sedimentation is from earthworks, where large quantities of earth are cleared of protecting vegetation and bare surfaces left open (Galappatti, personal communication). With the first rains, massive quantities of mud are washed into rivers and are carried into estuaries and lagoons (IUCN, 2011b). In addition, development activities — such as building construction and road development — increase impermeable surfaces and enhance the 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).

Increased sedimentation also increases the extent of suspended material in these water bodies so that the turbidity increases. Increased turbidity decreases the sunlight reaching the water column below the surface. This profoundly affects the bottom water layers as well as the benthic organisms (common in shallow lagoons) and submerged habitats such as seagrass meadows. As a result, entire food webs in these water bodies become negatively impacted by sedimentation (Kennish and Paerl, 2010).

The Segara Anakan is an estuary on the south coast of Java. Freshwater enters this estuary from three major rivers the Citanduy, Cibeureum and Cikonde. The greatest threat to this ecosystem has been steady sedimentation. Sediment generated by deforestation and poor agricultural practices has increased erosion with the consequence that this estuary is only 28% of its size in 1900. Nearly one million m^3 of sediment are deposited annually in this estuary. This sedimentation has led to the collapse of fisheries in this estuary (Ardli and Wolff, 2008).

Mangroves are ecosystems that promote land accretion (the slow addition to land by the deposition of sediment carried in water). Because of their extensive and tangled supporting root systems, mangroves trap sediments and prevent them from washing into the sea.

After the Indian Ocean tsunami of December 2004, planting mangroves a bioshields was seen as a panacea to all coastal environmental problems, and mangroves were planted in estuaries and lagoons, in areas where they had not been found before. This hastened sedimentation, resulting in the loss of habitats for fin and shellfish (Samarakoon and Samarawickrama, 2012).

In contrast, when sedimentation decreases, lagoon and estuary banks, as well as coastal shorelines will erode; habitats such as mangroves that require replenishment of sediments become affected, in turn, affecting the flora and fauna that live in them (Olsen et al., undated).

Dredging of lagoons and estuaries — frequently used as a means of improving the quality of water — when carried out without prediction modelling and scientific investigation, can sometimes have negative effects such as the destruction of benthic habitats and damage to water quality (Kennish, 2002).

Aquaculture

Aquaculture is the cultivation or farming of aquatic animals or plants for food (http://www.fao.org/fishery/cwp/handbook/J/en) and is a practice that dates back to 475 BC when it was first recorded in China. All over the world, many lagoons and estuaries are used as sites for aquaculture. Habitats associated with lagoons and estuaries — such as mangroves and salt marshes — are destroyed for the construction of aquaculture ponds (IUCN, 2011). In addition, aquaculture farms discharge polluting effluents, rich in both nutrients and sediments, into the environment. In order to grow as much fin or shellfish as possible, aquaculturists add artificial feeds with chemical additives (including chlorine) and insecticides (including organochlorides which persist in the environment), as well as antibiotics to prevent disease. Many of these farms in Asia have no effective methods of effluent treatment and discharge their usually untreated effluent into surrounding land and/or downstream waterways. This negatively impacts water quality and aquatic life (IUCN, 2011). Suspended solids are also discharged, making the water turbid.

In addition to pollution by chemicals and nutrients, shrimp farms also produce organic waste such as faeces and unused food. (Overfeeding is a common problem in shrimp farming.) Shrimps farm effluents that have excess organic matter may have a high biological oxygen demand (BOD), which means that the waters into which these effluents are discharged become depleted in oxygen. This depletion in oxygen can, in turn, result in fish deaths, eutrophication and HABs as well as damage the seagrass meadows and coral reefs (EJF, 2004).

It is reported that 90% of organic matter entering the Tulang Bawang River in Lampung, Indonesia, and HABs — are from the area south of a shrimp farm in Lampung (EJF, 2004).

Aquaculture changes not only water quality but also water quantity, as large quantities of water are extracted to aerate and top up water levels in ponds.

Effluents released by shrimp farmers into Puttalam Lagoon (technically an estuary) have increased the pH of the water. The pH values were acidic (4.8-6) in 1983 and, in 1994, had turned basic (8-8.8). Many surveys carried out during this same period have revealed that there has been a gradual increase of ammonia concentration in coastal areas around the Puttalam Lagoon, particularly in the southern part of the water body, making the water basic. This increase in ammonia is a direct result of activities of shrimp farms (IUCN 2011).

Scientists believe that high levels of nutrients are the cause of eutrophication resulting in substantial fish deaths in the Dutch Canal, south of the Puttalam lagoon, connected to it by a narrow canal (Corea et al., 1995 in litt. Dayaratne et al., 1997). All the canals draining into the Lagoon are becoming eutrophic, overly-nitrified, and de-oxygenated (IUCN, 2011).

Changes in water quantity — changes to fresh water and tidal water inflows:

Changes in the natural ebb and flow in lagoons and estuaries have profound effects on these coastal ecosystems and are common worldwide (Kennish, 2002).

Changes to fresh water inflows

Freshwater is an estuary's life blood' (Olsen et al., undated). Freshwater and seawater mix and circulate in ways characteristic to a particular type of estuary (see section on

‘What are estuaries?’). Human modifications of the water cycle upstream and downstream affect not only the quality of the water (discussed in the previous section) but also the quantity of water flowing from rivers into estuaries (Olsen et al., undated).

The most common alteration of the quantity of freshwater flowing into estuaries is a reduction in the volume of water (Olsen et al., undated).

Dams and diversions upstream significantly affect the quantity and timing of water reaching estuaries downstream. In the mid-twentieth century, some 5,000 large dams had been constructed across various rivers all over the world, mainly in industrialised countries, but by the end of the twentieth century there were 45,000 large dams in some 140 countries (Olsen et al., undated).

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 salinity regime is altered.

The Narmada Valley Development Project is the single largest river development scheme in India. The 1,200 km Narmada river flows through the states of Madhya Pradesh, Maharashtra and Gujarat. Mooted as early as the 1940s, a multimillion dollar project to construct some 3,200 dams, of varying sizes, across the river began in 1979. The largest of these dams is the Sardar Sarovar dam at the lower end of the catchment. This dam was expected to provide drinking water to 40 million people, irrigate 4.4 million acres, and generate 1,450 mW of electricity. At 455 feet, this dam was expected to submerge 91,400 acres in the three states and displace more than 152,000 people, who would lose not only their homes, but also their livelihoods. Opponents of the dams predicted that the dam would cause a range of major environmental impacts such as water logging and siltation.

The Department of Forestry recommended several mitigation measures, while grass roots organisations proliferated and protested against the construction. The World Bank, which initially funded the project, withdrew their financial support after an independent commission — the Morse commission — reported that the project was flawed.

After more than a decade of conflict, the Supreme Court of India ruled in favour of the construction but with a reduced height of the dam (http://www1.american.edu/ted/ice/narmada.htm).

Also significant is ground water extraction (Olsen et al., undated).

When freshwater inputs are reduced by upstream anthropogenic actions, salinity in estuaries increases because there is less flushing (Olsen et al., undated). This salinity can spread upstream — increasing salinity in rivers — and also move into ground water aquifers resulting in salt water intrusion.

These salinity changes profoundly affect the different habitats and species found within these water bodies (Olsen et al., undated). When salinity increases, stenohaline species, that cannot tolerate changes in salinity, decrease, and euryhaline species, that can tolerate a wide range in salinity, increase, resulting in a change in the species composition of these water bodies. When the composition of fish species changes, there are serious impacts on fisheries.

The Indus River has a total length of more than 3,000 km and a drainage area of some 950,000 km^2. The Indus Delta is a typical fan-shaped delta, built up by the discharge of large quantities of silt washed down from upland and mountain areas.

The total available freshwater flow in the Indus is about 180 billion m^3, carrying with it some 400 million tonnes of silt. Over the last 60 years a series of dams, barrages and irrigation schemes have been built in upstream parts of the Indus River. Today, it is estimated that up to 60% of the Indus water is used to feed Pakistan's irrigation networks, and that the Indus watershed irrigates up to 80% of Pakistan's farmland.

As a result of upstream water abstraction, by the time the Indus reaches some 200 km from the Arabian Sea, there is inadequate flow to maintain the natural ecosystems of the Indus Delta.

The annual flow reaching the Delta before 1994 was less than 43 billion m^3, and quantities of silt discharged estimated to be 100 million tonnes/year. Even at this level, the amount of freshwater reaching the Delta was argued to be insufficient to maintain healthy natural ecosystems, and had resulted in severe saltwater intrusion and salinization. With the existing reduction in flow, downstream Sindh Province already claims it is short of the minimum 12 billion m^3 of water needed to maintain the Delta. Loss of freshwater flow, and consequent saltwater intrusion, has had devastating effects on the ecology and human economy of the Indus Delta. Land in the area has become unsuitable for agriculture, and potable water sources have become very scarce or have disappeared altogether. In Thatta, a district in Sindh Province, almost $1/3^{rd}$ of land has been affected by saltwater intrusion. It is estimated that about 12% of total cultivated area in the entire Province, is now affected by sea water intrusion (IUCN, 2007).

These salinity changes profoundly affect the different habitats and species found within these water bodies (Olsen et al., undated). When salinity increases, stenohaline species, that cannot tolerate changes in salinity, decrease, and euryhaline species, that can tolerate a wide range in salinity, increase, resulting in a change in the species composition of these water bodies. When the composition of fish species changes, there are serious impacts on fisheries.

In contrast, certain human actions increase rain water runoff, in turn, increasing freshwater inflows into estuaries and lagoons. Deforestation, conversion of natural habitats to agriculture and urbanisation (which increases impervious surfaces) increase freshwater runoff (Kennish and Paerl, 2010; Olsen et al., undated). Salinity decreases, again changing the species composition in these ecosystems.

Under natural conditions, rivers carry less water during dry seasons and more during rainy seasons. This pulsing (changes in volume, seasonally) can be altered by the damming of rivers during the dry season and their release during the wet season. Rivers therefore end up carrying even less water during the dry season and more during the wet season as a consequence of damming affecting salinity in both estuaries and lagoons (Olsen et al., undated). These pulsed changes have had serious impacts on fisheries (Olsen et al., undated).

Changes to tidal flows

One the major impacts on lagoons and estuaries is the development of structures that change the physical configuration of a lagoon or estuary (Samarakoon and Samarawickrama, 2012). A normal flushing regime in a lagoon or estuary involves freshwater inflow from rivers or surface runoff and the natural ebb and flow of tides. When structures impede this flow of water or isolate parts of the water body there are serious impacts, one of which is the exacerbation of flooding inland when the natural ebb of the tide, which could drain excess water from lagoons and estuaries, is obstructed (Samarakoon and Samarawickrama, 2012).

Batticaloa lagoon (technically a bar-built estuary) on the east coast of Sri Lanka, extending over about 14-15,000 ha, has three outlets into the sea. Freshwater volume changes seasonally, with less water during the dry season, when the mouth narrows and closes as a result of the formation of a sand bar. During the northeast monsoon, rainwater runoff increases and naturally breaches this sand bar, expelling the additional water to the sea.

After the Indian Ocean tsunami of December 2004, a tarred road was built across one of the outlets, Dutch Bar, impeding water flow. In 2010, heavy rains flooded the Batticaloa area, and this new road had to be breached to drain flood water (Samarakoon and Samarawickrama, 2012). It is estimated that it cost 160 million rupees (1.26 million USD) to achieve flood relief and rescue, rehabilitation and restoration (OCHA, 2011 in litt. Samarakoon and Samarawickrama, 2012).

An expressway from the main international airport at Katunayake to the capital Colombo isolates part of the Negombo lagoon (technically an estuary) on the north west coast of Sri Lanka, and the fragmented strip is being illegally used for development (Samarakoon and Samarawickrama, 2012). The Environmental Impact Assessment for this project recommended that a suitable land area along the lagoon verges should be identified to expand the lagoon area to compensate for the loss of water area after construction (Ranjit Galappatti pers.comm and Hewage, 2013).

Changes to the physical structure

Coastal infrastructure development — the construction of piers, ramps, groynes, ports, harbours and jetties — as well as aquaculture development, can have serious impacts on circulation patterns of freshwater and the tidal ebb and flow is disrupted, leading to a cascade of changes that could include all of the above impacts.

Overexploitation

Overexploitation of fisheries resources is another threat facing lagoons and estuaries. Because of the sheltered and safe environment of these water bodies, it is easier to fish in these waters than exposed to the elements in coastal waters. As a result, fish are harvested to a point where stocks can no longer recover naturally — i.e., above maximum sustainable yield (‘the largest catch that can be harvested from a species’ stock over an indefinite period’) (http://en.wikipedia.org/wiki/Maximum_sustainable_yield).

The maximum sustainable yield (MSY) for the Puttalam lagoon fishery is estimated at 5,536 million tonnes (Dayaratne et.al, 1997). Estimates for 2009 and 2010 from the Puttalam Department of Fisheries show that annual fish production for lagoon fisheries was already 1.2 times and 1.5 MSY respectively (Dayaratne et.al, 1997).

Tam Giang Lagoon, extending over 22,000 ha, is located in central Viet Nam. It is estimated that some 300,000 or more people live in the surrounds of this lagoon, with 100,000 people directly dependent on the lagoon for capture fisheries and aquaculture. Another 200,000 part-time fishermen and cultivators are dependent on the lagoon. There are also some 10,000 'Sampan' people who live on boats in the lagoon. There is a rich aquatic diversity that has historically supported a capture fishery in the lagoon and since the 1980s, aquaculture as well (Tuyen et al., 2010). It is reported that the number of fishermen increased from 5,575 in 1982 to 9,120 in 1993; in contrast, total production dropped from 4,042 tonnes in 1966 to 1,973 tonnes in 1994.

This lagoon is heavily overexploited by fishermen, who not only used fixed and mobile fishing gear, but also use methods to generate electricity (electric fishing) to electrocute fish within a radius of one mile with the consequence that fisheries resources have been depleted (Sharma, 1997).

Irresponsible fishing and tourism

Mooring, propellers and jet skis are emerging as a major threat to benthic organisms in lagoons and estuaries as well as habitats — such as seagrass meadows — found within lagoons and estuaries (Fonseca et al., 1998). Propellers of boats — used either for fishing or recreation — can slash the leaves of seagrasses and other submerged vegetation, leading to degradation of the habitat (http://www.sms.si.edu/IRLspec/Seagrass_Habitat.htm). Trampling or using fishing gear that rakes up vegetation and organisms is also damaging. For example, push nets and drag nets cause immense damage to seagrass meadows in coastal wetlands in Sri Lanka (C. Bambaradeniya, personal communication).

Similarly, irresponsible mooring and recreation can also endanger these habitats and benthic organisms.

Invasive alien species

Invasive Alien Species (IAS) are introduced species that do not stay confined to the area into which they were introduced, which compete vigorously with native species, become established in natural ecosystems, threaten native species and have the potential to eradicate them. When they displace native species and disrupt ecosystem interactions, they damage ecosystem services and can cause severe economic damage (IUCN, 2000).

Aquatic invasive alien plants — such as Water hyacinth (*Eichhornia crassipes*), Salvinia (*Salvinia molesta*) and Hydrilla (*Hydrilla verticillata*) — have filamentous roots that can block underwater channels. Their leaves form dense mats on the surface, clogging waterways, impeding water traffic and preventing fishing. This surface covering prevents sunlight from reaching submerged plants, with a subsequent drop in photosynthesis and an eventual reduction of aquatic biodiversity. These species can tolerate some salinity and trap sediments among their roots (Bambaradeniya et al., 2002).

Aquatic invasive alien animals can also cause disruption in aquatic food webs. When these animals are carnivorous, they eat up naturally found fauna in lagoons and estuaries. When they are herbivorous, they compete for resources such as food.

IAS can be brought in accidentally by various pathways, such as hitchhikers in ship and boat hulls, or escapees from aquaculture ponds (Kennish, 2002).

The Kalametiya lagoon, located on the southeastern coast of Sri Lanka, has been invaded by Water hyacinth and Salvinia (Ekanayake et al., 2005).

Habitat destruction

Habitat destruction is another serious threat facing lagoons and estuaries because destruction that occurs in the catchment of a river (for an estuary) or inland (for a lagoon) has as profound impacts on these water bodies as destruction that occurs within them.

On site, reclamation of wetlands for agriculture, aquaculture and infrastructure development results in a cascade of detrimental changes — such as changes in water inflows, increased sedimentation — and ultimately changes in species composition (Kennish, 2002). Coastal ecosystems all over the world are under considerable threat from habitat destruction (Duarte et al. 2008; Kennish, 2002; Waycott et al., 2009).

Ecosystem	Ariel extent (ha)	Published rates of loss (percentage loss per year)
Seagrass	18,000,000	7*
Salt marshes	140,000,000	1-2
Mangroves	15,000,000	1-3
Coral reefs	62,000,000	4-9
Tropical forests	1,900,000,000	0.5

(Duarte et al., 2008; * Waycott et al., 2009)

More insidious but as damaging but is destruction inland — deforestation — in watershed areas of rivers which can increase sedimentation and water flows (see sections above).

Climate change

Climate change has been called ‘the major, over-riding environmental issue of our time, and the single greatest challenge facing environmental regulators’ (http://www.unep.org/climatechange/Introduction.aspx). Between 1970 and 2004, the annual emissions of carbon dioxide (CO_2) grew by about 80%, and during the last century, the concentration of CO_2 in the atmosphere has risen by twelvefold. Increased emissions into the atmosphere of CO_2 and methane (CH_4) — so called greenhouse gases — cause a distinct warming of the earth. These gases function much like glass panes in a greenhouse, allowing light in, but preventing heat from escaping. This greenhouse effect, as it is called commonly, is important: without it, the earth would be too cold for humans to live. The problem is that now there is just too much greenhouse gas, making the earth too hot.

During the last century, the concentration of CO_2 rose through excessive use of coal and oil, countless vehicles using quantities of petrol, and industries emitting enormous amounts of CO_2 into atmosphere. Meanwhile, forests (that serve to soak up CO_2) are being cut down. Every year, 29.8 billion metric tonnes of CO_2 are emitted into the atmosphere (http://mdgs.un.org/unsd/mdg/SeriesDetail.aspx?srid=749&crid=). The result of these emissions and increased greenhouse effect is a distinct warming of the earth. During the last century, global temperature increased by about 0.8°C — measured as the largest increase in a thousand years.

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/planet-in-peril/page/1321.aspx). The current rate of sea-level rise is three times the historical rate and sea levels have already risen by 10-20 cm in the last century (IPCC, 2007). The IPCC predicts that global sea levels will rise between 0.09 to 0.88 m by 2100.
- Changes in rainfall patterns and
- Increases in extreme weather events such as cyclones, floods and droughts (http://unfccc.int/files/press/backgrounders/application/pdf/press_factsh_science.pdf).

All of the above will have serious impacts on lagoons and estuaries. Changes in temperature will increase evaporation, changing salinity. Changes in temperature also affect the amount of oxygen dissolved in the water body, so there could be profound impacts on both flora and fauna in lagoons and estuaries. Changes in rainfall will also alter freshwater inputs, as well as increase sedimentation from upstream. Increased storms could increase erosion on banks of lagoons and estuaries (Anthony et al., 2009). In contrast, sediments in shallow lagoons and estuaries may offset ocean acidification, particularly calcium carbonate-rich sediments, which can counteract the acidification effect by reacting with dissolved carbon dioxide and releasing calcium bicarbonate (de Wit, personal communication).

At a glance: services provided by and threats to lagoons and estuaries

(References as in text.)

Ecosystem service	Description	Threats
Provisioning services (Goods)		
Sustaining coastal fisheries	Many edible shell fish and fish are found in lagoons, estuaries and their associated habitats such as mangroves and seagrasses. Lagoons and estuaries serve as breeding and nursery grounds for many important fin and shellfish.	*Overexploitation:* fish are harvested to a point where stocks can no longer recover naturally — i.e., above maximum sustainable yield ('the largest catch that can be harvested from a species' stock over an indefinite period').
Providing places for coastal fishermen to anchor their boats	Many old cities are sited on estuaries because they provided safe ports for boats and small ships.	*Coastal infrastructure development* — the construction of piers, ramps, groynes, ports, harbours and jetties — as well as aquaculture development, can have serious impacts on circulation patterns of freshwater and the tidal ebb and flow is disrupted leading to a cascade of changes that could include all of the above impacts.
Supporting services		
Primary production	The mouths of estuaries, where rivers meet the sea are areas of high productivity. The primary productivity of estuaries matches that of tropical rain forests and coral reefs.	One of the main threats facing lagoons and estuaries is *point and non-point source pollution.* Non-point pollution leads to eutrophication, depleting oxygen dissolved in water, affecting marine animals such as fish, which die. Sometimes, the increase in phytoplankton can contain toxins and cause harmful algal blooms. The impacts of climate change will exacerbate existing threats.

Ecosystem service	Description	Threats
Supporting services contd.		
Cycling nutrients	In lagoons and estuaries, nutrients come in and are cycled within and are flushed to the open ocean.	As in previous page, under Primary Production.
Supporting coastal biodiversity	Because of their high primary production and efficient nutrient cycling, lagoons and estuaries support coastal biodiversity. Within the landscape of a lagoon or estuary, there is a mosaic of habitats, giving rise to rich ecosystem diversity and from this ecosystem diversity, species diversity.	*Changes in sedimentation:* increased sedimentation leads to increased turbidity profoundly affecting benthic organisms (common in shallow lagoons) as well as submerged habitats such as seagrass meadows, and later entire food webs in these water bodies. When sedimentation decreases, lagoon and estuary banks, as well as the coastal shorelines will erode; habitats such as mangroves that require replenishment of sediments become affected, in turn, affecting the flora and fauna that live in them. *Dredging* of lagoons and estuaries can sometimes have negative effects such as the destruction of benthic habitats and damage to water quality. *Aquaculture:* habitats associated with lagoons and estuaries — such as mangroves and salt marshes — are cleared for the construction of aquaculture ponds. In addition, aquaculture farms discharge polluting effluents, rich in both nutrients and sediments, into the environment altering water quality. Extraction of water for aquaculture also changes the quantity of water. *Changes in water flows* — through as dams and diversions — are also serious threats. The impacts of climate change will exacerbate existing threats.

Ecosystem service	Description	Threats
Regulating services		
Absorbing storm energy and providing flood protection and drainage	The water bodies of lagoons and estuaries function like buffer zones, protecting coastal communities from the full force of weather related events such as storm surges, floods and cyclones, by dampening wave action, dissipating river discharge and temporarily storing water. When there is flooding, lagoons and estuaries function like gigantic sponges to absorb excess water and drains this water to the sea. These interfaces also protect rivers from erosion from water and wind.	*Habitat destruction:* This loss leaves the coast vulnerable to the full force of physical impact of weather events. The impacts of climate change will exacerbate existing threats.
Trapping sediments and filtering water	The mosaic of habitats found in lagoons and estuaries (such as mangroves, salt marshes and seagrass meadows) function as large filters to extract pollutants, excess nutrients and sediments from carried from municipal and industrial wastewater inland and storm water runoff. The high rate of nutrient cycling that occurs within these water bodies quickly absorbs and removes these pollutants.	*Changes in water flows, changes in sedimentation.*
Cultural services		
Human habitation	Through the course of history, it is along the banks of rivers and near estuaries (where nutrient-rich, easily-cultivable soils are found) that humans have lived.	*Climate change.*
Important for recreation	Worldwide, lagoons and estuaries are used for recreation: for sailing and boating, fishing, swimming, other water sports such as jet skiing and kite surfing, as well as bird watching.	All the above threats.
Supporting traditional fisheries	Traditional fishing — fencing and amassing fish — has been practised in lagoons and estuaries since the 1st century. A common practice in South and Southeast Asia is brush pile fishery.	All the above threats.


What is being done to conserve lagoons and estuaries?

Because lagoons and estuaries are complex systems influenced by many factors, management must necessarily be holistic (Samarakoon and Samarawickrama, 2012).

However, holistic management is often hampered by a multitude and range of factors. Poverty and unemployment and other socio-economic factors are often indirect drivers of negative change. Layered onto these issues are the complexities of the jurisdictions and mandates of the organisations operating in the lagoons and estuaries. For example, in Sri Lanka, four agencies have overlapping jurisdiction over coastal and marine ecosystems. The Coast Conservation and Coastal Resources Management Department, under the Ministry of Defence, has primary authority over all coastal areas in Sri Lanka. It is responsible for developing national management plans, as well as overseeing current management and research. The Department of Wildlife Conservation manages marine and coastal protected areas, while the Forest Department has jurisdiction over mangroves, which are found in coastal areas (Joseph, 2003; IUCN, 2012). The Department of Fisheries and Aquatic Resources has management jurisdiction over fisheries resources in lagoons. Added to these layers are players from provincial and local governments.

Despite these drawbacks, a holistic approach is the ideal, and must be the aim with which management of these water bodies is undertaken.

Under the aegis of two projects of IUCN Sri Lanka, a multi-stakeholder platform (that include government officials from relevant organisations — to ensure a holistic approach, as well as communities — to safeguard their rights, was formed in Periyakalapu, a lagoon on eastern coastline. This multi-stakeholder platform has been responsible for changing a decision made by the Road Development Authority, to develop two causeways across the lagoon. With the influence of the multi-stakeholder platform, two bridges were built instead of causeways, minimising damage to the lagoon. (Causeways impede natural water movement in and out of lagoons, whereas bridges, because they are raised, allow water flow underneath them.)

Shifting to a landscape approach to management

Conservation biologists have realised that ecosystems cannot be viewed in isolation, but are a part of an interconnected and interdependent mosaic of habitats that may not be only spatially but also temporally distributed and that are impacted by actions both within and without the landscape (Meffe et al, 1997). This is clearly seen on coastlines, where human impacts in catchment areas of upland forests can have detrimental impacts on coastal habitats such as lagoons, estuaries, mangroves, seagrasses and coral reefs.

After the Indian Ocean tsunami of December 2004, the German Federal Ministry for Economic Cooperation and Development (BMZ) financed a project implemented under the auspices of Mangroves for the Future (MFF) to rehabilitate and conserve coastal ecosystems in Sri Lanka and Thailand. Commonly called the BMZ project, this project promoted coastal ecosystem rehabilitation and conservation activities in critically degraded ecosystems in coastal stretches of Puttalam Lagoon in northwest Sri Lanka and the Andaman Sea coast from Phang Nga to Ranong Province in western Thailand. The overall aim of the project was to highlight the linkages between ecosystem health and livelihoods in the selected sites.

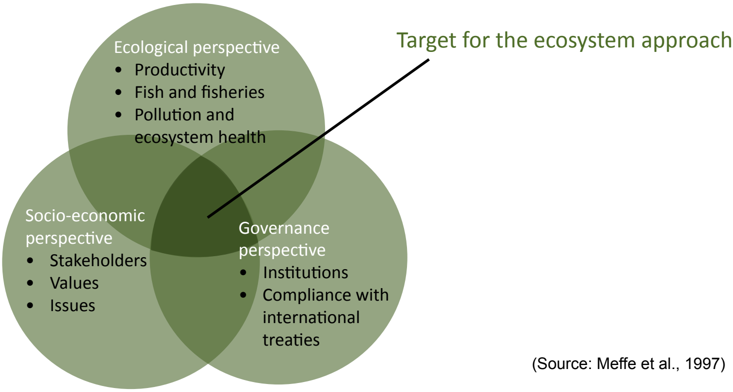
IUCN Thailand adopted a Ridge to Reef (R2R) approach to management focusing on a target area in southern Thailand which spanned approximately 130 km and encompassed the Kuraburi and Kapoe watersheds, with a population of 6,500 persons within 1,800 households. The area consisted of a wide range of inter-connected habitats from undisturbed evergreen forest to grasslands, mangrove and swamp forests, sub tidal flats, coral reefs, and seagrass meadows (Soonthornawaphat and de Silva, in press). Distances from undisturbed montane ecosystems to sea-grass ecosystems were as little as 15 km reflecting a 'reef to ridge' landscape (Soonthornawaphat and de Silva, in press).

Shifting to a holistic, ecosystem approach to management

Because of their complexity, lagoons and estuaries also need a central holistic approach of integrated coastal management that recognises the essential need for spatial, temporal, sectoral, political and institutional integration. Often, interventions for coastal development are carried out by engineers, while the management of fisheries lies with fisheries departments and conservation actions are guided by departments mandated with biodiversity conservation. To this end, the ecosystem approach, that '. . . maintain[s] or restor[es] the composition, structure or function of natural and modified ecosystems for the goal of long-term sustainability [is ideal]. [The ecosystem approach] is based on a collaboratively developed vision of desired future conditions that integrates ecological, socioeconomic and institutional perspectives, applied within a geographic framework defined primarily by natural ecological boundaries' (Meffe et al., 1997).

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).

The Ecosystem Approach



(Source: Meffe et al., 1997)

In the coastal zone, Integrated Coastal Zone Management embodies the ecosystem approach. The concept of Integrated Coastal Zone Management predates the ecosystem approach and the Millennium Ecosystem Assessment and was developed during the Earth Summit of 1992, held in Rio de Janeiro. However, 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 issues of common concern, which leads to information collection, dialogue and cooperation leading to joint decision making, coordinated management and monitoring of implementation — all of which promotes integration across space and sectors (European Communities, 1999).

The Chilika Lagoon, Odisha, is a highly productive brackish water lagoon that extends over 1,100 km^2 and supports some 20 million people. It is listed as a wetland of International Importance. Overuse and degradation resulted in the placement of this lagoon, in 1993, on the Montreux record of the register of wetland sites on the List of Wetlands of International Importance. (The Montreux record notes where detrimental changes have occurred in wetlands of International significance.) The Government of Odisha created the Chilika Development Authority (CDA) which began a process of integrated management process to address the complex issues related to the degradation of the lagoon. The CDA extended their reach to include the watershed and the coast, and used a bottom-up participatory approach that empowered local communities and provided alternative livelihoods but linked experts and institutions at state, national and international levels. This approach resulted in an increase in fisheries and an improvement of water quality and led to the removal of Chilika lagoon from the Montreux record (http://www.cbd.int/kb/record/sideEvent/2942?FreeText=side; Pattnaik, 2005).

Ensuring community participation

Lagoons and estuaries are complex systems with a range of natural and human-induced influences acting upon them (Samarakoon and Samarawickrama, 2012). Therefore, integral to the management of lagoons and estuaries are the immediate users of such water bodies — local communities that depend on the ecosystem services provided by these water bodies. Samarakoon and Samarawickrama (2012) propose the use of the phrase social-ecological-system for this framework.

The Negombo lagoon on the west coast of Sri Lanka is relatively small and shallow, but is important economically for long term use in traditional fisheries, trade and tourism. In the mid-1950s, it was the focal point of modernisation of fisheries, and then became the main fishery outlet in the country. It was heavily polluted in the 1960s by industrial waste and is surrounded by heavy urbanisation and industrialisation, with the first free trade zone in the country established on its eastern border. It is also an important and long established tourist destination (Samarakoon and Samarawickrama, 2012).

Some 3,000 traditional lagoon fishers, and as many coastal fishers, use the Negombo lagoon to fish and anchor their boats. While modernization only occurred in the mid-1950s, traditional fisheries (in particular, stake-net fishery) date back several centuries (Samarakoon and Samarawickrama, 2012). There is an indigenous management system that is operated and implemented successfully. There are some 285 members of fisheries cooperative societies, run democratically, under the chairmanship of a senior Roman Catholic priest. These societies set codes of conduct with penalties for violation of these codes. Rotating stake net stations are allocated by lottery, for equitable sharing of benefits (BOBLME, 2011).

These fisheries cooperatives have been responsible for preventing the construction of a fisheries harbour, a seaplane landing site and various hotels on the Negombo lagoon (Samarakoon and Samarawickrama, 2012).

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Page no.	Caption	Credit
iii	Catamarangs in Kokkilai lagoon, northeastern Sri Lanka	Kumudini Ekaratne © IUCN
5	Mangroves in Puttalam lagoon, northwestern Sri Lanka	© Sriyanie Miththapala
10	Bentota estuary, southwestern Sri Lanka	© Sriyanie Miththapala
15	Egrets in Kokkilai lagoon	Kumudini Ekaratne © IUCN
17	Mangroves in Puttalam lagoon	© Dilup Chandranimal
19	Water monitor (*Varanus salvator)*	© Riaz Cader
20	Seagrasses	© Terney Pradeep Kumara
21	Mangroves showing stilt roots, Bentota estuary	© Luxshmanan Nadaraja
22	Top: Barnacles on mangrove stilt roots; bottom: Mudskippers	Sanjeewa Lelwala © IUCN; Anoma Aligiyawadu
24	Pencil breathing roots	© Harith Gunawardana
25	Fishermen in Batticaloa lagoon, eastern Sri Lanka	© Sriyanie Miththapala
27	Anchored boats, Batticaloa lagoon	© Sriyanie Miththapala
31	Top: Seagrass meadows and middle: tidal flats in Puttalam lagoon; bottom: mangroves in Muthurajawela marsh, northwestern Sri Lanka	Naalin Perera © IUCN; (top and middle); Sriyanie Miththapala
32	Top: Greater flamingo (*Phoenicopterus ruber*); Bottom: Spot-billed pelican (*Pelecanus philippensis*) in Bundala lagoon	© Studio Times; Luxshmanan Nadaraja
34	Brush pile fishery, Negombo, Sri Lanka.	© Chamara Amarasinghe
41	Coastal erosion in Maha Oya, northwestern Sri Lanka, as a consequence of upstream sand mining	© CRMP
43	Aeration of shrimp farms using large amounts of water, Puttalam lagoon	© Dilup Chandranimal
46	View of Batticaloa lagoon	© Sriyanie Miththapala
47	Dutch Bar road, Batticaloa	© Ananda Galappatti
50	Push nets which damage lagoon floor beds	© Dilup Chandranimal
51	Water Hyacinth (*Eichhornia crassipes*), spread in Kalametiya lagoon, southern Sri Lanka	© Channa Bambaradeniya
52	Destruction of mangroves in Puttalam	Naalin Perera © IUCN

Page no.	Caption	Credit
57	Top: Fisherman in Kokkilai lagoon; Bottom: Plovers in Bundala lagoon	Kumudini Ekaratne © IUCN; Luxshmanan Nadaraja
62	Top and Bottom; Negombo, lagoon fishers	© Riaz Cader
71	Top: Fishers in Puttalam; Bottom: Fisher in Negombo lagoon	© Niroshan Mirando; Riaz Cader
73	Sunset at Bundala lagoon	© Luxshmanan Nadaraja

Mangroves for the Future
INVESTING IN COASTAL ECOSYSTEMS

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 recently expanded to include 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.

http://www.mangrovesforthefuture.org/