

BEFORE THE NATIONAL GREEN TRIBUNAL (SZ) CHENNAI

**MEMORANDUM OF APPLICATION
(Under Section 18(1) read with Sections 16 (h) of National Green Tribunal
Act, 2010)**

Appeal No.14 of 2022

M. Yuvadeeban

...Appellant

Vs.

Department of Fisheries & Ors

...Respondents

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Through

A.Yogeshwaran
Counsel for the Appellant

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...Appellant

Vs.

Department of Fisheries & Ors

...Respondents

Additional rejoinder filed by the Appellant

I, M. Yuvadeeban s/o Margaret Lawrence, aged about 26 years, residing at B2, Ramaniyam Marvel, Seshadripuram, 1st main road, Velachery, Chennai 42, do hereby solemnly affirm and sincerely state as follows:

1. I am the Appellant herein and am aware of the facts and circumstances of the case and am competent to affirm to the contents of this affidavit.
2. The project proponent had filed a pleading titled "Counter affidavit of the 1st respondent" dated 23.09.2022. I had filed a reply to the same. I submit that the importance of the estuary mouth, the sand bar and shallow waters to birdlife and biodiversity has been completely ignored in the project documents and the affidavits filed by the respondents.
3. In this context, I am filing along with this affidavit, a note on the importance of protecting Coastal Estuarine Mudflat habitats for shorebirds authored by Dr. V. Santharam, Director, Institute of Bird Studies & Natural History, Rishi Valley Education Centre. References mentioned therein and studies along with his CV are also filed along with this affidavit. The importance of protection of mudflats habitats for shorebirds is clear from these documents. The dredging of the estuary, removal of the sand bar etc would destroy critical habitats.
4. It is submitted that these aspects have not even been disclosed or considered in the EIA reports submitted by the project proponent and by the SEIAA during the clearance process. It is prayed that this Hon'ble Tribunal consider these aspects while deciding the validity of the impugned clearance.

Solemnly affirmed and signed his

Name this the 10th day of November, 2022

At Chennai



BEFORE ME

ADVOCATE : CHENNAI

Nivedita
 Nivedita
 10/11/22
 No. 21/10/22
 Public Hearing
 Dr-90

Institute of Bird Studies & Natural History

Rishi Valley Education Centre

(Krishnamurti Foundation India)

Rishi Valley 517352

Annamayya District

Andhra Pradesh

INDIA



V. Santharam

Director

A note on the importance of protecting Coastal Estuarine Mudflat habitats for shorebirds – a compilation

Coastal wetlands provide important services, such as food and bio-materials as direct resources, habitat for wildlife, carbon sequestration, protection against storm surges, and sediment accumulation for land accretion. They also provide water purification, tourism resorts, and other functionalities.

[Reference: Anthropocene Coasts 1: 1–15 (2018) dx.doi.org/10.1139/anc-2017-0001]

Tidal flats are found on coastlines and on the shores of lagoons and estuaries in intertidal areas (areas that are flooded at high tide and exposed at low tides). Even though tidal flats — largely devoid of vegetation — initially look as if they had no life, they are teeming with organisms.

The most important autotrophs in tidal flats are microscopic blue-green organisms called cyanobacteria. There is usually an abundance of invertebrates in these coastal ecosystems and these serve as food for larger fish and a wealth of shore birds and water birds. Among the most important functions that tidal flats perform is to provide feeding grounds to migrant birds, most of which use tidal flats during stopovers while they are migrating.

[Reference: Miththapala, Sriyanie (2013). *Tidal flats*. Coastal Ecosystems Series (Vol 5). iii + 48pp. Colombo, Sri Lanka: IUCN.]

The impacts of river dredging on the aquatic ecosystem and the life it supports have been relatively well-studied.

Dredging will affect a river's composition, diversity and resiliency in a variety of ways. After a river is dredged, its banks will become prone to erosion. Eroded banks will stimulate further build-up of silt, exacerbating rather than improving problems with navigation. Moreover, disturbance of bank vegetation caused by erosion will remove cover and shade. This will increase light penetration and hence water temperature, which will cause fish to migrate. Besides, loss of soils will disturb the habitat of river bank fauna.

River dredging can have a number of impacts on local fish populations. Many fish species depend on structured habitats for refuge from the current. The loss of natural habitat can render new dredged habitats unsuitable for shallow-water fish. Furthermore, deeper habitats may make a river more vulnerable to exploitation by invasive non-native species.

Fish eggs, fry, larvae and juveniles can be sucked up and displaced by dredging, which will cause death. If they do survive, they will experience higher mortality rates due to injuries, physiological stressors, disorientation, abrasions and infections. Molluscs and amphibians which are important parts of the aquatic ecology can also suffer death from dredging equipment.

Dredging has significant impacts on fish and amphibians during reproduction. Spawning is a stressful period and fish are highly vulnerable to disturbance during this time. High levels of human activity can result in fewer fish eggs.

Dredging activities often disturb sediments, thereby reducing visibility and increasing the turbidity of water to the point where the amount of photosynthesis that can occur in the water is curtailed with the result that there will be an overall impairment of the function of the ecosystem. Consequently, growth of fish and other organisms will be affected since food supply will be reduced in the turbid conditions. Other adverse effects of turbidity include decrease in disease resistance, suffocation and death.

One of the potential consequences of dredging is a change in the water transport and circulation patterns in the area. In an estuarine situation, the dredged river can allow saltwater from the Bay of Bengal to move further into the estuary than would occur otherwise. This will have grave consequences on freshwater marine life.

There are documented evidences showing clearly that rivers which have been dredged, silt-up more frequently and return to their pre-dredged state. Thus, dredging is an unsustainable activity since it needs to be repeated frequently. That's why there is a growing awareness among environmentalists that artificially deepening a river may not be helpful after all and may even be counter-productive.

[Reference: <https://www.thedailystar.net/opinion/environment/adverse-effects-river-dredging-the-aquatic-ecosystem-1302262>]

Many intertidal coastal environments, mostly those linked to estuaries, have been historically used as natural harbors, an activity that is often associated with constant or periodic dredging in order to keep or increase the depth of these water bodies. The material (clay, sand or mud) extracted during such dredging is often dumped close to the dredging area to minimize the economical cost of the transport. One of the main consequences of dredging and dumping actions is habitat burial or destruction, with a negative impact on the ecosystem, especially on the macrobenthos that is situated in the bottom of the trophic network. Thus, any negative effect on such communities can alter the entire trophic structure related to the mudflats and, consequently, induce negative effects on upper trophic levels.

Clayey-muddy and sandy substrates do not host the same communities of macrobenthos that constitute the food of many shorebirds. In general, mudflats are commonly richer in shorebird food than sandy areas. Dredging and dumping actions carried out in estuary areas often cause habitat loss in very ecologically-sensible habitats, such as mudflats. Thus, dumping of sand in some sensitive estuarine areas where there is an active sediment transport could cause a coverage of the mudflats and, consequently, long-lasting negative effects on benthic communities, as well as severe negative consequences for shorebirds using these areas.

A strong dredging and dumping episode carried out at Urdaibai (North of Spain) resulted in a covering of existing mudflats by sandy sediment which promoted a decrease of the population size of a number of shorebird species wintering in this area. This effect was much clearer in species more dependent on mudflats to feed. [Reference: DOI: 10.1016/j.jnc.2017.02.006]

Shorebirds, also known as waders, gather in intertidal areas or on the fringes of freshwater wetlands. They generally have long legs in relation to their body size, no webbing on their feet and they don't swim. The shape and size of their bill gives a clue to their preferred diet and habitat. For example, the long, probing bill of the eastern curlew is ideal for fishing out worms and crustaceans from deep mud, whereas the short, stubby bill of the ruddy turnstone can flip aside stones and shells on a rocky foreshore.

Some shorebirds weighing as little as 30 grams may migrate 25,000 km annually. Some species may fly more than 6,000 km non-stop. In doing this, they use favourable weather patterns when they can, but even so will commonly lose 40 per cent of their bodyweight, flying at more than 60 km/hr, non-stop for three days and nights. Shorebirds make the journey in several weeks, stopping two or three times along the way. When they stop, they must 'refuel': they feed and rest to build up energy reserves. At these times they may increase their body weight by more than 70 per cent before undertaking the next marathon stage of their journey.

Through wind and storm, enduring unbearably hot days and freezing nights, avoiding waiting hunters, shorebirds miraculously navigate along a precious chain of wetlands, including Moreton Bay, to complete their global journey. Migrating shorebirds travel these remarkable distances each year because of their special breeding requirements. Breeding takes place in areas where melting snow signals masses of insects, providing a vital food source for self-feeding chicks. Once breeding is complete, and before the onset of the Arctic winter, the adults and newly fledged chicks begin their incredible return journey to the plentiful feeding grounds of the south.

Migrating shorebirds need huge amounts of energy to complete this perilous journey. One of the best-studied species, the eastern curlew, dramatically builds up its body weight just before migration. During its flight from Siberia to Australia, it will burn off 40 per cent of this weight to fuel its 13,000 km journey. This is like an 80 kg person running 16 million kilometres almost non-stop and losing 32 kg, twice a year!

The routes that shorebirds travel along on their annual migration are called flyways. A flyway is broadly defined as the migration route of a population, species, or group of species of birds, between a breeding area, through the staging sites and non-breeding area. Flyways are like invisible highways. How does a migrating shorebird know which way to go? Are there maps in the stars? Patterns on the land? Memories in their genes? Or are they guided by the sun and the moon or the earth's magnetic field? Scientists say it is probably a combination of all of these but they are still unclear exactly how migratory shorebirds find their way.

Like weary travelers on a lengthy journey, shorebirds need rest stops along the way to refuel and have a break. Flyways are like chains with many links. Each link is an important wetland, such as an estuary or bay, where the birds can stopover to feed and regain their strength for the next leg of their migration. The message is clear, everything is interconnected — remove enough of these links and species may disappear altogether!

[Reference: <https://environment.des.qld.gov.au/wildlife/animals/living-with/shorebirds>]

Shorebirds facilitate the energy and nutrient exchanges between land and sea. Because a lot of them are long-distance migrants, they also facilitate the energy and nutrient exchanges across different ecosystems and continents, something that is usually overlooked and underappreciated.

Recent research showing that more than 15%, or more than 12,000 square miles, of the world's natural tidal flats were lost between 1984-2016.

[Reference: <https://www.sciencedaily.com/releases/2020/06/200609130020.htm>]

Shorebird droppings, called guano, fertilize the mudflats in which they feed and the water over which they fly. The guano helps microscopic plants, called phytoplankton, grow. Phytoplankton form the base of the food chain upon which the fish we eat depend.

Because shorebirds are dependent upon wetlands, they are good indicators of wetland health. The health of an indicator species tells biologists something about the health of other creatures using or composing that habitat. For instance, if there is a change in population of a shorebird, then perhaps populations of worms on which it feeds are being similarly changed. A change in condition of one shorebird species might lead us to hypothesize that other shorebirds using the same resources will be similarly affected. Perhaps one of the abiotic (nonliving) components of the ecosystem, like the water, is polluted. An indicator species is usually an easily observable organism, and you might find that a change in a shorebird population is the first indication, or hint, that a water source is polluted.

[Reference: <https://shorebirds.pwnet.org/migration/importance.htm>]

Coastal wetlands in India provide winter refuge for migratory waterfowl from different parts of the world such as north, central and west Asia, Europe and Mediterranean regions. Birds migrating from Arctic to east Africa use the coastal wetlands of northwestern India as a stopover sites.

Coastal wetlands in India also provide habitat for several federally listed threatened and near threatened bird species. The threatened species, namely Spotted Greenshank *Tringa guttifer*, Spoonbill Sandpiper *Calidris pygmeus*, Dalmatian Pelican *Pelecanus crispus*, Spot-billed Pelican *Pelecanus philippensis*, Pallas's Fish-eagle *Haliaeetus albicilla*, Wood Snipe *Gallinago nemoricola* and Indian Skimmer *Rynchops albicollis* and the near threatened Darter *Anhinga melanogaster*, Painted Stork *Mycteria leucocephala*, Lesser Flamingo *Phoenicopterus minor*, Asian Dowitcher *Limnodromus semipalmatus*, Beach Stone-Plover *Esacus magnirostris* and Black-bellied Tern *Sterna acuticauda* are some of the important species, which are found in the coastal wetlands. The body mass (weight) gained at the wintering and staging areas generally help the migratory birds to breed successfully at their northern breeding grounds. In India, most of the freshwater bodies dry up during the spring passage (return migration to their breeding grounds in March and April), and hence, migratory birds depend only on the coastal wetlands to build up their body mass.

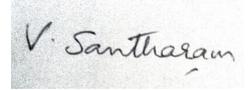
In east coast of India, due to the degradation of wetlands habitats, populations of various waterbird species are dwindling in their traditional wintering sites. One of the greatest threats to the sustainability of the coastal wetlands and the survival of the flora and fauna, which depend on this unique habitat, is human disturbance to the shoreline. In India, due to the degradation of wetlands habitats, populations of various waterbird species are dwindling in their traditional overwintering sites.

Over one million migratory waders and ducks were reported from Point Calimere during the 1980s which declined to less than 150,000 in the late 1990s. However, in recent years the population goes upto 3,50,000 which may be due to the shifting of population from other coastal wetlands which traditionally supported more coastal birds. It is clear that different species utilise different suites of sites during northbound and southbound migration. Therefore, protection of only the best sites will not provide an adequate site network for all migratory species and broader protection of as many sites as possible is required. [Reference: <https://www.upsbdb.org/pdf/Souvenir2012/ch-19.pdf>]

There has been about 47% decline in Wetland birds 2000-2018 in India.

India ranks 6th in the list of Ten countries/territories with the greatest number of globally threatened bird species with 20 “Critically Endangered” and 20 “Endangered” and about 50 Vulnerable bird species.

[Reference: **State of the World's Birds 2022** Report]

A rectangular box containing a handwritten signature in black ink that reads "V. Santharam".

V. Santharam

Rishi Valley
7 November 2022

Anthropocene Coasts 1: 1–15 (2018) [dx.doi.org/10.1139/anc-2017-0001](https://doi.org/10.1139/anc-2017-0001)

https://www.researchgate.net/publication/322238920_Coastal_wetland_loss_consequences_and_challenges_for_restoration

Miththapala, Sriyanie (2013). Tidal flats. Coastal Ecosystems Series (Vol 5). iii + 48pp.

Colombo, Sri Lanka: IUCN <https://portals.iucn.org/library/node/44946>

Adverse effects of river dredging on the aquatic ecosystem

<https://www.thedailystar.net/opinion/environment/adverse-effects-river-dredging-the-aquatic-ecosystem-1302262>

The negative effect of dredging and dumping on shorebirds at a coastal wetland in northern Spain <https://www.sciencedirect.com/science/article/abs/pii/S1617138117300705>

Shorebirds <https://environment.des.qld.gov.au/wildlife/animals/living-with/shorebirds>

Study on shorebirds suggests that when conserving species, not all land is equal

<https://www.sciencedaily.com/releases/2020/06/200609130020.htm>

Importance of shorebirds <https://shorebirds.pwnet.org/migration/importance.htm>

Avian Diversity in Coastal Wetlands of India and their Conservation Needs

<https://www.upsbdb.org/pdf/Souvenir2012/ch-19.pdf>

State of the World's Birds 2022 <https://www.birdlife.org/papers-reports/state-of-the-worlds-birds-2022/>

Briefly about myself

V. Santharam

Have been birding since 1977. Studied Commerce at the Graduation level and completed my Masters in Ecology and PhD in Ecology from Pondicherry University. Have been working in Rishi Valley Education Centre, Andhra Pradesh, as a teacher since 1998 besides being the Director, Institute of Bird Studies & Natural History in Rishi Valley.

My research experience includes:

Avi-Faunal survey of scrub-jungles around Madras (1989; M.S. Thesis project).

Worked in the Bird Migration Project of the Bombay Natural History Society from January 1990 - April 1990 at Sriharikota (Pulicat Lake).

Study of the Avifauna of Lakshadweep Islands, 1990-91 (Sponsored by the Department of Science and Technology, Lakshadweep Administration).

Ecological study of woodpeckers at the Peechi-Vazhani Wildlife Sanctuary, Kerala (1991 - 1993; Ph.D. Dissertation work). - Supported by Wildlife Conservation Society, New York.

Worked as a Research Associate in the project "Conservation Planning for the Western Ghats of Kerala" from December 1994 to September 1995 at Salim Ali Centre for Ornithology and Natural History (SACON), Coimbatore.

A survey of the Great Black Woodpecker in the Western Ghats (1994-1996). - Supported by Wildlife Conservation Society, New York.

A status survey of inland wetlands of the Kancheepuram and Tiruvallur districts of Tamil Nadu, (1997) for the Bombay Natural History Society, Mumbai for its ENVIS programme.

Ornithological survey of the Sirumalai Hills, Tamilnadu (2006-2007), study funded by Oriental Bird Club, UK.

Besides, I have been monitoring birdlife in Chennai and Rishi Valley over several years and have compiled checklists of birds for these areas. Have been participating in Asian waterfowl Census since 1987. Participated in several short-term bird surveys conducted in Kerala, Karnataka, Tamilnadu and Andhra Pradesh organised by Forest departments along with local NGOs. Have also birded in various parts of the country including Himalaya and Gujarat.

Publications: Over 220 papers, articles, notes and popular articles. List can be had from: <http://www.southasiaornith.in/records/search?type=&field%5B0%5D=&field%5B1%5D=1&term%5B0%5D=Santharam&term%5B1%5D=>

Other Activities:

Life member of Madras Naturalists' Society and the founder-editor of its quarterly journal 'Blackbuck'.

Organised and/participated as a resource person in nature camps conducted by Madras Naturalists' Society, Youth Hostels Association of India and Rotary Club.

Participated in several workshops, slide shows and photographic exhibition.

Active involvement in the conservation efforts of Adyar Estuary in Madras and Silent Valley in Kerala.

Participated as a resource person for the Avian Red Data Book, Asia workshops and Important Bird Area (IBA) regional workshops. State Coordinator IBA programme for Tamil Nadu.

Organised Nature Camps for students of Rishi Valley School to Garhwal Himalayas in 2001, Sikkim in 2002 and Periyar Tiger Reserve and Eravikulam (Kerala) in 2003.

Trustee, New Ornithology Foundation, Hyderabad and Associate Editor, Indian Birds (formerly Newsletter for Ornithologists), Published from Hyderabad (2004 -)

Conducted a Field Study Course in Ornithology, Rishi Valley School July, 2007 and at Chennai in April, 2008.

Conducted workshops on Bird-watching for students and teachers at various schools in India since 2008.

Resource Person at the "Bioresources Vacation Course" conducted by the Murugappa Chettiar Research Centre (MCRC), Chennai at Mahabalipuram in May 2006 and 2008.

Moderator of Tamilbirds Yahoo Group since 2006 (now a google Group).

Involved with the organising and conduct of Tamilbirders' Meet in various locations in Tamilnadu since 2014.

Regional editor of eBirds (Tamilnadu) and consultant for Andhra Pradesh.

Have also participated in several workshops and seminars as a resource person from 1989.

Coastal wetland loss, consequences, and challenges for restoration

Xiuzhen Li, Richard Bellerby, Christopher Craft, and Sarah E. Widney

Abstract: Coastal wetlands mainly include ecosystems of mangroves, coral reefs, salt marsh, and sea grass beds. As the buffer zone between land and sea, they are frequently threatened from both sides. The world coastal wetland lost more than 50% of its area in the 20th century, largely before their great value, such as wave attenuation, erosion control, biodiversity support, and carbon sequestration, was fully recognized. World wetland loss and degradation was accelerated in the last three decades, caused by both anthropogenic and natural factors, such as land reclamation, aquaculture, urbanization, harbor and navigation channel construction, decreased sediment input from the catchments, sea level rise, and erosion. Aquaculture is one of the key destinations of coastal wetland transformation. Profound consequences have been caused by coastal wetland loss, such as habitat loss for wild species, CO₂ and N₂O emission from land reclamation and aquaculture, and flooding. Great efforts have been made to restore coastal wetlands, but challenges remain due to lack of knowledge about interactions between vegetation and morphological dynamics. Compromise among the different functionalities remains a challenge during restoration of coastal wetlands, especially when faced with highly profitable coastal land use. To solve the problem, multi-disciplinary efforts are needed from physio-chemical–biological monitoring to modelling, designing, and restoring practices with site-specific knowledge.

Key words: coastal wetlands, functionalities, loss, consequence, restoration.

Introduction

The world's wetlands have been diminishing since the 19th century. Many wetlands were reclaimed for other use (e.g., agriculture) before their significance was recognized. Coastal wetlands, which lie between the land and the ocean, are threatened from both human activity and natural hazards, such as climate change, sea level rise, local subsidence, decreased sediment supply, and acidification.

According to the Ramsar Convention ([Ramsar Convention Secretariat 2010](#)), coastal wetlands include mangroves, salt marshes, seagrass, coral reefs, beaches, estuaries, and coastal water bodies within –6 m depth. Of these, mangroves and salt marshes are the most prominent. Mangroves are mainly distributed along tropical muddy coasts, with a total area of 150 000 km², while salt marshes dominate the muddy coasts from subtropical, temperate to sub-polar and arctic zones, with a total area of 45 000 km² ([Scott et al. 2014](#), see also <http://www.ramsar.org>). But a century ago, the area of mangroves and salt marshes used

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X. Li. State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai 200062, China.
R. Bellerby. State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai 200062, China; Norwegian Institute for Water Research, Bergen N-5006, Norway.
C. Craft and S.E. Widney. School of Public and Environmental Affairs, Indiana University, Bloomington, IN 47405, USA.
Corresponding author: Xiuzhen Li (e-mail: xzli@sklec.ecnu.edu.cn).
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to be at least 100% larger (Scott et al. 2014). The latest global coral reef assessment estimated that 19% of the world's coral reefs are dead, with warming sea-surface temperatures and expanding seawater acidification as major threats (Worldwatch Institute 2016). The exact area loss of seagrass is not clear because their distributions are not clear yet in many places. But the consequences of coastal ecosystem loss were obvious.

Lotze et al. (2006) divided human influences on coastal ecosystems into seven periods: prehuman; hunter gatherer; agriculture; market-colonial establishment; market-colonial development; global market 1900–1950; and global market 1950–2000. With the development of human economic stages, the status of marine mammals, coastal birds, fish, reptiles, invertebrates, vegetation, water quality, and invasive species have all faced serious deterioration, and the trend has accelerated since the global market economy began in the 1900s. The general deterioration trend continued after year 2000 with limited restoration efforts scattered at different sites. It is a critical time to stop depletion of this vulnerable ecosystem and make efforts to restore the coastal wetlands wherever possible.

The purpose of this paper is to provide a comprehensive understanding of the importance of coastal wetlands, their current status of losses and consequences at different regions, and challenges faced for restoration. Some recommendations are also proposed for consideration in the future conservation and restoration practices.

Importance of coastal wetlands

Coastal wetlands provide important services, such as food and bio-materials as direct resources, habitat for wildlife, carbon sequestration, protection against storm surges, and sediment accumulation for land accretion. They also provide water purification, tourism resorts, and other functionalities.

Bioproductivity and habitats

Although the area of coastal wetlands is rather small compared to many other terrestrial ecosystems, their productivity is comparable to the most productive ecosystems. For example, the average net primary productivity of mangroves is as high as that of the tropical rain forest ($2.2 \text{ kgm}^{-2}\text{year}^{-1}$), while the productivity of algal beds and reefs ($2.5 \text{ kgm}^{-2}\text{year}^{-1}$) is even higher (Whittaker 1975). The net primary productivity of temperate salt marshes ($1.7 \text{ kgm}^{-2}\text{year}^{-1}$) is also higher than that of temperate forests ($1.2\text{--}1.3 \text{ kgm}^{-2}\text{year}^{-1}$) (Whittaker 1975; Bertness 1999).

As key habitats for many terrestrial and marine species, vegetated zones and tidal creeks provide diverse shelter and food sources for a large variety of wild animals, resulting in high biodiversity and unique food webs. About two-thirds of marine animals, such as fish, shrimps, crabs, mollusks, and turtles, have to spend some time at coastal wetlands during their life history, and over 90% of marine fisheries are sourced from coastal zones, either through harvesting of wild organisms or mariculture (Hinrichsen and Olsen 1998). In the meantime, the coastal wetlands provide food sources and habitats for millions of waterbirds.

Carbon sequestration

In terms of carbon sequestered in the soil or sediments of different ecosystems, the mean long-term rates of carbon sequestration for salt marshes, mangroves, and seagrasses ($>100 \text{ g C m}^{-2}\text{year}^{-1}$) are more than 20 times higher than that of the forest ($<5 \text{ g C m}^{-2}\text{year}^{-1}$) (Mcleod et al. 2011). That is why “blue carbon” has become a great concern in the last decade (Duarte et al. 2005; Laffoley and Grimsditch 2009; Vaidyanathan 2011; Howard et al. 2017). Although freshwater wetlands are often considered a source of greenhouse gas emissions (Schlesinger 1997), coastal wetlands produce less greenhouse gas because sulfate-reducing bacteria in the saline water can inhibit the methanogens

by outcompeting them for energy sources, especially in polyhaline tidal marshes (salinity >18) (Bartlett et al. 1987; Poffenbarger et al. 2011).

Carbon sequestration by mangroves, salt marshes, and seagrass beds is highly variable with estimations of combined global rates ranging between 0.23 and 0.77 Pg CO₂ year⁻¹, which is about 10%–13% of the global ecosystem CO₂ uptake (Hopkinson et al. 2012), while the total emission is estimated as 0.14–1.02 Pg CO₂ year⁻¹, equivalent to 3%–19% of the CO₂ emission caused by global deforestation (Pendleton et al. 2012). Overall, it is considered that there is a net uptake of CO₂ by the coastal vegetated wetlands.

Like the organic carbon in terrestrial ecosystems, most of the organic carbon in coastal wetlands is stored underground and insufficiently investigated (Schorn 1997). Donato et al. (2011) found that more than 90% of the organic carbon in the mangroves is stored in the soil and sediments, which is also the case for salt marshes (Lü et al. 2006). Carbon stored in the top 1 m of sediments was estimated as 1800–40 000 g C m⁻² for seagrasses, 9000–54 000 g C m⁻² for salt marsh, and 28 900–55 100 g C m⁻² for mangroves, which are all much higher than that in the forests (Lavery et al. 2013; Ninan 2014).

Coastal protection

Mangroves and salt marshes protect the coasts and invaluable lives and treasures behind them. Dahdouh-Guebas et al. (2005) showed the significant difference between damage with and without mangroves after the Indian Ocean tsunami occurred in December 2004. Areas behind true mangroves were largely unaffected, while the cryptically degraded area dominated by associate species was destroyed. Villages protected by wider mangroves on the coast had significantly fewer deaths than ones with narrower or no mangroves (Das and Vincent 2009). When waves penetrate into the mangrove forest, they are diminished quickly (Massel et al. 1999), and the reduction of tsunami pressure can be 90% within 100 m in dense mangrove stands (Tanaka et al. 2007). According to a study at the Florida coast, a 7 km wide strip of mangroves can reduce more than 70% of wave height during hurricanes (Zhang et al. 2012). In salt marshes, the wave height decreased exponentially with the landward distance from the marsh edge (Yang et al. 2012).

Under storm surge conditions, marsh vegetation can reduce wave energy by 60% (Möller et al. 2014). However, the spatial pattern of marsh distribution and species attributes affect the wave attenuation substantially. For example, the marsh die-offs directly connected to tidal channels have a much greater effect on increased landward flood propagation than their counterparts at inner marsh locations (Temmerman et al. 2012). According to a plume experiment, flexible low-growing plant canopies have high resilience to storm surge conditions, while more rigid and tall plant canopies experience stem folding and breakage (Rupprecht et al. 2017).

The vegetated zone can also trap enormous amount of sediments, helping survival of salt marshes with land accretion horizontally and vertically (Mudd et al. 2010). At East Chongming Island, Yangtze Estuary, the vertical accretion rate in the *Spartina alterniflora* zone was as high as 108.7 ± 80.6 mm year⁻¹, while in the pioneer zone of *Scirpus* spp., it was 57.0 ± 47.0 mm year⁻¹ during 2008–2012 (Li et al. 2014). The grain size of sediments become finer from tidal flats to inner vegetated zones (Yang 1998), while the total suspended solid concentrations tend to decrease logarithmically with distance from the canopy edge in dense vegetated areas (Leonard and Croft 2006).

The functions and services presented here demonstrate the indispensable value of coastal wetlands. However, the global coastal wetlands have diminished rapidly during the past century, especially in the last 50 years, at a rate of 0.5%–1.5% per year (Scott et al. 2014). Apart from direct land reclamation (see the following sections), decreased sediment input due to reservoir construction and degradation at the estuaries and coasts are also

Table 1. Coastal wetland loss in some of the regions.

Type	Region	Area lost	Period	Source
Mangroves	Thailand	>50%	1960~	Scott 1993
	Philippines	75% (from 448 000 to 110 000 ha)	1920s–1990	Scott 1993
	Ecuador	20%–50% overall, 90% in Muisne region	—	Mangrove Action Project 2015
Salt marshes	Singapore	97%	—	Yee et al. 2010
	Bohai Bay, China	73% (from >100 km ²)	2000–2010	Li et al. 2013
	South Korea	>1500 km ²	—	Worldatlas 2017
	The Netherlands	~7000 km ²	—	Worldatlas 2017
	Venice Lagoon, Italy	>70% (from ~180 to 50 km ²)	1811–2002	Roner et al. 2016
	Mississippi Delta, US	4900 km ²	Since 1930s	Environmental Defense Fund 2015
Coral reefs	San Francisco Bay, US	2000 km ²	—	Gedan et al. 2009
	Caribbean Sea	80%	—	The Guardian 2013
	Western Pacific	50%	—	Bruno and Selig 2007

driving factors for the loss. Projected sea level rise is another potential factor threatening the vulnerable coastal wetlands (Nicholls and Cazenave 2010). IPCC estimated that as much as 33% of the coastal wetland habitats would disappear in the next hundred years if the sea level rise keeps the current rate (Meehl et al. 2007).

Coastal wetland loss and degradation: a global problem

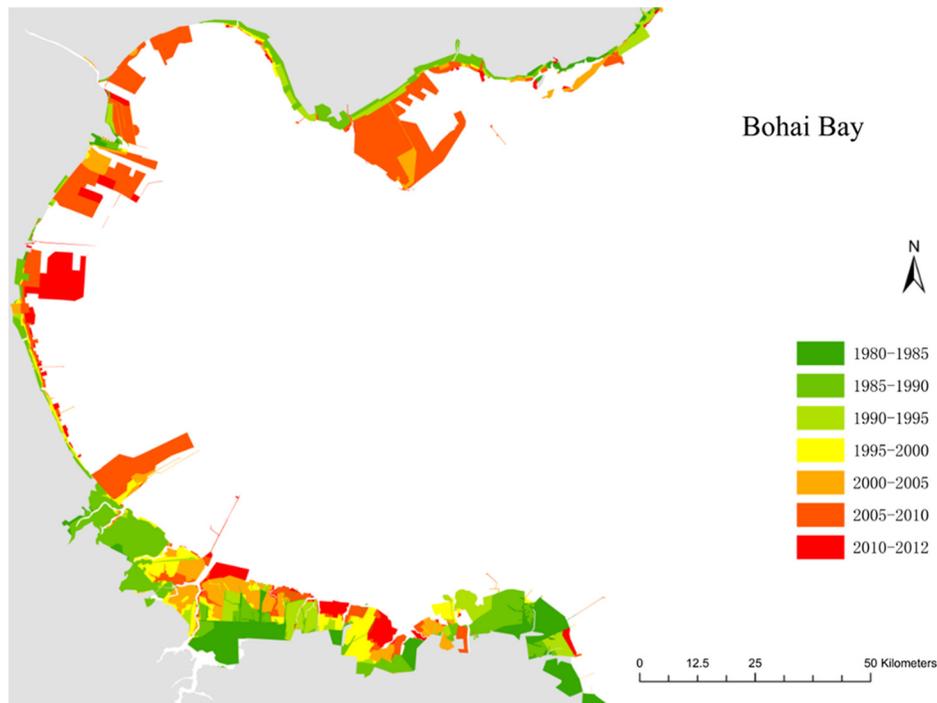
Mangroves faced a global loss of about 50% in the last decades (Table 1), most of which was transformed into mariculture ponds (Valiela et al. 2009). Ecuador, Indonesia, and many other countries are also witnessing a transformation from tidal wetlands to other more apparently profitable land uses in the eyes of the local people, such as aquaculture, harbors, paddy fields, and even parks. Along the coast of Puttlama Lagoon, Srilanka, the area of shrimp farm increased by 2777% from 1994 to 2012, while the area of salt farms increased by 60%, with the area of mangrove deceased by 34% during the same period (Jil et al. 2015). This is just an example of rapid transformation from coastal wetlands to other land use types. Like the mangroves, coral reefs are also under threat of loss or degradation in the Caribbean (~80%, The Guardian 2013) and Western Pacific region (~50%, Bruno and Selig 2007).

According to the Worldatlas (2017), China, the Netherlands, and South Korea ranked as the top three countries with the most land reclaimed from seas and wetlands (Table 1). Some countries still have plans to reclaim more land in the near future (Valiela et al. 2009; Worldatlas 2017). The Venice Lagoon also faced an over 70% marsh loss in the last 200 years due to land subsidence and low sediment input (Brambati et al. 2003; Roner et al. 2016).

Land reclamation has been the main reason of coastal wetland loss in China in the last decades. Surrounding the Bohai Sea, Northern China, more than 2000 km² were reclaimed between 1980 and 2012 (Fig. 1). Using new technology for land reclamation, muddy water can be pumped into the levee and new land can be created within a few months. This has happened along almost all of the Chinese coast wherever muddy subsurface is available, driven by rapid economic development.

Between 1780 and 1980, the United States faced extensive loss of its wetlands across the continents; some states lost more than 80% of their wetland coverage (Yuhás 2013). However, the most extensive wetland loss happened in the southeastern coastal states in the 1970s (Mitsch and Gosselink 2007). The Mississippi Delta alone has lost 4900 km² of land since the 1930s (Environmental Defense Fund 2015).

Fig. 1. Land reclamation around the Bohai Bay, China, between 1980 and 2012 (Courtesy of Dr. Bo Tian).



Dams and reservoirs constructed in rivers have prevented 20% of the global sediment inputs from reaching the coast (Syvitski et al. 2005). But for some large rivers, the situation has been more serious. For example, the Nile Delta has lost 98% of its sediment input, the Indus Delta lost 94%, and the Mississippi lost 69%, compared to the sediment input from when the first dam was built in the catchment (Syvitski et al. 2009; Giosan et al. 2014). By 2004, the Yangtze River lost 65% of its sediment input load of average between 1951 and 2004 (Yang et al. 2006), and was estimated to decrease further to ca. 110 Mt year⁻¹, which is only 20% of its level in the 1960s (Yang et al. 2014). This has induced “sediment starvation” in large estuaries (Kondolf et al. 2014), and resulted in erosion in some parts of the large deltas (Syvitski et al. 2009). On the other hand, levees have been built along the main river channels to protect populated areas from flooding, which have reduced the number of tributaries that can migrate at river deltas and maintain the ground surface level. Levee construction may reduce flooding risks in the short term, but may increase strong risks in the future (Temmerman and Kirwan 2015).

Subsurface mining of oil, gas, and water often accelerate ground compaction and delta sinking, causing frequent flooding. In fact, 80% of the world’s large deltas have experienced severe flooding in the last decades (Syvitski et al. 2009).

Moreover, degradation caused by saltwater intrusion, drought, and pollution are also threatening the health of coastal wetlands (Howard and Mendelssohn 1999; Dai et al. 2013). Eutrophication in coastal waters can influence the coastal wetland ecosystem by changing the structure of biotic communities, as well as the relationships between different species (He and Silliman 2015).

Invasive species often cause coastal wetland degradation. *Spartina alterniflora*, a native salt marsh species in the southeastern US, was introduced to China in 1979 for coastal

Table 2. Major consequences of wetland loss.

Consequence	Examples	Source
Habitat loss for marine species	Indus River Estuary, Bohai Sea coast, Florida coast	Scott 1993; Iftikhar 2002; Tang et al. 2015
Habitat loss for migratory birds	China coast	Ma et al. 2014
Saltwater intrusion	Indus River Delta, Mississippi River Delta, Pearl River Delta	Rasul et al. 2012; Zhang et al. 2013; Environmental Defense Fund 2015
CO ₂ and N ₂ O emission	All coastal wetlands replaced by aquaculture	Hu et al. 2012
Flooding	Mississippi River Delta, Chao Phraya River Delta, Ganges River Delta	Syvitski et al. 2009; Tessler et al. 2015
Erosion	Mississippi River Delta	Martinez et al. 2009

protection. Now it has spread almost all along the Chinese coast from the north to the south. It out-competes native species (such as the *Suaeda* spp. and *Scirpus* spp.) in the temperate and subtropical coasts, and in some of the mangrove communities in the tropical zone, resulting in habitat degradation for birds, with its dense, hard, and tall cohorts. In contrast, the common reed widely distributed in the old world turned out to be an invasive species in many sites of the US (Valiela et al. 2009).

Sea level rise is thought to be one of the potential threats for coastal wetlands; it is still controversial because wetlands can migrate landward if no seawall or steep relief exists behind the wetlands, but this is often not the case. “Coastal squeeze” is the concept proposed to describe coasts without retreating space facing sea level rise (Doody 2013). However, if relative sea level rise rate is slow (<4 mm year⁻¹), salt marsh can still establish, and biophysical feedbacks can even allow established marshes to survive at conditions of rising 7 mm year⁻¹ if suspended sediments in the coastal water are high enough (e.g., ≥1 mgL⁻¹) (Kirwan et al. 2011; Kirwan and Megonigal 2013). But sediment availability and tidal conditions are often critical restrictions for the marsh survival (Marani et al. 2007; D’Alpaos et al. 2011). It was predicted that marshes can adapt to fast relative sea level rise of a few centimetres per year at tidal ranges >1 m and suspended sediment concentrations >30 mgL⁻¹ (Kirwan et al. 2016). On the other hand, marshes can be drowned where available suspended sediment concentrations are very low (1–10 mgL⁻¹) and tidal range is very small (<1 m) (Kirwan et al. 2016).

Wind waves also play an important role in the erosion and loss of salt marshes worldwide, especially at boundary zones (Marani et al. 2011; Leonardi and Fagherazzi 2015). Low-wave-energy conditions can even result in large portions of marsh loss (Leonardi and Fagherazzi 2015). Still, short-term extreme conditions, such as storm surges, droughts, or saltwater intrusion may cause diebacks of brackish and fresh tidal water wetlands with more serious influence than slow sea level rise, and need further investigations under different conditions (Elmer et al. 2013).

Consequences of coastal wetland loss

Loss of wetland area means the loss of its corresponding ecological services for human beings (Table 2), with economic gain only for a special group of people making profits from aquaculture or other land use forms. Profound changes have been caused by conversion of coastal wetlands into other land use forms with damage from flooding or other indirect influences (Worm et al. 2006).

Flooding and storm damage

In southeastern Asia, great destruction has been caused by flooding with reduced or no protection from mangroves and salt marshes, as seen in Bangladesh, Thailand, the Philippines, and Indonesia (NASA-Earth Observatory 2013). Flooding is reported almost every year in this region. Many people have migrated out of the Indus River Delta, Pakistan, due to saltwater intrusion and reduced fishery output from the reduced mangroves (Iftikhar 2002). Similarly, in New Orleans, the population in 2010 had dropped by 24% since 2005, following hurricane Katrina, where coastal wetland protection had been falling since the 1930s (The Guardian 2010). The annual damage caused by coastal flooding will reach \$1 trillion by 2050, with the most vulnerable cities located in North America and Asia (Hallegatte et al. 2013). Although the flooding damage cannot be attributed to coastal wetlands loss alone, their buffering function must play a vital role for some of the area.

Fishery structure change and biodiversity loss

The world fishery capture and aquaculture production has been increasing steadily since the 1950s, among which, the contribution from China has been prominent since the 1980s. But the production of Chinese fishery is mainly from aquaculture (>70%) (FAO 2016). The Chinese aquaculture not only produces fish, shrimp, and shells but also sea cucumbers, crabs, and a wide variety of algae. Within 1 km from the coastline, 80% of the sea surface has been used, mostly by aquaculture (Liu et al. 2015). To ensure a high harvest, the farmers have to use feedstuff and antibiotics, which may result in excessive nutrient discharge, food chain accumulation of pollutants, and antibiotic resistance effects in microbes (Romero et al. 2012). The structure of breeding sites also changes the hydro-sediment-biochemical dynamics in the coastal water.

Coastal wetland reclamation often results in the destruction of spawning and nursery ground for many marine species, while birds lose their food and shelter with more disturbed habitats. The buffer function for pollutant degradation, erosion, and land subsidence will be lowered, with increased risk from storm surge and flooding. In the Bohai Bay of Northern China, a sharp decline of fishery resources has been witnessed as a result of wetland loss and pollution from inorganic nitrogen and phosphorous, oil, and heavy metals, which greatly decreases the food available to migratory birds (Tang et al. 2015).

China's coastal wetlands have an area of 5.8 million ha, supporting 230 waterbird species, which is about 25% of the global total. They are also on the migration routes of 19% of the globally threatened migratory bird populations. Unfortunately, the vast coastal wetlands are seriously threatened by the 11 000 km long "Great Seawall", or 60% of the Chinese coast line (Ma et al. 2014). Since the 1980s, land reclamation along the coast has been increasing steadily to 400 km²year⁻¹ in 2010, and the projected reclamation speed will reach nearly 600 km²year⁻¹ by 2020. The migratory bird populations in eastern Asia are greatly endangered due to the "hostile shores" in China, Korea, and Japan (Larson 2015). Although the "armored seawall" favors some rocky shore organisms (Huang et al. 2015), it is incomparable to the ecological value lost during reclamation. Fortunately, new laws have been established to stop this trend, accompanied with restoration efforts supported by the central and local government.

The losses of biodiversity result in the damage of some critical coastal ecosystem services, such as fishery, nursery habitats, and filtering and detoxification services, which further contribute to the decline of water quality and increase of harmful algal blooms, oxygen depletion, and mortality of benthic and nekton fauna (Worm et al. 2006). Invasion of exotic species may enhance productivity, but could not compensate for the services borne by the native taxa (Lotze et al. 2006).

Fig. 2. Newly established salt marsh between the high and low levees along the Shanghai Coast (Courtesy of Linjing Ren, 2014).



Climate change feedbacks

Clearing of mangroves and subsequent excavation of the substrates for aquaculture ponds could result in the potential oxidation of 1400 t C ha^{-1} . If half of this becomes oxidized over 10 years, then $70 \text{ t C ha}^{-1}\text{year}^{-1}$ is estimated to be returned to the atmosphere. This is some 50 times the sequestration rate, and would contribute to increased atmospheric CO_2 concentrations, leading to climate change and sea level rise (Ong 2002; Mcleod et al. 2011). Moreover, aquaculture is also an important source of N_2O due to addition of feed and wastes (Hu et al. 2012). Therefore, transformation of coastal wetlands into aquaculture will result in the increase of greenhouse gases in both CO_2 and N_2O emission. Pendleton et al. (2012) estimated that about $0.04\text{--}0.28 \text{ Pg C year}^{-1}$ can be released from these systems caused by conversion into non-wetland types and degradation. However, few land owners would consider the potential climate warming effect when constructing aquaculture ponds from coastal wetlands.

Restoration efforts and challenges

While coastal wetlands are facing loss, many countries have started taking measures to rebuild marshes with dredged sediments, or divert the river channels to elevate ground surface. Some new concepts, such as “building with nature” (De Vriend et al. 2015), “living shore lines” (Rose et al. 2014), or “blue forest” (Norwegian Blue Forest Network 2015), have also been proposed and implemented in different parts of the world to support practices for coastal wetland restoration.

Efforts of coastal wetlands restoration at different regions

Yangtze Estuary, China

Along the Shanghai coast, to facilitate salt marsh restoration out of the strongly armored seawall, a low levee near the 0 m elevation was constructed and muddy water was pumped into the space between the two levees, so that natural vegetation can establish and eventually encroach into the tidal flat outside the low levee (Fig. 2). This narrow vegetation zone can act as a buffer to protect the seawall, but whether this is wide enough or not under storm surges is as yet unknown. The time taken for vegetation to disperse over the low levee is also different among different sections of the coastline due to hydro- and morpho-dynamic differences at local sites.

Atlantic coast, US

In the Mississippi River Delta, a project called the “Coastal Wetland Planning, Protection and Restoration Act” has been implemented since the 1990s (CWPPR 2015). It combined sediment dredging with marsh restoration and recreation, and tried to divert sediment-laden river water back onto the delta plain (Temmerman and Kirwan 2015). Assisted with vegetation planting, they tried to stabilize the bank and protect the shoreline. The cost is high and measures are only effective within a limited area. Much more efforts are still needed to prevent the marsh from sinking.

An example of “living shorelines” is to use shellfish aquaculture as a management strategy for nitrogen reduction and bank protection (Rose et al. 2014), with removal rate at 100–1300 g N m⁻²year⁻¹. Now the technique has been widely used across the US coastal states and by several countries.

San Francisco Bay, US

The first project of wetland restoration in San Francisco Bay was enacted in 1972, after losing 90% of its marshes from the beginning of American colonization (Williams and Faber 2001). With a series of restoration experiments evolved from vegetation planting to providing the right physical conditions, manipulating wetlands, and restoring physical processes, it has become a laboratory for testing different restoration techniques that can be considered by other parts of the world (Williams and Faber 2001).

The San Francisco Bay restoration efforts provided a series of lessons, such as (Williams and Faber 2001): (i) the need for explicit restoration objectives; (ii) understanding of restored salt marshes as evolutionary systems that have changing functions with time; (iii) the need to incorporate morpho-dynamics, or interaction of key physical processes in restoration; and (iv) the need to integrate long-term monitoring into the restoration plan.

The Netherlands

The Dutch people have implemented the approach of “building with nature” for years by nourishing the coast with sediments from the North Sea (Sonneville and Van der Spek 2012), creating oyster reefs to protect the coast from erosion with natural reproduction and some economic benefits, and implementing a managed retreat allowing for potential sea level rise along the River Rhine valley (De Vriend et al. 2015). These efforts will provide invaluable supports for the coastal protection from continual erosion and periodic storm surges.

Other areas

Restoration of mangroves with plantations has been achieved in Thailand, Vietnam, China, and other countries. Measures were also taken to control *S. alterniflora* along the Chinese coastline. However, compared to the wetland area already lost, the restoration efforts are quite limited and often fail.

Challenges for coastal wetland restoration

Lack of comprehensive understanding of coastal ecosystems

Knowledge gaps still exist for successful coastal wetland restoration. Geomorphic units where coastal wetlands can develop are often complicated, from high tidal zones to low lands, lagoons, and tidal creeks. They are ever-shifting due to human activities and natural processes, and there is insufficient real-time monitoring for critical processes, such as water and sediment redistribution, subsidence, or ecosystem dynamics. Sediment budgets and ratios of mud, sand, and organic matter in the soil of deltaic plain are generally unknown, yet are crucial for preventing drowning (Giosan et al. 2014).

From an academic point of view, the challenge for coastal wetlands restoration is also a great opportunity for landscape ecologists to transfer their knowledge into practice. For example, how to compromise between the different functionalities of coastal wetlands, such as *S. alterniflora*? Its functions for coastal protection and sediment trapping are considered to be positive along the Chinese coastline (Yang et al. 2008, 2012), but as an invasive species, it has negative effects on the native organisms (He et al. 2012), especially in southern China (Gao et al. 2014). In contrast, in the middle Atlantic coast of the US, the invasive *Phragmites australis* proved to be more effective in combating sea level rise with higher mineral and organic sediment trapping ability than the local *S. alterniflora* (Rooth and Stevenson 2000).

Lack of knowledge about site-specific bio-morphological interactions

For vegetation restoration in the tidal zone, it is necessary to consider how the ecosystem will interact with the physical environment. Waves and sediments will be redistributed and attenuated differently by different species, also depending on their density and biomass, thus changing the landforms, which, in turn, will affect the vegetation diversity and distribution (Leonardi and Fagherazzi 2015). Yet the knowledge for the mechanism of bio-morphological interaction is rather limited, and is often site-specific in terms of tidal ranges, wave energy, salinity gradients, suspended sediment contents, morphological conditions, and species structure. General interpretations of marsh mechanisms obtained at large scale also need site-dependent data input to support successful rehabilitation (Marani et al. 2011).

Coastal wetland restoration practice should also be “site-specific”. The location, species, size, and spatial orientation of the wetland must be carefully considered according to the tide and substrate conditions. Successful restoration requires both semi-natural vegetation structure and a high diversity of fauna groups, to ensure multi-functionality of the restored ecosystem. More importantly, when restoring the ecosystem occupied by aquaculture, the income of local people should not be reduced. New benefits for those people must be explored, such as ecotourism, apiculture, and horticulture. Incorporating ecosystem services into coastal planning will achieve greater returns from coastal protection and tourism than from achieving conservation or development goals only (Arkema et al. 2015).

Moreover, while faced with quick economic development along the world coast zones, we also need to make room for potential sea-level rise. By combining conventional engineering with ecosystem-based engineering, we may mitigate potential big flooding risks in the long run (Temmerman and Kirwan 2015; Tessler et al. 2015), and provide important habitats for numerous wild and commercial species.

Conclusion and recommendations

The world coastal wetlands are faced with great pressure of being “squeezed” by human land use and sea-level rise. Serious consequences have already been caused by the coastal wetland loss, such as coastal flooding, erosion, and biodiversity decrease. It is a critical time to take actions to avoid further loss of this precious ecosystem with many important functionalities, and to restore it wherever possible. However, more efforts are still needed to understand the site-specific relationship between coastal wetlands and hydro-sediment dynamics, or the bio-physical conditions for pioneer species establishment. Social-economic effects must also be fully considered for successful restoration of coastal wetlands in the future.

Here are some suggestions for the ecological restoration of coastal wetlands:

1. *Right species at the right place.* Site selection is critical for successful coastal wetland restoration, while local species are of first priority. Most of the species' establishment needs a critical threshold of hydro-dynamics, such as flow speed and direction, inundation period and depth, even suspended sediment content. These critical conditions for different species should be studied first before taking actions.
2. *Make use of ecosystem's self-organization strength.* Once the vegetation community is established, a positive feedback between sediment accumulation and vegetation expansion and succession will be formed. It will be much more cost-effective to build small patches than to plant seedlings at large scale.
3. *Probe reliable economic benefits for the local society.* For example, the high biomass of *S. alterniflora* can be used to extract bio-mineral liquid while the residua with high crude protein can be used as forage or organic fertilizer (Qin et al. 2016). The harvested area can provide habitat for birds if cutting is planned carefully. Ecotourism and apiculture are other well-known alternatives that are economically profitable and can stimulate the protection and restoration of coastal wetlands.

Conflict of interest

The authors declare that they have no conflict of interest.

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Colombo 7, Sri Lanka
Phone: ++94-011-2694094, 2682418, Fax: 2682470
<http://iucn.org/srilanka>

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Introduction

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

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

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

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



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

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

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

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

What are tidal flats?

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

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

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

Comparison of mud flats and sand flats

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

(Source: www.uvm.edu/~mbeekey/WFB279/Soft_substrate.../Soft_substrate.ppt)

Where are tidal flats found in the world?

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

- The extent of tidal flats worldwide has not been mapped.
- The Wadden Sea, a UNESCO World Heritage Site, combining the Dutch Wadden Sea Conservation Area and the German Wadden Sea National Parks of Lower Saxony and Schleswig-Holstein, is the largest area of connected tidal flats in the world, extending over a length of some 500 km and an area of 10,000 km² (<http://whc.unesco.org/en/list/1314>).
- Along the entire west coast of Korea there is a stretch of tidal flat as much as 10 km wide, extending over 2850 km², which are part of a tidal flats found along the southeastern banks of the Yellow Sea (<http://whc.unesco.org/en/tentativelists/5482/>).
- According to a survey carried out in 2002, there were 23,800 ha of tidal flats (formerly called salt marshes) in Sri Lanka, with extensive tracts from Mantai to Vankalai, on the northwestern coastline, and patches in sedimented areas of lagoons and estuaries such as Hambantota, Puttalam, Kalpitiya and Mundel (Dela, 2009).



The biodiversity of tidal flats

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

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

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

The most important autotrophs¹ in tidal flats are microscopic blue-green organisms called cyanobacteria that often form a velvety mat — called 'lab lab' — visible on the surface of tidal flats (<http://www.cbbep.org/projects/molliebeattie/lifeonflats.htm>). These cyanobacteria were formerly called blue green algae, and are still commonly referred to in this way. They harness energy from the sun and, like plants, convert it into food that can be used by other organisms (<http://www.cbbep.org/projects/molliebeattie/lifeonflats.htm>). Seemingly innocuous, this mat of cyanobacteria plays a major role in shaping tidal flat communities, because it is in this mat that the food for the rest of the food web is produced.

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

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

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

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

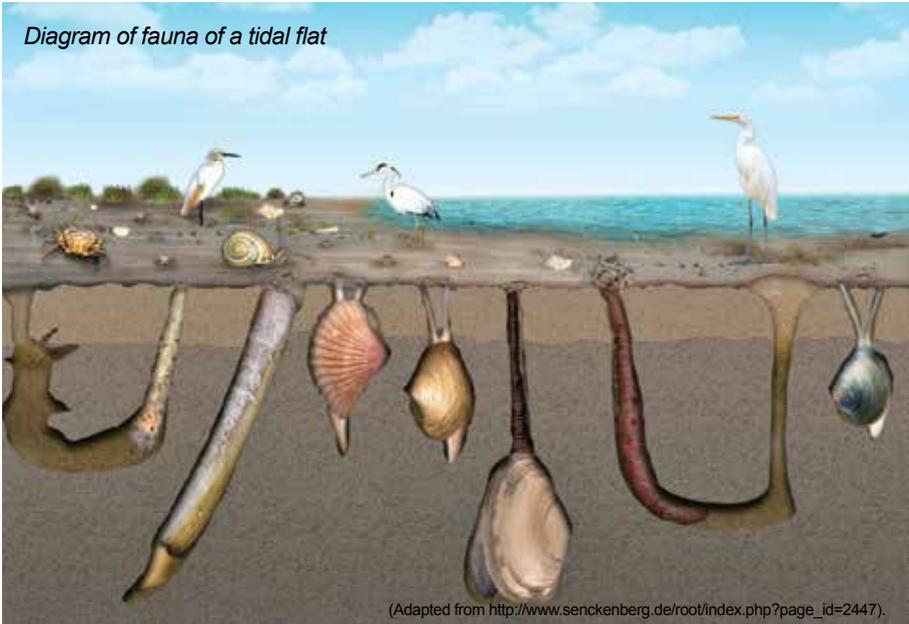
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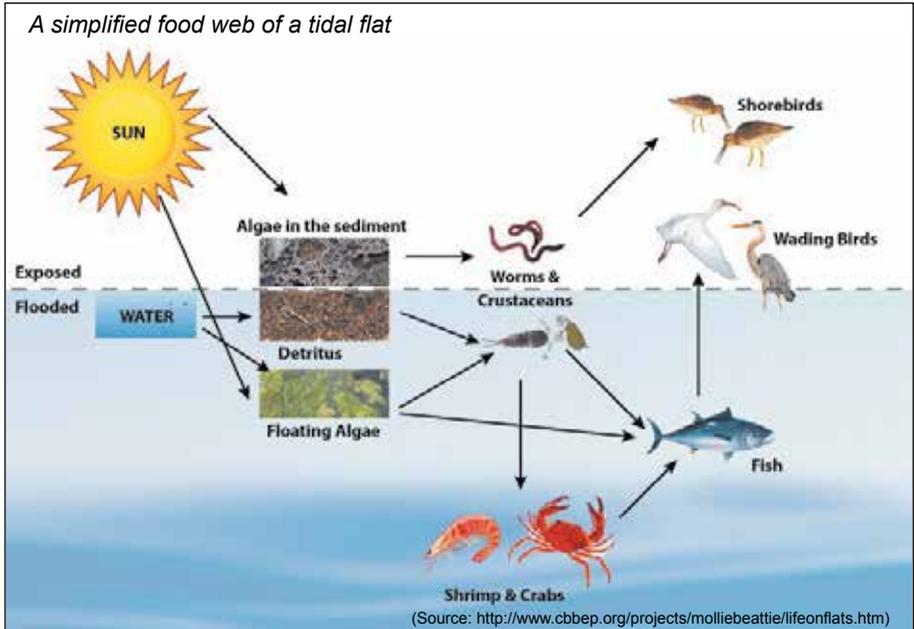
Many of the fauna of tidal flats are benthic organisms, i.e., organisms that live on or in the bottom of aquatic environments. There are several groups of benthic organisms. Epibenthic organisms or **epifauna** live on the mud. Epifauna include crabs and other crustaceans, cockles, mussels and other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

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

Infauna burrow into the mud and are sometimes called ecosystem engineers because they alter the microenvironment around them (http://www.sms.si.edu/irlspec/Tidal_Flats.htm). Infauna in tidal flats include molluscs, worms, crustaceans, echinoderms² and acorn worms (http://www.sms.si.edu/irlspec/Tidal_Flats.htm). These organisms serve as food for wading birds.



² Sea stars, sea urchins and sea cucumbers belong to the group Echinodermata.



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

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

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

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

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

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

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

Adaptations to cope with changes in salinity

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

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

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

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

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

Adaptations to withstand desiccation

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

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

Adaptations to cope with changes in oxygen content

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

What is the importance of tidal flats?

Provisioning services

Tidal flats provide goods for human use.

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

The subtidal area of tidal flats are prime sites for filter feeders³ such as mussels and oysters which are harvested for food (Reise et al., 2010).



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

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

Supporting services

Tidal flats are highly productive systems.

Although species richness may be low in tidal flats, they are highly productive areas because they support a high biomass⁴ of microorganisms (both autotrophic and heterotrophic⁵). These, in turn, support invertebrates, fish and ultimately large numbers of shore birds and wading birds (http://www.sms.si.edu/irlspec/Tidal_Flats.htm). The daily inflow of freshwater runoff and tidal influxes brings in nutrients that promote high levels of photosynthesis by algae found in these tidal flats.

Tidal flats enrich nutrients in coastal waters.

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

Tidal flats support coastal biodiversity.

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

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

⁵ Heterotrophs cannot manufacture their own food and feed on autotrophic organisms.

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

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

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

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



Tidal flats and salt marshes are carbon sinks.

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

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

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

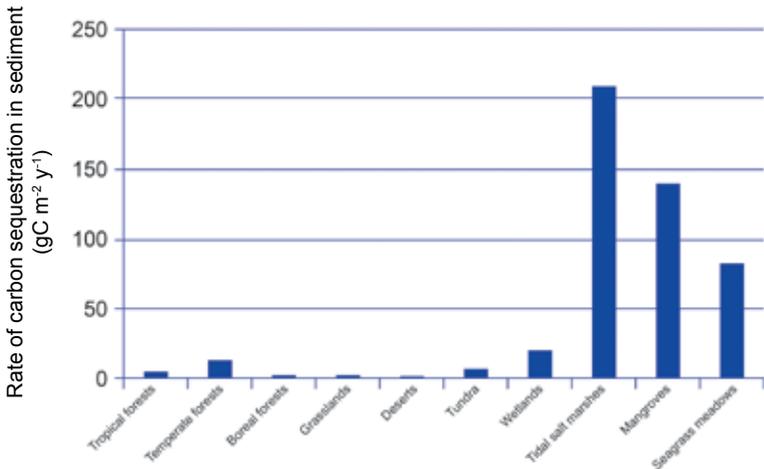
In addition, the sulphates produced by cyanobacteria in tidal flats prevent the production of methane (which is a far more potent greenhouse gas than carbon dioxide) and which is normally produced in wetlands that contain decaying material (Chmura, 2009).



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

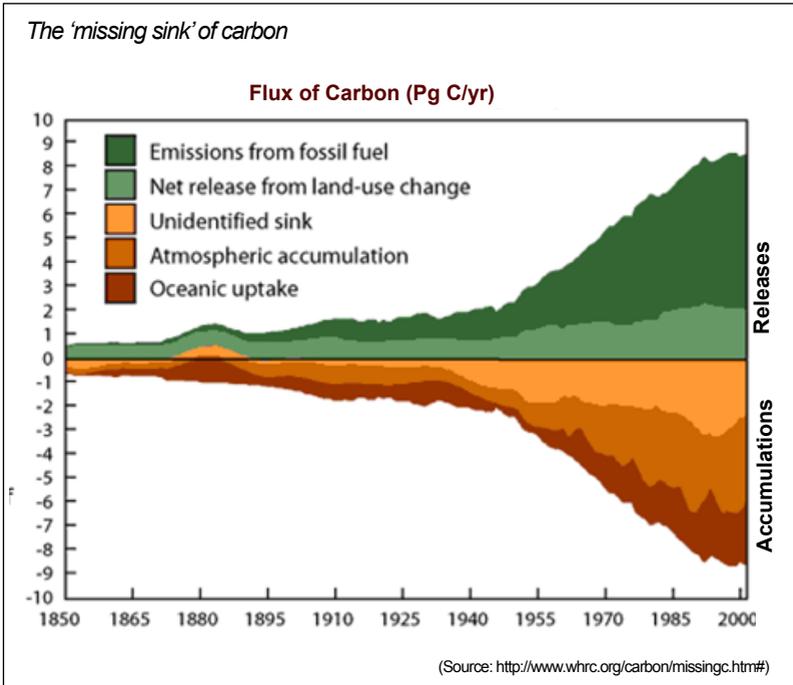
The dramatic difference between carbon absorption in coastal marine and terrestrial ecosystems is the capacity in coastal ecosystems for long-term carbon sequestration in their sediments.

Comparison of carbon sequestration in among terrestrial and coastal ecosystems



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

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



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

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

Regulating services

Tidal flats provide protection from floods.

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

- It is estimated that an acre of wetland can usually store about three-acre feet of water, or 3,786 m³ of water. An acre-foot is one acre of land, covered one foot deep in water. Three acre-feet is one acre, covered by three feet of water (<http://water.epa.gov/type/wetlands/outreach/upload/EconomicBenefits.pdf>).

Tidal flats absorb storm energy.

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

Tidal flats trap sediments and filter water.

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

When water enters a tidal flat, the speed of flow is retarded by the mud. The sediment in the water then settles to the floor of these ecosystems; the pollutants are adsorbed⁶ on to mud particles. The net result is that excess nutrients and pollutants from inland runoff are trapped and effectively removed from the system (<http://water.epa.gov/type/wetlands/outreach/upload/EconomicBenefits.pdf>; (http://www.sms.si.edu/irlspec/Tidal_Flats.htm).

⁶ Held as a thin film on the surface.

Tidal flats prevent erosion.

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

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

Cultural services

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

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

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

What are the threats to tidal flats?

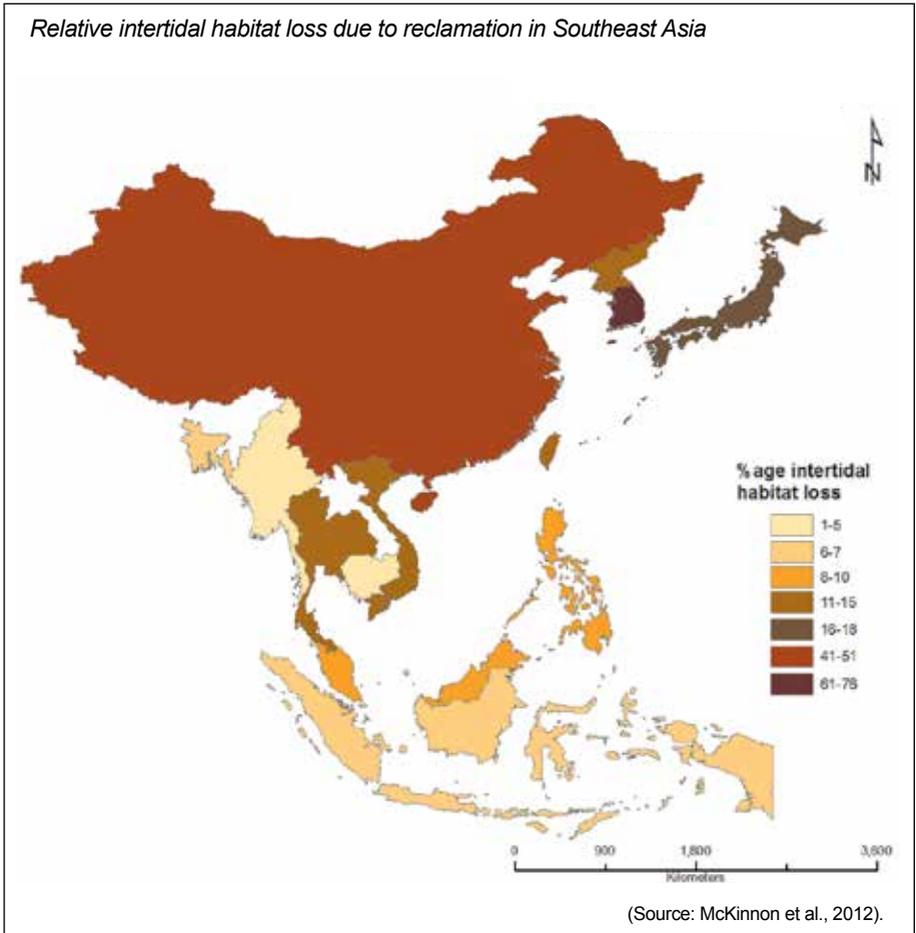
The underlying drivers of change in many ecosystems all over the world are increased human population and its associated pressures, such as unplanned and uncontrolled development (Duarte et al., 2008). This is especially true of the coastal zone, where, often, there is a denser concentration of human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

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

Habitat destruction and fragmentation

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

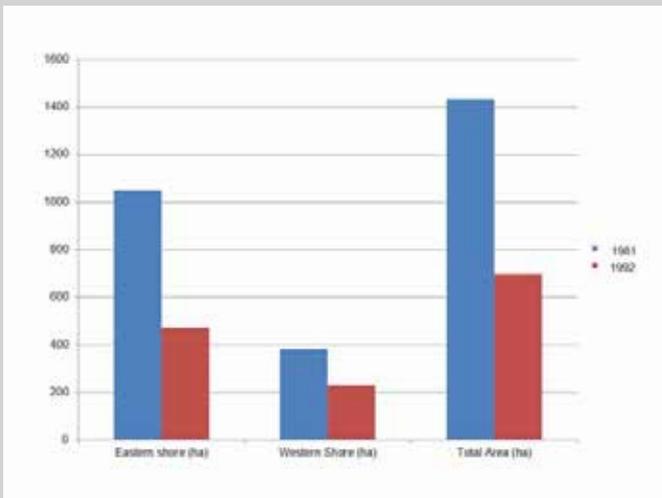
Relative intertidal habitat loss due to reclamation in Southeast Asia



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

Tidal flats are also reclaimed for salt production.

- Tidal flats in Japan are found on Kyushu and Okinawa islands, on the Pacific coast. Historically, they were important fishing grounds. The extent of tidal flats decreased by 35% in 33 years, between 1945 and 1978 (Akiko and Okamoto, 2008).
- During the past few decades, about 25% of the tidal flats in Korea have been lost (Jong-Geel Je et al., undated).
- About 1.19 million ha of coastal tidal flats in China have been reclaimed for urban development or mining. This represents 51% of all China's coastal wetlands (McKinnon et al., 2012).
- Land reclamation in the Wadden Sea, has decreased the extent of tidal flats to one-third of the extent compared to 1500 AD (Reise et al., 2010).
- In Sri Lanka, there has been a 20% reduction in the extent of tidal flats⁷ over a period of 16 years (CZMP, 2003 in litt. Joseph, 2003).
- In the Puttalam District on the northwestern coastline of Sri Lanka, more than 85% of the extent of tidal flats⁷ was lost between 1986 (3,461 ha) and 2002 (499 ha) (Joseph, 2003). The following graph shows the extent of loss within a decade, around the Puttalam Lagoon (Pathirana et al., 2008).



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

⁷ These were listed formerly as salt marshes.

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

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

Pollution:

Tidal flats, like the other habitats of the coastal mosaic to which they belong, are also affected by point-source pollution⁸ and non point-source pollution⁹.

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

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

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

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

⁹ 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.

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

Hydrological alteration

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

Changes to fresh water inflows

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

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

As a consequence of upstream damming, sediments along the Haihe River in China have reduced from an average of 0.75 kg/m^3 to 0.1 kg/m^3 . The reduction in the amount of sediments reaching the coast has resulted in a loss of accretion¹⁰ and the eastern coastline in China is now eroding at a rate of 5 m per year (McKinnon et al., 2012).

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

Changes to tidal flows

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

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

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

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

Changes in sedimentation

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

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

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

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

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

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

It notes that there has been a dramatic increase in river sand mining in the Deduru Oya, Maha Oya Kelani Ganga, Kalu Ganga, Gin Ganga and Nilwala Ganga (in the northwestern, western and southern provinces of the island) — from 1.2 million m³ in 1984 to 5.5 million m³ in 2001 (CZMP, 2006).



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

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

Overexploitation

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

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

Invasive alien species

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

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

Climate change

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

Currently, there are 390.9 parts per million of carbon dioxide (CO₂) and 1,813 parts per billion of methane, in the atmosphere, a 140% and or 259% increase respectively, of pre-industrial levels (WMO, 2013).

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

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

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

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

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

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

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

Lack of knowledge about these ecosystems

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

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

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

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

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

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

References as in text.

What is being done to conserve tidal flats?

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

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



Increasing general awareness

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



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

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

Shifting to a holistic approach to management

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

Shifting to a landscape approach

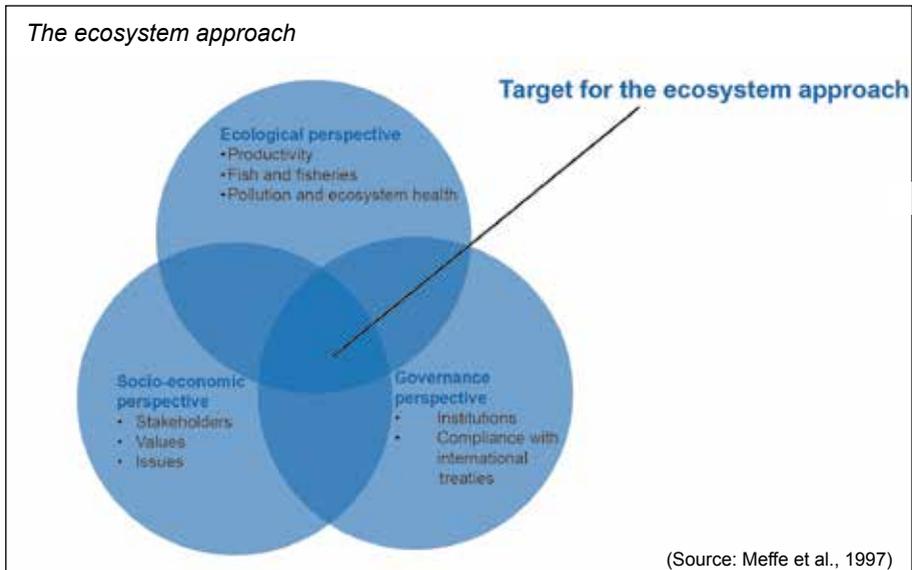
Coastal ecosystems are severely affected by human activities carried out inland. (See under section on 'What are the threats to tidal flats?'). From a single action inland, there could be a cascade of impacts in the coast. For example, mining for river sand upland could result in decreased sediment loads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

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

Shifting to an ecosystem approach

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

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



Integrated coastal zone management (ICZM)

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

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

Taking innovative approaches

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

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

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

Establishing protected areas

Globally, there are now 168 contracting parties and 2,161 Wetlands of International Importance (Ramsar sites)¹⁰ extending over 2,056,812 km². Among these sites, 411 sites, extending over 326,732.7 km² contain tidal flats (http://www.ramsar.org/cda/en/ramsar-sept13-homeindex/main/ramsar/1%5E26292_4000_0__).

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

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



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

Mangroves for the Future

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

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

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

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

Learn more at: www.mangrovesforthefuture.org



Avian Diversity in Coastal Wetlands of India and their Conservation Needs

S. Balachandran

E-mail : bnhsbala@rediffmail.com

Introduction

Coastal wetlands are special types of wetlands that are influenced by the fluctuating water levels provide a habitat for a vast array of organisms, including many endangered species. These critically important features act as water purifier, fish spawning area and feeding grounds and habitat for many animal species. Some birds depend on wetlands almost totally for breeding, nesting, feeding, or shelter during their annual cycles. Birds that need functional access to a wetland or wetland products during their life cycle can be called "wetland dependent". The important migratory birds utilizing the coastal wetlands are ducks, shorebirds, gulls, terns and flamingos. The birds of any coastal wetlands can be divided into at least four groups based on their seasonal occurrence. 1. Summer (breeding) residents 2. Winter residents (occurring throughout the winter) 3. Transients (passing through during either fall or spring migrations or both); and 4. Permanent residents. Furthermore, because of their frequently high abundance and their substantial food requirements resulting from high metabolic rates, birds often have a substantial impact on the infaunal invertebrates of coastal habitats (Schneider 1978). Many birds that inhabit intertidal habitats are migrants and travel annually along the Central Asian-

Flyway (CAF)- the flyway which extends from Central Siberia through the Himalayas to the Indian subcontinent). During peak annual migration periods, hundreds of thousands of birds migrating along the Central Asian Flyway descend upon the coastal wetlands of India in search of refuge and food. Some shorebirds (waders) weighing as low as 25g fly as far as 9,000, km from the arctic breeding grounds and South Indian wintering grounds. Prior to breeding, they again fly northwards to their nesting grounds, thus, in one year they may fly 18,000 km.

Coastal birds play the role in the coastal ecosystem both as primary and tertiary consumers cum predators to maintain the ecological balance. Their role in recycling the nutrients to the ecosystem through guano deposition is commendable and helpful to enhance the local fisheries. Many coastal birds for instance sea gulls play a scavenger role and many shorebirds feeding on harmful insects play role in vector control.

During the annual migrations, the birds depend on a great diversity of habitats, ranging from Arctic tundra to forests, grasslands, rivers and estuaries, lakes and marshes, sandy beaches, intertidal mud flats, coral reefs, atolls, and mangroves most of which are wetlands. Such long distant migrant coastal birds frequent in more



numbers in the coastal wetlands along the south-east coast than the wetlands of other regions in India. During the migration flights, the birds need to feed (refuel) and to do this they stop (and feed) at a number of sites along the route. These sites need to be productive (to provide enough food) and also undisturbed (to provide a safe roosting area). The major traditional wintering grounds for the waders of the Central Asian Flyway are located in India. Besides waders, coastal wetlands provide wintering and passage sites for hundred thousands of ducks, terns, gulls and flamingos, which migrate from central and west Asia, and Europe. The wintering population at these traditional wetlands in the last three decades had shown a decline trend in most of these species. In India, coastal birds are one of the least studied groups among the wildlife. The Bombay Natural History Society has undertaken several field projects specially to study the migratory movements between the Arctic breeding ground and the Indian wintering grounds through bird ringing for the last five decades and generated baseline information on the population status and movement of migratory waterbirds in major coastal waterbird habitats. The important coastal wetlands along the east coast of India are, Gulf of Mannar, Point Calimere, Pulicat, and Chilika. Population decline in waders and Greater Flamingo *Phoenicopterus roseus* during the last three decades, the major causes for the decline and measures for restoration of coastal wetlands are discussed in the paper.

Major Coastal Bird Habitats of India

Point Calimere Wildlife Sanctuary and the adjoining Great Vedaranyam Swamp

The Point Calimere Wildlife Sanctuary (10°18' N; 79°51' E) is situated on a low promontory on the Coromandel Coast (Southern Deccan Plateau) in the Bay of Bengal. The Great Vedaranyam Swamp (henceforth referred to as GVS or swamp) stretches parallel to the Palk Strait for about 48 km, and is separated from it by a sand-bank. In total, it has an area of about 349 km². Among the coastal wetlands, Point Calimere has been well studied through bird ringing.

The linkages of Point Calimere with other wetlands during migration within India and across the country were well established through the studies conducted

during 1980s. Waders ringed at the breeding grounds in the Arctic tundra of Russia and in Kazakhstan Uzbekistan, were recovered at Point Calimere in the same and subsequent seasons. Common Terns *Sterna hirundo* ringed in Poland, Lesser Crested Tern *Sterna bengalensis* Ringed in Saudi Arabia, Caspian Tern ringed at Caspian sea, Flamingos ringed in Iran and Caspian Sea were recovered at Point Calimere. Curlew Sandpiper *Calidris ferruginea* ringed in Australia was also recovered at Point Calimere. Waders ringed at Point Calimere were recovered in all the SAARC countries, China, Russia, and other former USSR countries. Within India, birds ringed at Point Calimere were recovered in many wetlands in northern India and vice versa. The Point Calimere is of great importance as a staging place for migrants on their way to and from Sri Lanka and other wintering grounds. No other waterbird refuge in India can claim to share this distinction with the Vedaranyam Swamp.

Pulicat Lake

The Pulicat wetland is situated in south coastal Andhra Pradesh (13° 25' to 13°55' N and 80° 03' to 80° 19'E) on the eastern seaboard of India with an area of about 450 sq. km thereby making it the second largest brackish water lagoon in India next to Chilika Lake. The lake was declared as a bird sanctuary by the Andhra Pradesh Forest Department in the year 1976. The entire area is a vast brackish to saline lagoon with extensive mud and sand flats. The sanctuary is bounded on its eastern side by the spindle shaped Sri Harikota Island.

The major groups of birds wintering in Pulicat Lake are ducks, terns, gulls flamingos and waders. Over 200,000 waterbirds were recorded during 1988 and 1989 at Pulicat. Out of them, over 30,000 were Greater Flamingo. Other dominant waders were Little Stint, Curlew Sandpiper and Lesser Sand Plover, Black-tailed Godwit and Ruff. A total of 88 species of birds has been recorded from Pulicat Bird Sanctuary during a BNHS Study (Rao and Mohapatra 1993). The population data available for the last two decades showed the declining trend (Table 4).

Gulf of Mannar

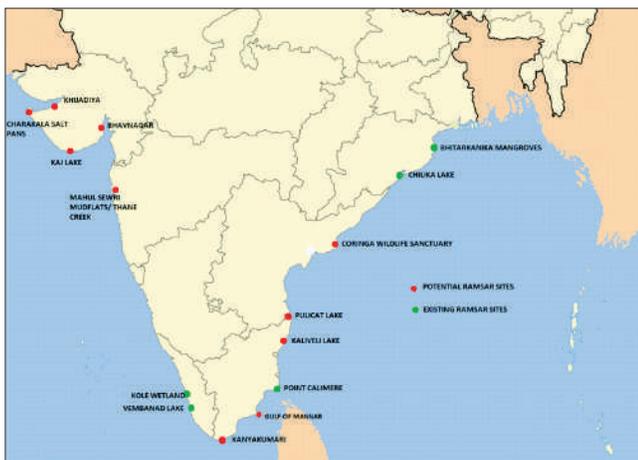
At distances ranging from 5-8 km from the mainland, the Gulf of Mannar has a chain of islands



running roughly parallel to the coast. These islands are mainly of coral origin probably of the nature of fringing reefs. Among the islands Manali Island, Hare Island, and Dhanuskodi Lagoon of Rameshwaram are the major bird congregation areas along the Gulf of Mannar. It supported overall 50,000 coastal birds (waders, terns and other wading birds) including 13,000 flamingos during 1980s (Balachandran, 1990 and 1995) and it ranks third as an important wintering ground for Greater Flamingos *Phoenicopterus ruber* along the East Coast. Its proximity to Sri Lanka makes Mandapam as an important site in the Central Asian Flyway for migratory birds. Among the waders, the Lesser Sand Plover *Charadrius mongolus*, Curlew Sandpiper and Little Stint were the most abundant. Red Knot *Calidris canutus* and Great Knot *Calidris tenuirostris* are the regular winter visitor in small numbers, and these species are not vagrant species as reported previously.

Chilika Lake

Chilika Lake, a designated Ramsar site, is the world's second largest brackish-water lagoon, situated between 19°28' N and 19°54' N and between 85°05'E and 85°38'E. Chilika is also renowned for the vast numbers of migratory waterfowl congregating in India



Existing and Potential Coastal Ramsar sites in India

(Scott 1989). A total of 226 species of both migratory and resident birds, including nine threatened species (Balachandran *et al.* 2005), have been recorded here.

The various habitats include marshes, mudflats, freshwater pools and areas of open water with varying

depths and salinity. A submergible island (Nalabana Island) with extensive mudflats (c. 19 sq.km), exposed only during the dry season (December to May), attracts over 300,000 waterbirds. The island supports the largest concentrations of waders in the lake, and a few thousands of flamingos.

Altogether the lake support over 800,000 waterbirds predominantly ducks. The commonest duck species for which the population exceeds over 100,000 are the Northern Pintail, Gadwall, Northern Shoveller, Eurasian Wigeon, and tufted duck. The numbers exceeded over 50,000 in three duck species namely Garganey, Common Teal, Common Poacard. In Waders, the Black-tailed Godwit is the only species for which the numbers exceeded over 50,000.

Table 1. Population trend of common waders at Point Calimere

Species Name	1980s	1990s	2000-2008
Curlew Sandpiper	>1,50,000	> 80,000	< 25,000
Little Stint	> 2,00,000	> 1,00,000	< 30,000
Lesser Sand Plover	> 1,00,000	> 75,000	< 40,000
Ruff	> 1,00,000	30,000	< 10,000
Black-tailed Godwit	> 50,000	> 40,000	>15,000
Black-winged Stilt	> 15,000	3,000	>1,000
Pied Avocet	> 7,000	> 500	< 100

Decline of Migratory Waterbirds

In east coast of India, due to the degradation of wetlands habitats, populations of various waterbird species are dwindling in their traditional wintering sites. One of the greatest threats to the sustainability of the coastal wetlands and the survival of the flora and fauna, which depend on this unique habitat, is human disturbance to the shoreline. In India, due to the degradation of wetlands habitats, populations of various waterbird species are dwindling in their traditional overwintering sites.

The decline in Greater Flamingo numbers was well pronounced since 1990s, as the numbers between 2000 and 2007 never exceeded 5500. However, the peak



Table 2. Population trend of common waders at Gulf of Mannar

Species Name	1985-1988	1993	2001	2005-2007
Curlew Sandpiper	>10,000	>8,000	>5,000	< 1,000
Little Stint	>8,000	>3,000	>2,000	< 1000
Lesser Sand Plover	>13,000	>8,000	>4,000	< 2,500
Crab Plover	900	150	65	< 20
Eurasian Curlew	450	120	67	55
Grey Plover	970	230	180	100
Great Knot	350	140	450	< 200
Red Knot	300	85	90	< 50
Common Greenshank	250	>3,500	180	< 50

Table 3. Population of trends of waterbirds in major coastal wetlands

Site	1980s	1990s	2000	2011-12	Major groups
Point Calimere	10,00000	6,00000	2,50000	4,50000	Shorebirds, ducks, Gulls, terns, flamingos, storks, egrets and herons, ibises, spoonbill
Pulicat	3,00000	2,00000	1,50,000	1,50,000	Shorebirds,, Ducks, flamingos, Gulls, terns, egrets and herons
Chilika	12,00000	6,00000	8,00000	9,00000	Ducks, Shorebirds,, Gulls, terns, flamingos, storks, pelicans egrets and herons
Bhiterkanika	-	-	1,50,000	150,000	Ducks, shorebirds, storks egrets and herons.
Kaliveli	50,000	35,000	15,000	15,000	Shorebirds, Pelican, Ducks, terns, flamingos, Gulls, egrets and herons
Sundarbans			40,000	-	Shorebirds,, Ducks, terns, Gulls, egrets and herons
Gulf of Mannar	75,000	50000			Gulls, terns, flamingo, shorebirds.
Saltpans of Kanyakumari	25,000	25,000	30,000		Terns, ducks, storks, pelicans, ibises, flamingo, egrets and herons

numbers are seen only for a short duration of two months (January - February). It is interesting to note that in the 1980s and early 1990s two to three thousand Greater Flamingos were regularly observed during the summer also. For last three years, during summer the number is less than 50.

Among the migratory waterbird groups, the decline in numbers for waders is drastic and worldwide which varied from 60 to 80% for most of the species during the last three decades. The similar kind of decline also reported from the major wetlands like Point Calimere, Gulf of Mannar and Pulicat.



Population estimates of waders in Chilika

Common Name	2001-2005	2005-2010	2010-2012
Black-tailed Godwit	32000-55000	44000-60,000	55,000-65000
Curlew Sandpiper	25,000-54000	12000-20,000	5000-8000
Lesser Sand Plover	40,000-45,000	11,000-29,000	8,000-14,000
Ruff	3,000-10,000	1500-3200	4,000-6000
Marsh Sandpiper	2,100-12000	2,300-4,000	3000-3500
Grey Plover	200-2500	400-1600	350-850

The maximum number of Greater Flamingo recorded during the three years study undertaken between 1985 and 1988 at Gulf of Mannar was 14,000, 5,000 and 7,000 respectively (Balachandran, 1990). The regular fortnightly bird population monitoring carried out between August 2005 and April 2006 from the same area has recorded the maximum of 5500.

The Greater Flamingo was an abundant winter visitor to Nalabana Island, arriving in August and departing in July. A dramatic decline (from 5000 to 150) during 2003-2004 was observed in the Greater Flamingo numbers from the stable peak numbers of the previous two years. In 2004-2005, though an increase in numbers was noticed, the peak never matched that of the first two years.

Reasons for the population decline in waders in Point Calimere

The extension of salt based industries; the diminishing rainfall and disturbances caused by fishermen have altered the habitats

Depletion of ground water and salt intrusion

The ground water extraction has increased manifold to cater the needs of the floating fisherfolk population, which is on the increase at Point Calimere. The ground water recharge is inadequate due to the consistently diminishing rainfall in the area over the last two decades. The ingress of seawater into larger areas of the swamp affected by the strong summer wind, made the swamp not only habitable for the waterbirds

Population trend of Greater Flamingo

Species Name	1980s	1990s	2000-2008
Point Calimere	> 40,000	> 10,000	1,500-5,500
Pulicat	> 30,000	> 8,000	3,000-15,000
Dhanushkodi Lagoon	>14,000	> 7,000	3000 - 5,500
Chilika Lake	7,000	6,500	150 - 5000

during summer, but also helped to prevent the mudflats from drying up completely.

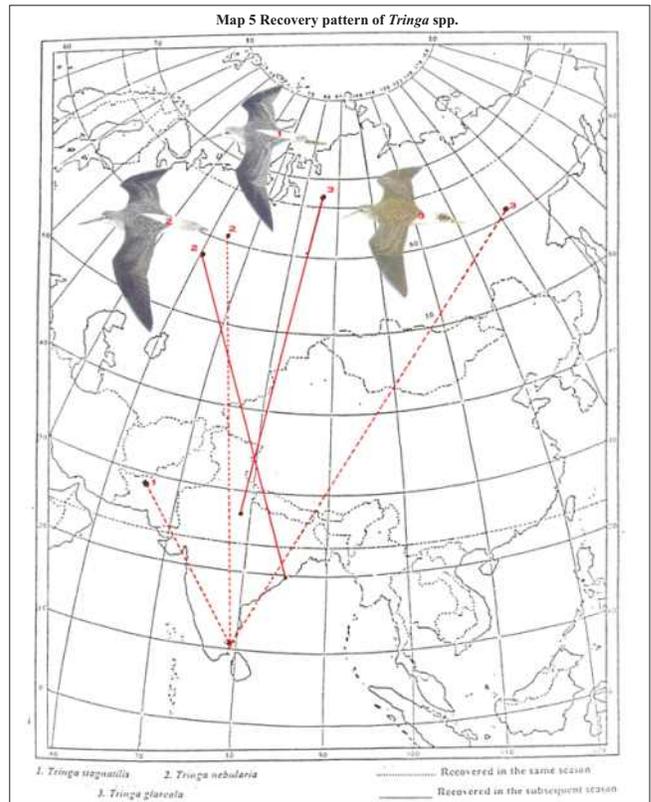
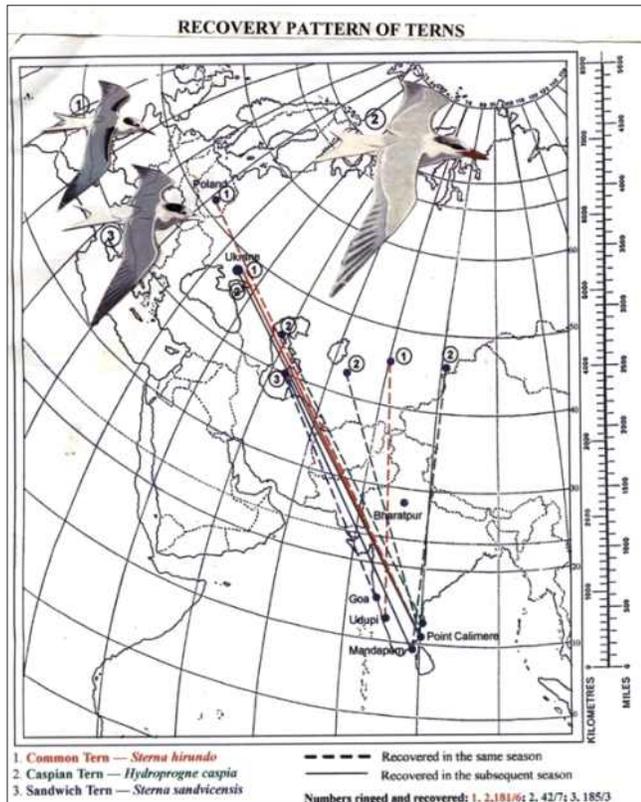
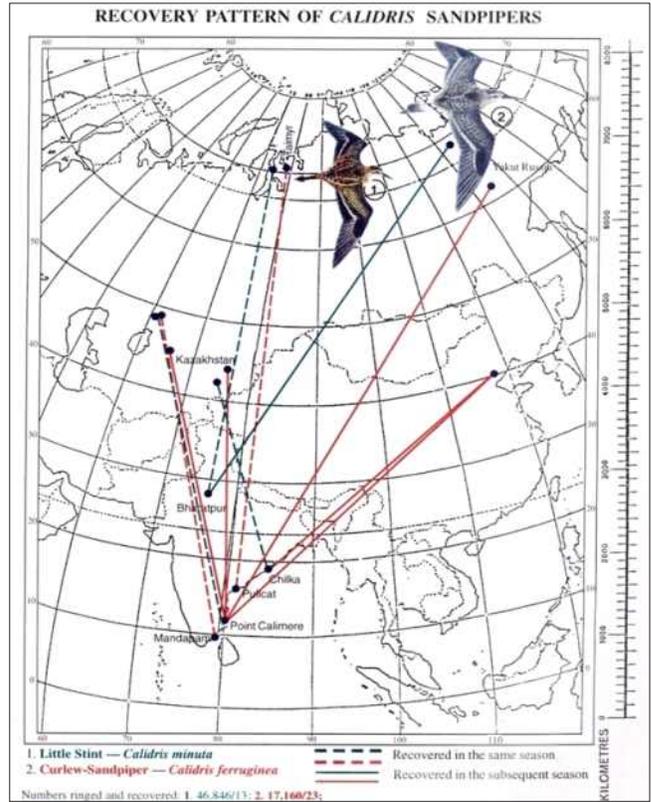
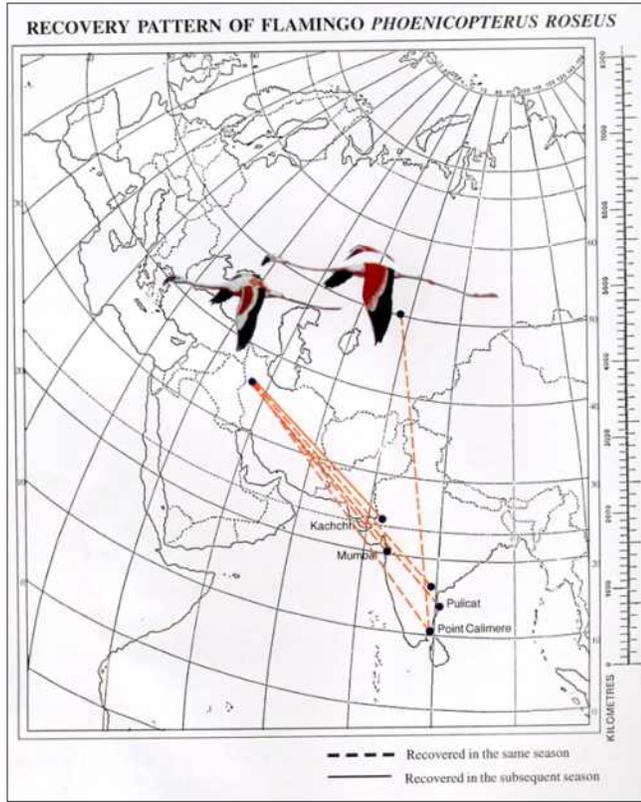
Conclusion

The migratory waterbirds connect continents and countries and are therefore excellent environmental indicators at both global and local scales. There are indications of serious problems along the Flyway Reduction in overall flyway population for the coastal birds was evident as their numbers are on the decline globally. Most of the threats are either at the wintering and staging/refueling sites whereas threats (natural and human-induced) at the breeding grounds are negligible due to the inaccessibility. Hence, habitat degradation complemented by poaching (at unprotected buffer zone) form the major threats during their migration journeys.

Coastal birds, with their range of specialized feeding and migration ecologies are sensitive indicators of change in their environments. Knowledge of the status of coastal bird populations can provide important information on the wider environment, including that caused by climate changes as well as from habitat loss,



Coastal birds migratory routes





Lesser Crested Tern Migratory routes Through Ringing Recoveries



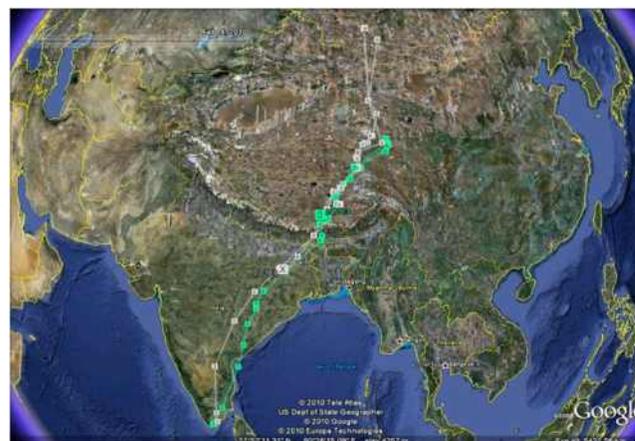
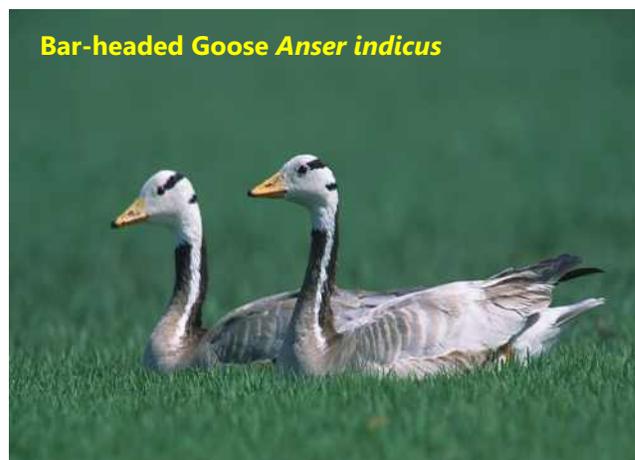
harmful industrial developments, unregulated agricultural practices, human disturbance, climatic and environmental changes, they are becoming scarce at many key sites.

Need for the conservation of coastal birds and their habitats

The role of Indian coastal wetlands for the maintenance of global waterbird population

As many as 89% of all monitored populations of Arctic breeding shorebirds in northeastern Russia now show decline (Syroechkovskiy 2012).

Migratory Routes of Bar-headed Goose through Satellite Tracking



Coastal wetlands in India provide winter refuge for migratory waterfowl from different parts of the world such as north, central and west Asia, Europe and Mediterranean regions. Birds migrating from Arctic to east Africa use the coastal wetlands of northwestern India as a stopover sites. Coastal wetlands of Gulf of Kachch and the intertidal zones of Saurashtra coast, and Gulf of Mannar are the favourite wintering haunts for the Crab Plover an uncommon and restricted range species which breeds in Iran and Persian Gulf. These two wetlands also support large population of Lesser Crested and Large Crested *Sterna bergii* terns, which migrate from Persian Gulf to India. All the coastal wetlands of India are frequented by arctic breeding shorebirds such as Curlew Sandpiper, Little Stint, Ruddy



Turnstone *Arenaria interpres* and Grey Plover *Pluvialis squatarola* and temperate breeders such as Common Greenshank *Tringa nebularia*, Redshank *Tinga totanus*, Lesser Sand Plover and Kentish Plover.

Among the ducks the Arctic breeding species such as Northern Pintail, Garganey *Anas querquedula* and Northern Shoveller *Anas clypeata* Eurasian Wigeon *Anas Penelope* migrate to the coastal wetlands up to the southernmost part of India.

Coastal wetlands in India also provide habitat for several federally listed threatened and near threatened bird species. The threatened species, namely Spotted Greenshank *Tringa guttifer*, Spoonbill Sandpiper *Calidris pygmeus*, Dalmatian Pelican *Pelecanus crispus*, Spot-billed Pelican *Pelecanus philippensis*, Pallas's Fish-eagle *Haliaeetus albicilla*, Wood Snipe *Gallinago nemoricola* and Indian Skimmer *Rynchops albicollis* and the near threatened Darter *Anhinga melanogaster*, Painted Stork *Mycteria leucocephala*, Lesser Flamingo *Phoenicopterus minor*, Asian Dowitcher *Limnodromus semipalmatus*, Beach Stone-Plover *Esacus magnirostris* and Black-bellied Tern *Sterna acuticauda* are some of the important species, which are found in the coastal wetlands.

The body mass (weight) gained at the wintering and staging areas generally help the migratory birds to breed successfully at their northern breeding grounds. In India, most of the freshwater bodies dry up during the spring passage (return migration to their breeding grounds in March and April), and hence, migratory birds depend only on the coastal wetlands to build up their body mass.

Population decline of some common waders

Over one million migratory waders and ducks were reported from Point Calimere during the 1980s which declined to less than 150,000 in the late 1990s. However, in recent years the population goes upto

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3,50,000 which may be due to the shifting of population from other coastal wetlands which traditionally supported more coastal birds.

It is clear that different species utilise different suites of sites during northbound and southbound migration. Therefore, protection of only the best sites will not provide an adequate site network for all migratory species and broader protection of as many sites as possible is required.

Management recommendations

Protect coastal bird habitats

- Enhance and maintain coastal bird habitats,
- Avoid further degradation or loss of critical wintering and staging sites,
- Restrict coastal development to areas where its impact on coastal bird habitat is minimal.

Community education

- Educate the community about coastal birds conservation,
- Collaborate with the primary stakeholders (wildlife division) in the delivery of key messages about coastal birds conservation.
- Encourage establishment of eco-tourism programs that provide coastal bird education and interpretation.

Research and monitoring

- Monitoring population of coastal birds in key wintering and staging sites.
- Collaboration with relevant organisations (BNHS, ZSI, SACON etc).
- Investigate the use of coastal birds as bio-indicators in ecosystem health assessment.
- Encourage research on shorebird migration and conservation

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Study on shorebirds suggests that when conserving species, not all land is equal

Date: June 9, 2020

Source: Princeton University

Summary: Researchers may have solved the long-standing puzzle of why migratory shorebirds around the world are plummeting several times faster than coastal ecosystems are being developed. They discovered that shorebirds overwhelmingly rely on tidal zones closest to dry land, which are most often lost to development. The findings suggest that protecting species requires a detailed understanding of how animals interact with the landscape so that preserved habitats best serve endangered species' needs.

FULL STORY

Princeton University researchers may have solved a long-standing mystery in conservation that could influence how natural lands are designated for the preservation of endangered species.

Around the world, the migratory shorebirds that are a conspicuous feature of coastal habitats are losing access to the tidal flats -- the areas between dry land and the sea -- they rely on for food as they travel and prepare to breed. But a major puzzle has been that species' populations are plummeting several times faster than the rate at which coastal ecosystems are lost to development.

Nowhere is the loss of tidal flats and shorebird species more acute than along the East Asia-Australasian Flyway (EAAF). An estimated 5 million migratory birds from 55 species use the flyway to travel from southern Australia to northern Siberia along the rapidly developing coast of China -- where tidal flats can be more than 6 miles wide -- at which birds stop to rest and refuel.

Since the 1980s, the loss of tidal flats around the Yellow Sea has averaged 1.2% per year. Yet, the annual loss of the most endangered bird species has averaged between 5.1 and 7.5%, with populations of species such as the critically endangered spoon-billed sandpipers (*Calidris pygmaea*) climbing as high as 26% each year.

In exploring this disparity, Princeton researchers Tong Mu and David Wilcove found a possible answer -- the birds don't use all parts of the tidal flat equally. They discovered that migratory shorebirds overwhelmingly rely on the upper tidal flats closest to dry land, which are the exact locations most often lost to development.

They report in the journal *Proceedings of the Royal Society B* that China's upper tidal flats provided more than 70% of the cumulative foraging time for the species they studied at two Yellow Sea sites along the EAAF. The middle and lower flats that birds are increasingly pushed toward by human activity were less frequently foraged upon due to the tide cycle, which may be impacting species health and breeding success.

The findings stress the need for integrating upper tidal flats into conservation plans focused on migratory shorebirds, the authors reported.

"This is a new insight into Asian shorebirds, but I suspect that the upper intertidal is disproportionately important to shorebirds in other places, too, such as the East and West coasts of North America," said Wilcove, who is a professor of ecology and evolutionary biology and public affairs and the Princeton

Environmental Institute (PEI).

"People start at the upper zone and work their way outward, so the best spots for the birds are the first to go," he said. "It would probably be best to extend current developments farther into the intertidal zone rather than keep building parallel to the coast, which consumes more of the upper intertidal.

"Think of it as advocating for a rectangle with the long side pointing into the sea versus a rectangle with the long side hugging the shore," Wilcove said.

The study results also suggest that protecting species and their habitats may mean more than designating land for wildlife -- it may require identifying the right land to set aside by gaining a detailed understanding of exactly how animals interact with the landscape.

"Recognizing the importance of a kind of habitat to specific species or groups of species takes time, effort and thought," said Mu, who is the paper's first author and a Ph.D. candidate in ecology and evolutionary biology.

"Sometimes we just don't know what to look for, or looking requires challenging some prevalent and maybe false perceptions," he said. "But the situation is getting better and better. People are paying more attention to environmental issues, and the advances in technology are helping us gain more and newer insight into these questions."

Mu conducted fieldwork between September 2016 and May 2017 at two well-known stopover sites -- one outside of Beijing, the other near Shanghai -- for migratory shorebirds in the Yellow Sea region. He focused on 17 species of birds, noting where along the tidal flat the animals preferred to feed.

A key difference to his approach, Mu said, is that most previous research focused on the low-tide period when all the tidal flats are exposed and the full range of intertidal species can be observed.

"It makes sense from an ecological point of view. During the high tides when only a portion of the tidal flats is accessible, the relationship usually still holds for the exposed area," Mu said. "So, there's little incentive to look at the periods other than low tide when researchers can get a more complete picture."

What Mu thinks was missed, however, was that the upper tidal flats provide the most amount of foraging time for birds that have places to be. Even if the lower half of a 6-mile wide mudflat is set aside for migratory birds, they're not getting the energy they need for the trip ahead during the high tide, he said.

"The value of the tidal flats comes from not only their size, but also how much foraging time they can provide," Mu said. "The upper tidal area is exposed for a longer period during tidal cycles, compared to the middle and lower areas, which I think permits shorebirds to forage for a longer time and thus get more energy."

The preservation of shorebirds should be driven by how integral the animals are to the health of intertidal zones, Mu and Wilcove said. In turn, tidal flats are not only vital to other marine life, but also provide people with seafood such as clams and crabs and protection from storms and storm surges that cause coastal flooding.

"Shorebirds facilitate the energy and nutrient exchanges between land and sea," Mu said. "Because a lot of them are long-distance migrants, they also facilitate the energy and nutrient exchanges across different ecosystems and continents, something that is usually overlooked and underappreciated."

Wilcove and Mu cited recent research showing that more than 15%, or more than 12,000 square miles, of the world's natural tidal flats were lost between 1984-2016.

"Some of the greatest travelers on Earth are the shorebirds that migrate from Siberia to Southeast Asia and Australia," Wilcove said. "Now, they're declining in response to the loss of the tidal areas, and the full range of benefits those tidal flats provide are in some way being diminished."

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1. Tong Mu, David S. Wilcove. **Upper tidal flats are disproportionately important for the conservation of migratory shorebirds**. *Proceedings of the Royal Society B: Biological Sciences*, 2020; 287 (1928): 20200278 DOI: 10.1098/rspb.2020.0278
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Shorebirds



Sooty oystercatcher

What is a shorebird?

Shorebirds, also known as waders, gather in intertidal areas or on the fringes of freshwater wetlands. They generally have long legs in relation to their body size, no webbing on their feet and they don't swim. The shape and size of their bill gives a clue to their preferred diet and habitat. For example, the long, probing bill of the eastern curlew is ideal for fishing out worms and crustaceans from deep mud, whereas the short, stubby bill of the ruddy turnstone can flip aside stones and shells on a rocky foreshore.

Shorebirds make up about 10 per cent of Australia's species of birds. Fifteen species of shorebird are resident in Australia and an additional 34 species are regular migrants. Most of the migrant species breed in northern China, Mongolia, Siberia and Alaska during June and July and then migrate to Australia for the non-breeding season. Each year, more than a million shorebirds migrate to and from Australia, and many more millions worldwide travel great distances between their breeding and non-breeding habitats. About 40,000 shorebirds of the 34 species migrate to Moreton Bay in Queensland each year.



A year in the life of Moreton Bay shorebirds

Amazing migrations

Some shorebirds weighing as little as 30 grams may migrate 25,000 km annually. Some species may fly more than 6,000 km non-stop. In doing this, they use favourable weather patterns when they can, but even so will commonly lose 40 per cent of their bodyweight, flying at more than 60 km/hr, non-stop for three days and nights. Shorebirds make the journey in several weeks, stopping two or three times along

the way. When they stop, they must 'refuel': they feed and rest to build up energy reserves. At these times they may increase their body weight by more than 70 per cent before undertaking the next marathon stage of their journey.

Through wind and storm, enduring unbearably hot days and freezing nights, avoiding waiting hunters, shorebirds miraculously navigate along a precious chain of wetlands, including Moreton Bay, to complete their global journey. Migrating shorebirds travel these remarkable distances each year because of their special breeding requirements. Breeding takes place in areas where melting snow signals masses of insects, providing a vital food source for self-feeding chicks. Once breeding is complete, and before the onset of the Arctic winter, the adults and newly fledged chicks begin their incredible return journey to the plentiful feeding grounds of the south.

One of Queensland's migratory shorebirds, the double-banded plover, follows the same principle, but rather differently. It breeds on the pebble beds of the rivers of New Zealand's South Island in the summer months from September to March, and then flies trans-Tasman to spend the southern winter in the comparatively warm conditions of Australia's east coast. So it arrives in Queensland in March/April when all other migratory shorebirds are leaving for Siberia and Alaska, and leaves in August/September when the others are returning.

Migrating shorebirds need huge amounts of energy to complete this perilous journey. One of the best-studied species, the eastern curlew, dramatically builds up its body weight just before migration. During its flight from Siberia to Australia, it will burn off 40 per cent of this weight to fuel its 13,000 km journey. This is like an 80 kg person running 16 million kilometres almost non-stop and losing 32 kg, twice a year!

Each year about 15 per cent of the migrating shorebirds that visit Moreton Bay in the summer stay for the whole year. These include birds that are too young to breed or adults that are not strong enough for the journey north.



The East Asian-Australasian flyway

Highways in the sky

The routes that shorebirds travel along on their annual migration are called flyways. A flyway is broadly defined as the migration route of a population, species, or group of species of birds, between a breeding area, through the staging sites and non-breeding area. Flyways are like invisible highways. How does a migrating shorebird know which way to go? Are there maps in the stars? Patterns on the land? Memories in their genes? Or are they guided by the sun and the moon or the earth's magnetic field? Scientists say it is probably a combination of all of these but they are still unclear exactly how migratory shorebirds find their way.

Like weary travelers on a lengthy journey, shorebirds need rest stops along the way to refuel and have a break. Flyways are like chains with many links. Each link is an important wetland, such as an estuary or bay, where the birds can stopover to feed and regain their strength for the next leg of their migration.

The message is clear, everything is interconnected – remove enough of these links and species may disappear altogether!

Moreton Bay is an important habitat in the East Asian–Australasian Flyway, which is one of eight flyways in the world. The East Asian–Australasian Shorebird Reserve Network is an international chain of wetlands recognised for their importance to shorebirds. The network ensures there are safe and convenient stopover points for shorebirds to rest and feed along their "endless summer" between the Arctic north and the warm south.

Shorebirds' lives are driven by tides

At low tide, regardless of day or night, shorebirds feed constantly – pecking and probing for worms, insects and crustaceans. With highly variable and specialised bills they feed around intertidal flats, beaches, rocky headlands and along the fringes of freshwater wetlands.

As the incoming tide covers these feeding areas, they begin to congregate in large numbers at relatively safe and nearby roost sites. These roost sites provide areas where they can interact, preen, digest their food and rest while waiting for the ebbing tide to again expose their feeding areas. During particularly high spring tides, all the shorebirds of Moreton Bay crowd together on a limited number of higher elevation roost sites. Disturbance during this time is more damaging than usual.

What else is so special about shorebirds?

There are many special and fascinating things about shorebirds. Being able to fly is something many people dream of, and to be able to travel thousands of kilometres in flight is amazing.

When a flock of shorebirds takes flight on the next leg of its journey, watch how they circle overhead – some will form a beautiful "V" formation in the sky before heading off like a giant arrow.

Some shorebirds have beautiful or haunting calls. Listen for the eerie cry of the bush stone-curlew at night, or the signature call of the eastern curlew during its annual summer stopover.

Other special features of shorebirds include their sleek design, specialised bills for feeding and expert hunting skills. Near the end of summer, many species will moult and change into spectacular breeding plumage – announcing their suitability as potential partners.

In Australia there are Aboriginal stories about shorebirds and in some cases there is evidence of their traditional use. For the Aboriginal people of Moreton Bay the eastern curlew, known as the "sea curlew" – *Gurrrell* – was a source of food during summer. The "land curlew" (bush stone-curlew), also known as the "messenger bird" – *Bulligan* – because of its eerie cries, brought a message from Aboriginal spirits to the people. When an Aboriginal person is about to depart this life, the messenger bird visits his home at night and gives three calls.

You can help protect shorebirds

Shorebirds are not like streetwise urban birds such as noisy miners, crows, pigeons or magpies; they are very easily disturbed by close activity. When shorebirds are disturbed they waste hard-earned energy

reserves, reducing their ability to survive on their long migration.

Dogs, in particular, disturb shorebirds. In local government areas adjoining Moreton Bay, and on some other areas along the coast of Queensland, dogs must be on a leash at all times unless in a designated "off leash" area. Penalties apply.



Keeping a dog leashed while on the beach Photo: J Esdaile

So what is disturbance and how can we avoid it?

Disturbance is any action that interrupts the breeding, feeding or resting of shorebirds. Causing a shorebird to take flight represents a significant disturbance as it makes the bird waste vital energy.

You can prevent shorebird disturbance if you follow these guidelines:

- Keep domestic animals under control and well away from shorebirds. Every time shorebirds are forced to take flight, they burn vital energy.
- Avoid driving or operating all forms of vehicles, vessels and recreational devices near shorebirds. Imagine a shorebird confronting a kite surfer for the first time; it probably thinks it is the biggest predator it has ever seen!
- Don't drive along the beach at high tide or above the high-water mark – you'll destroy shorebird nests.
- If fishing from a sandbar, choose the opposite end to where the birds are gathered.
- Feral animals can kill shorebirds – you can report any sightings of feral animals to [FeralScan](http://www.feralscan.org.au) (<http://www.feralscan.org.au>) or contact the Department of Agriculture and Fisheries on 13 25 23.
- Consider how your actions may disturb shorebirds. This can include where you set up camp or a simple stroll through a roost site at high tide.
- Prevent pollution – remember that almost all rubbish and pollutants discarded on the land end up in the bay.

By disturbing shorebirds we reduce their survival prospects. Remember it is an offence to cause disturbance to shorebirds and their habitat in Moreton Bay and hefty on-the-spot penalties apply.



Grey-tailed tattler with leg flag circled

How to watch shorebirds

For a good look at shorebirds, sit quietly at a distance, ideally in a bird-hide, and study them through binoculars or a spotting scope.

You can look out for birds that are tagged with coloured plastic leg "flags". Birds banded in:

- Moreton Bay have a green tag,
- north-western Australia have a yellow tag,
- southern Australia have an orange tag over a yellow tag.

Many other areas have unique colour flag combinations. For further details, please go to the [Australasian Wader Studies Group](http://awsg.org.au/) (<http://awsg.org.au/>) and select "wader flagging program".

Noise, speed and movement easily disturb shorebirds. Avoid approaching flocks of birds where possible.

The Queensland Wader Study Group regularly conducts shorebird monitoring in Queensland and welcomes new members. For further information see [Birds Queensland](http://birdsqueensland.org.au/) (<http://birdsqueensland.org.au/>).

What if the shorebirds just disappear?

Unfortunately, around the world and within Australia, wetlands are rapidly disappearing and being developed for farming, housing, industrial and coastal developments.

As people place more demand on land, wildlife can just slip away unnoticed and be forgotten. Many areas that were once habitat for shorebirds are now unsuitable. This results in increased pressures on the remaining areas and a reduction of shorebird numbers in Moreton Bay.

If too much habitat is lost or disturbed local and international shorebirds and a vital link in the flyway will be gone.

Would we miss the cry of the curlew, the antics of a lifelong pair of oystercatchers or the spectacular overhead "V" formation of migratory shorebirds? What would happen to the delicate ecological balance of Moreton Bay if thousands of hungry shorebirds were lost? It would certainly be better not to have to answer these questions.

Resident Queensland shorebirds

Common name	Scientific name
Beach stone-curlew	<i>Esacus magnirostris</i> (conservation status: Qld - vulnerable)
Australian painted snipe	<i>Rostratula australis</i> (conservation status: Qld - vulnerable)
Pied oystercatcher	<i>Haematopus longirostris</i>
Sooty oystercatcher	<i>Haematopus fuliginosus</i> (Conservation status: Qld - rare; national - least concern)

Migratory shorebirds

Common name	Scientific name
Black-tailed godwit	<i>Limosa limosa</i>
Bar-tailed godwit	<i>Limosa lapponica</i>
Little curlew	<i>Numenius minutus</i>
Whimbrel	<i>Numenius phaeopus</i>
Eastern curlew	<i>Numenius madagascariensis</i> (Conservation status: Qld - endangered; national - critically endangered)
Marsh sandpiper	<i>Tringa stagnatilis</i>
Common greenshank	<i>Tringa nebularia</i>
Wood sandpiper	<i>Tringa glareola</i>
Terek sandpiper	<i>Xenus cinereus</i>
Common sandpiper	<i>Actitis hypoleucos</i>
Grey-tailed tattler	<i>Tringa brevipes</i>
Wandering tattler	<i>Tringa incana</i>
Ruddy turnstone	<i>Arenaria interpres</i>
Asian dowitcher	<i>Limnodromus semipalmatus</i>
Great knot	<i>Calidris tenuirostris</i>
Red knot	<i>Calidris canutus</i>
Sanderling	<i>Calidris alba</i>
Red-necked stint	<i>Calidris ruficollis</i>
Pectoral sandpiper	<i>Calidris melanotos</i>
Sharp-tailed sandpiper	<i>Calidris acuminata</i>
Curlew sandpiper	<i>Calidris ferruginea</i>
Broad-billed sandpiper	<i>Limicola falcinellus</i>
Pacific golden plover	<i>Pluvialis fulva</i>

Common name	Scientific name
Grey plover	<i>Pluvialis squatarola</i>
Mongolian plover (now lesser sand plover)	<i>Charadrius mongolus</i>
Large sand plover (now greater sand plover)	<i>Charadrius leschenaultii</i>

Shorebird strategies

There are ten bilateral agreements for migratory bird conservation in the East Asian Australasian Flyway, involving seven countries. The three agreements involving Australia are JAMBA (Japan/Australia Migratory Bird Agreement), CAMBA (China/Australia Migratory Bird Agreement) and ROKAMBA (Republic of Korea/ Australia Migratory Bird Agreement).

In addition to bilateral agreements there are two multilateral agreements that are relevant to flyway conservation of waders. The Ramsar Convention (Convention on Wetlands of International Importance especially as Waterfowl Habitat) promotes wetland conservation, and the Bonn Convention (Convention on the Conservation of Migratory Species of Wild Animals) provides a multinational framework for the conservation of migratory species. In the East Asian-Australasian flyway, 15 of the 22 countries in the flyway have signed the Ramsar Convention.

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Acknowledgement of Country

The Department of Environment and Science acknowledges Aboriginal peoples and Torres Strait Islander peoples as the Traditional Owners and custodians of the land. We recognise their connection to land, sea and community, and pay our respects to Elders past, present and emerging.



Design developed by Boyd Blackman, a Butchulla and Birri Birri man, featuring the artwork of Elaine Chambers, a Koa (Guwa) and Kuku Yalanji woman.

The Department of Environment and Science is committed to respecting, protecting and promoting human rights, and our obligations under the *Human Rights Act 2019*.

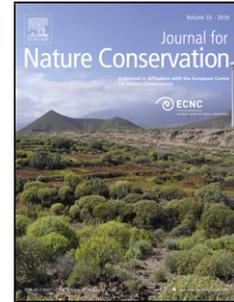
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1 The negative effect of dredging and dumping on shorebirds at a coastal wetland in
2 northern Spain.

3

4 Juan Arizaga¹, Juan A. Amat², Manu Monge-Ganuzas³

5 ¹Department of Ornithology, Sociedad de Ciencias Aranzadi, Zorroagaina 11, 20014
6 Donostia-S. Sebastián, Spain.

7 ²Estación Biológica de Doñana (EBD-CSIC), Américo Vespucio s/n, 41092 Sevilla,
8 Spain.

9 ³Service of Urdaibai Biosphere Reserve; Department of Environment and Territorial
10 Policy, Basque Government; Madariaga Tower, Gernika-Bermeo road. San Bartolome,
11 48350 Busturia, Spain.

12

13 *Corresponding author: jarizaga@aranzadi.eus

14

Accepted Manuscript

14 ABSTRACT

15

16 Dredging and/or dumping actions at coastal environments are a common phenomenon
17 worldwide. The re-working of dumped sediments from their disposal sites to places of
18 great ecological value can have a very strong impact on the ecosystems through deep
19 changes over the communities and the trophic web. Using a relevant dredging-dumping
20 episode carried out in 2003 at Urdaibai, one the chief estuary areas in northern Iberia,
21 we tested the consequence of this action on the subsequent use of the zone by
22 shorebirds. The surface sediment characteristics before and after the dredging and
23 dumping actions were also compared. The dredging at Urdaibai showed a negative
24 effect on bird abundance in three out of the eight species tested overall (dunlin, grey
25 plover, common ringed plover). Highest-ranked models supported a decrease in their
26 population sizes two years after the event. In this scenario, local authorities should be
27 appealed to take dredging and dumping effects into account in order to improve the
28 estuary management.

29

30 KEYWORDS

31

32 Aquatic bird populations; conservation biology; mudflats; population trends; sandy
33 areas; Urdaibai Biosphere Reserve.

34

34

35 INTRODUCTION

36

37 All ecosystems are subject to some degree of perturbation, and all organisms are well
38 adapted to cope with predictable perturbations, such as those determined by seasonal
39 events. However, extreme or unpredictable perturbations, either natural (e.g. hurricanes)
40 or owing to human activity (e.g. fires), could cause severe effects on ecosystems, from
41 which it might take decades to recover (Borja et al. 2010; Pons and Clavero 2010;
42 Manning et al. 2011).

43

44 The conservation of intertidal coastal environments is today a major concern for
45 ecologists, managers, and the society in general (Weller 1999; Ma et al. 2010). Habitat
46 loss and degradation are part of a problem that affects many intertidal wetlands all over
47 the world (Eddleman et al. 1988; Bildstein et al. 1991). For instance, the global annual
48 loss rate of coastal salt marshes is calculated to be 1-2% per year (Duarte et al. 2008), a
49 rate which is above of the 0.5% per year loss rate of tropical forests (Achard et al.
50 2002).

51

52 Many intertidal coastal environments, mostly those linked to estuaries, have been
53 historically used as natural harbors, an activity that is often associated with constant or
54 periodic dredging in order to keep or increase the depth of these water bodies (Bary et
55 al. 1997). The material (clay, sand or mud) extracted during such dredging is often
56 dumped close to the dredging area to minimize the economical cost of the transport
57 (Bary et al. 1997). One of the main consequences of dredging and dumping actions is
58 habitat burial or destruction, with a negative impact on the ecosystem, especially on the
59 macrobenthos that is situated in the bottom of the trophic network (Lindeman and
60 Snyder 1999; Lewis et al. 2001; Boyd et al. 2005; Erftemeijer and Lewis 2006). Thus,
61 any negative effect on such communities can alter the entire trophic structure related to
62 the mudflats and, consequently, induce negative effects on upper trophic levels.

63

64 Clayey-muddy and sandy substrates do not host the same communities of macrobenthos
65 that constitute the food of many shorebirds (Colwell 2010). In general, mudflats are
66 commonly richer in shorebird food than sandy areas (Burger et al. 1997). Dredging and
67 dumping actions carried out in estuary areas often cause habitat loss in very

68 ecologically-sensible habitats, such as mudflats (Monge-Ganuzas et al. 2013). Thus,
69 dumping of sand in some sensitive estuarine areas where there is an active sediment
70 transport could cause a coverage of the mudflats and, consequently, long-lasting
71 negative effects on benthic communities, as well as severe negative consequences for
72 shorebirds using these areas (Piersma et al. 2001).

73

74 Here, we used retrospective analyses of dredging episodes on shorebirds' abundance
75 and diversity in a tidal marsh, which could help to identify the consequences of
76 dredging on shorebirds using the marsh. We predicted that relevant dredging and
77 dumping actions may lower the capacity for shorebird populations to recover. To test
78 this we used long-term data of shorebird censuses conducted in a site (an intertidal
79 coastal environment located at the Urdaibai Biosphere Reserve, northern Spain) affected
80 by a very important dredging and dumping episode. Together with this analysis, we also
81 compared induced surface grain size trend before and after the dredging and dumping
82 episode. We also predicted that the effect of the dredging and subsequent dumping
83 episode should have been more severe on those species that forage mostly or only on
84 the mudflats.

85

86 MATERIAL AND METHODS

87

88 *Study area*

89

90 The Urdaibai estuary is a coastal wetland located in the North of Spain. It was declared
91 Biosphere Reserve in 1984, included within the Ramsar list in 1992, and SPA
92 (ES0000144) and SAC (ES213007) of Natura 2000 in 2014. With ca. 945 ha, Urdaibai
93 is used by a remarkable amount of mostly northern Euro-Siberian waterbirds (including
94 shorebirds) that use this area either as a stopover site during migration period or as a
95 wintering area (Galarza 1984; Garaita 2012). Shorebirds constitute a group of birds with
96 conservation interest within the region (Galarza and Domínguez 1989; Hidalgo and Del
97 Villar 2004). Urdaibai has suffered periodic dredging and dumping actions for the last
98 43 years (Monge-Ganuzas et al. 2013), with the last action occurring in 2003, when
99 243,000 m³ were extracted from the main channel of the estuary and dumped in a sandy
100 area close to the mouth. In comparison with previous dredging episodes, this last was
101 very much larger (e.g. ca. 310% higher than the previous dredging in 1998-1999). After

102 this dredging, wave winter storms together with tidal wave action progressively eroded
103 the sediment and spread some sand towards upper estuary areas (Monge-Ganuzas et al.
104 2008) over much of the existing intertidal mudflats, the main foraging area for
105 shorebirds within the estuary (Hidalgo and Del Villar 2004).

106

107 *Data collection*

108

109 In March 2003 (immediately before the dredging and dumping carried out at Urdaibai),
110 24 surface sediment samples were collected either by hand all along the main intertidal
111 mudflats or from a 4 m-long vessel by a Van Veen grab (this last used to take samples
112 along the chief estuary channel). Overall, the sampling net consisted in a 200 m each
113 side orthogonal grid (Fig. 1). This sampling protocol was repeated in July of 2016.
114 Samples were stored until their analysis in a laboratory (UPV/EHU).

115

116 Using a Laser diffraction particle size analyzer (Beckman Coulter counter LS 13 320),
117 three replica of each sediment sample were analyzed (Nayar et al. 2007) and statistically
118 integrated in order to obtain the weight percentage grain size distribution for each
119 sample (Udden 1914; Wentworth 1922).

120

121 Census data consisted in counts (species and numbers of shorebirds) conducted during a
122 single survey day in mid-January, coordinated by Wetlands International. Here, we
123 considered a period spanning from 1992 to 2011. Censuses were conducted using a
124 fixed, standard protocol, consisting in counting always from the same points, covering
125 the same survey area and, if possible, by a same observer from year to year, during high
126 tide. In general, due to the characteristics of Urdaibai, where birds accumulate in
127 relatively small areas easy to survey during high tide (J. Arizaga, pers. obs.), high tide-
128 census are recommended for counting waterbirds (but see Navedo et al. 2007).

129

130 Meteorological data (mean value for the daily mean temperatures in January) were
131 extracted from the NOAA website (www.esrl.noaa.gov). We considered an effect of
132 temperature because local numbers of waterbirds within the region can depend on
133 climatic conditions at a local scale level (Navedo et al. 2007).

134

135 *Data analyses*

136

137 Sediment characteristics (percentage of sand and silt-clay of each sample) before and
138 after the dredging and dumping actions at Urdaibai were compared with a *t*-test for
139 repeated measures.

140

141 With the aim of conducting models on counts we selected those species which showed a
142 median ≥ 10 individuals/year for the period spanning from 1992 to 2003 (i.e., before the
143 dredging and dumping episode of 2003). This provided us a list of only 8 species of
144 shorebirds to be considered within statistical models: dunlin *Calidris alpina*, purple
145 sandpiper *C. maritima*, common ringed plover *Charadrius hiaticula*, Eurasian curlew
146 *Numenius arquata*, grey plover *Pluvialis squatarola*, green redshank *Tringa nebularia*,
147 common redshank *T. totanus*, Northern lapwing *Vanellus vanellus* (Fig. 2). Because of
148 their trophic ecology these shorebirds may not depend on the mudflats in the same way,
149 since some of them also (or mostly) forage in other habitat types (e.g. Northern lapwing,
150 Eurasian curlew), such as the prairies and pastures surrounding Urdaibai (Navedo et al.
151 2013).

152

153 Moreover, we also calculated for each year the shorebird species diversity. We used for
154 that the Shannon index (H'). It accounts for both abundance and evenness of all
155 recorded species, and was calculated as: $H' = -\sum(p_i \times \ln p_i)$, where p_i is the proportion of
156 species i relative to the total number of species (R , richness) (Magurran and McGill
157 2011).

158

159 Data were analysed using Generalized Linear Models (GLMs). Bird counts (abundance)
160 of each species were used as object variable. We used the log-linear link function with
161 negative binomial distribution errors for the GLMs due to the nature of the object
162 variable (counts with over-dispersion). Additionally, we also conducted GLMs with H'
163 as an object variable. In this case we used a linear link function with Gaussian errors.
164 Overall, we considered four possible different explanatory variables: year (considered
165 as a linear variable to test for log-linear trends in shorebird abundance), temperature (as
166 a linear variable) and two effects that correspond to different responses of the shorebirds
167 to the dredging episodes (for details see Table 1).

168

169 All possible models were ranked according to their small-sample size corrected Akaike
170 (AICc) values (Burnham and Anderson 1998). Models differing in less than 2 AICc
171 values were considered to fit to the data equally well (Burnham and Anderson 1998). In
172 these cases, model averaging was carried out.

173

174 All analyses were run with R (R Core Team 2014), and the “lme4” (Bates et al. 2014)
175 and “MuMIn” (Barton 2014) packages. Package “lme4” allows us to run GLMMs and
176 “MuMIn” is used to calculate AICc values and for the model averaging procedure.

177

178 RESULTS

179

180 The percentage of sand within the estuary was observed to increase very significantly
181 (Table 2). Along a north-south gradient, the sediment was richer in sand in the north but
182 note the difference before and after the dredging and dumping of 2003 (Fig. 3).

183

184 The null model was the model best fitting data in seven out of the eight species tested
185 overall (Table 3). However, in two of such species (dunlin, common ringed plover),
186 models assuming an impact of the dredging and dumping were equally well supported.
187 In another species (grey plover), the top model was the one assuming an effect of the
188 dredging two years after it occurred (Table 3). Thus, overall, there were three species
189 for which the dredging and dumping episode had an impact on their population sizes
190 (Fig. 4). In addition, Northern lapwing population numbers and the diversity index were
191 found to be affected by temperature (Table 3), although this effect was non-significant
192 after model averaging (Table 4).

193

194 In those species where there was an effect of the dredging the higher-ranked model was
195 the one where the response was observed to occur two years after the dredging; Table
196 3).

197

198 DISCUSSION

199

200 Dredging and dumping actions at coastal environments is a common phenomenon
201 worldwide. The movement of sediments of different nature and its re-location in places
202 of great ecological value can produce, however, a strong impact on the ecosystems

203 through deep changes in the communities and the trophic nets (Sarda et al. 2000;
204 Vanaverbeke et al. 2007). Quite often, these activities have dramatic effects on benthic
205 communities (Powileit et al. 2006), with consequences at upper trophic levels. Using a
206 relevant dredging episode carried out at one the chief estuary areas from northern Iberia,
207 we observed a decrease in population size of several shorebird species which depended
208 on mudflats to forage just one or two years after this event.

209

210 Although dredging and dumping in Iberian estuaries is common, unfortunately we have
211 no evidence of available local information about their impact on shorebird assemblages.
212 In a broader context, however, it is well known that dredging can have a severe negative
213 impact on shorebirds as population size of bivalves or other potential prey is reduced,
214 either because direct sediment extraction at foraging places (Lewis et al. 2001; Piersma
215 et al. 2001) or because these feeding grounds are covered with sediments re-worked
216 from dumping sites that alter invertebrate populations, as surely occurred at Urdaibai.
217 The fact that the diversity of shorebirds remained constant at Urdaibai despite changes
218 in abundance after the dredging and dumping episode of 2003 suggests that the most
219 abundant species were similarly affected.

220

221 Although food availability was not analysed at our study sites our results would support
222 the idea that the sand covering of the mudflats had a dramatic change on the
223 macrobenthos that should be transferred to upper trophic levels (Boyd et al. 2005). Our
224 results also show that the effect was very fast: the population size of some of the species
225 was observed to decrease just two years after the dredging and dumping actions (with
226 some models even also supporting an affect just a single year after the event).

227

228 Interestingly, and as predicted, Northern lapwing numbers, as well as those from other
229 species less-dependent on marshes to forage) at Urdaibai were independent from the
230 dredging from 2003. Northern lapwings or Eurasian curlews feed mostly in the pastures
231 and cultivations existing around the estuary and, therefore, are little affected by
232 dredging episodes at these wetland sites. Some shorebirds, indeed, seem to benefit from
233 foraging in farmland habitats (Navedo et al. 2013), even if these would be subject to
234 intensive farming practices (Lindström et al. 2010). Model selection process supported
235 that Northern lapwings showed strong inter-annual fluctuations associated to winter
236 temperatures at a local scale, although this effect was non-significant after model

237 averaging, probably due to the high over-dispersion of data. The presence of this species
238 in southern Europe is well reported to be highly stochastic (Tellería et al. 1996), and is
239 mostly associated to dominant meteorological conditions during the winter in central
240 Europe (SEO/BirdLife 2012). Presented results partly support the idea that the
241 population that spends the winter in northern Iberia increases with decreasing
242 temperatures.

243

244 The specific variable effect of temperature on bird abundances (with a positive effect in
245 some shorebirds and a negative effect in others) along the coast of the Bay of Biscay
246 was also reported by Navedo et al. (2007). A positive effect of temperatures on local
247 numbers could be associated to better survival during warmer winters either due to
248 higher food availability (Yasué et al. 2003) or to lower thermoregulation costs (Ketersen
249 and Piersma 1987). However, local abundances of other species would be shaped by
250 decreasing temperatures, probably associated to displacements to the coastal marshes of
251 the Bay of Biscay from colder regions situated further north or inland (Galarza and
252 Tellería 1985).

253

254 Resilience is the capacity of an ecosystem to tolerate perturbation without switching to
255 an alternate state (Standish et al. 2014). Urdaibai has been subject to recurrent dredging
256 during the last 43 years. It may be that dredged material is re-worked by the tide and
257 wave induced currents, and this may allow the recovering of the system morphology
258 after some years (Monge-Ganuzas et al. 2013). However, even if a system could recover
259 after a perturbation, recurrent perturbations may lower its capacity for recovering over
260 the long-term (Díaz-Delgado et al. 2002). Noteworthy, we observed that even in 2016,
261 i.e. 13 years after the dredging and dumping actions carried out in 2003, the percentage
262 of sand within the sediment have passed from a mean of 38% to 64%, with this
263 percentage decreasing across a north-south axis (i.e., from the site where the sediment
264 was dumped towards upper estuary areas). This result suggests that the estuary has been
265 unable to come back to an original state before the dredging and dumping episode and it
266 may be discussed to what extent this effect is reversible, at least short- to medium-term.
267 The action of the waves and tide, together with the increase of the sea level (assessed to
268 be 2 mm/year) (Leorri et al. 2013), will probably strengthen this covering of the existing
269 mudflats by sand during next years, hence it is unlikely to expect a recovering of
270 shorebird abundance at these areas in Urdaibai.

271

272 In this scenario, local authorities should be appealed to take the dredging and dumping
273 effects into account in order to improve the Urdaibai estuary management because this
274 wetland is, in fact, an important Ramsar and Natura 2000 site managed by a Governing
275 Board composed by most regional public administrations (Basque Government, Bizkaia
276 Council, municipalities...). Dredging activities at Urdaibai were authorized or reported
277 by a number of public administrations, including the Basque Government (Environment
278 Department), Bizkaia Council, Basque Water Agency and the Ministry of Environment
279 of Spain, attending to their competences. As a part of the Urdaibai Governing Board, all
280 such public authorities should take into consideration both the dredging and dumping
281 effects and either promote alternative solutions or limitations to this activity if it is
282 incompatible with the preservation of the mudflats and the occurrence of shorebirds
283 within the area and, overall, the conservation and proper management of this wetland.

284

285 Given the sedimentary connection between the best disposal areas and the mudflats at
286 Urdaibai probably the best decision may be to forbid both the dredging and dumping
287 due to their dramatic consequences for the ecosystem. For instance, at Odiel estuary, in
288 southern Iberia, dredging material is dumped in areas apart from intertidal mudflats,
289 creating good conditions for the breeding of some species like the little tern *Sternula*
290 *albifrons*, Kentish plover *Charadrius alexandrinus* and the collared pratincole *Glareola*
291 *pratincola* (J. A. Amat, pers. obs.). Given the size and territory use at Urdaibai,
292 however, these sites would be hardly available hence apparently there would be no
293 place to dump the material extracted during dredging actions.

294

295 In conclusion, we obtained statistical data support that suggest that a strong dredging
296 and dumping episode carried out at Urdaibai resulted in a covering of existing mudflats
297 by sandy sediment which promoted a decrease of the population size of a number of
298 shorebird species wintering in this area. This effect was much clearer in species more
299 dependent on mudflats to feed, but had an apparent null impact in shorebirds that also or
300 mainly forage in other habitat types. Thus, it is highlighted that the management of the
301 dredging and dumping activities at Urdaibai should be improved by taking into
302 consideration the conservation of shorebirds, among other waterbird species.

303

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305

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309 this work.

310

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- 430
- 431
- 432

432

433 Table 1. Biological meanings of the models run for each species. Abbreviations:

434

Models	Meaning
1. Null	Population size is constant (or fluctuates from year to year but without any particular non-random effect).
2. 2004-2011	The impact of the dredging one year after the event (i.e., from 2004 onwards) is expected to have an effect on shorebird abundance.
3. 2005-2011	The impact of the dredging two years after the event (i.e., from 2005 onwards) is expected to have an effect on shorebird abundance
4. Year	Population size co-varies log-linearly with year.
5. Temp	Population size co-varies with the mean winter (Jan.) temperature.

435 *We also ran four additional models by adding “temp” (additive effect) to models 2 to

436 4. Overall, therefore, 8 models were tested.

437

437

438 Table 2. Mean ($\pm 95\%$ confidence interval) percentage of sand and mud in 25 sampling
439 points situated all along the mudflats at Urdaibai before and after the dredging and
440 dumping episode carried out in 2003. The percentage of gravel was zero for all samples.
441

<u>Type of sediment</u>	<u>2003 (before)</u>	<u>2016 (after)</u>	<u><i>t</i>-test (<i>P</i>)</u>
<u>Sand</u>	<u>38.3 \pm 9.9%</u>	<u>64.2 \pm 10.4%</u>	<u>4.814 (<0.001)</u>
<u>Mud</u>	<u>61.5 \pm 10.1%</u>	<u>35.8 \pm 10.4%</u>	<u>4.704 (<0.001)</u>

442

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445 Table 3. Ranking of the top four best-ranked models obtained for each species and the
446 species diversity (H' index) in relation to their small sample size-corrected Akaike
447 values (AICc). Δ AICc: difference in AICc values in relation to the top model. Model
448 abbreviations as in Table 1.
449

Models	AICc	Δ AICc	AICc weight
Dunlin			
...null	69.1	0.0	0.38
[2005-2011]	71.0	1.9	0.14
[2004-2011]	71.2	2.1	0.14
year	71.3	2.2	0.13
Northern lapwing			
...null	59.1	0.0	0.39
...temp	60.9	1.8	0.15
[2004-2011]	61.3	2.2	0.12
[2005-2011]	61.6	2.5	0.11
Eurasian curlew			
...null	66.3	0.0	0.41
[2005-2011]	68.7	2.4	0.13
[2004-2011]	68.7	2.4	0.12
...temp	68.7	2.4	0.12
Common greenshank			
...null	61.2	0.0	0.42
...year	63.6	2.4	0.13
[2004-2011]	63.7	2.5	0.12
[2005-2011]	63.7	2.5	0.12
Grey plover			
[2005-2011]	58.8	0.0	0.27
...year	59.4	0.6	0.20
[2004-2011]	59.6	0.7	0.18
...null	60.0	1.2	0.15
Common redshank			
...null	61.2	0.0	0.42
...year	63.6	2.4	0.13
[2004-2011]	63.7	2.5	0.12
[2005-2011]	63.7	2.5	0.12
Common ringed plover			
...null	59.5	0.0	0.32
[2005-2011]	60.8	1.3	0.17
...year	60.9	1.4	0.16
[2004-2011]	61.1	1.6	0.14
Purple sandpiper			
...null	54.5	0.0	0.43
...year	57.0	2.5	0.12
...temp	57.0	2.5	0.12
... [2005-2011]	57.0	2.5	0.12
Diversity index			
null	6.2	0.0	0.41
temp	8.1	1.9	0.16
[2004-2011]	8.8	2.6	0.12
[2005-2011]	8.8	2.6	0.11

450

450

451 Table 4. Coefficients (B -parameter estimates \pm SE) of best models ($\Delta\text{AICc} < 2$) from
 452 Table 2. Abbreviations as in Table 1; (ns), non-significant coefficient. Model averaging
 453 was carried out when there were two or more models with an $\text{AICc} < 2$ in relation to the
 454 top model (but see comments ² and ³).
 455

Species	Intercept	[2005-2011] ¹	Temp
Dunlin	+0.888	-0.327	
Northern lapwing	+0.574		-0.187 (ns)
Eurasian curlew	+0.666		
Common greenshank	+0.381		
Grey plover ²	+0.575	-1.318	
Common redshank	+0.275		
Common ringed plover ³	+0.324	-0.706	
Purple sandpiper	-0.026		
Diversity index (H')	+1.403		+0.040 (ns)

456 ¹Reference value ($B = 0$): period 1992-2004.

457 ²Coefficients only from the top model, since the other models included alternative (but
 458 not additive) effects.

459 ³Coefficients only after averaging model one and two, since the other models included
 460 alternative (but not additive) effects.

461

462

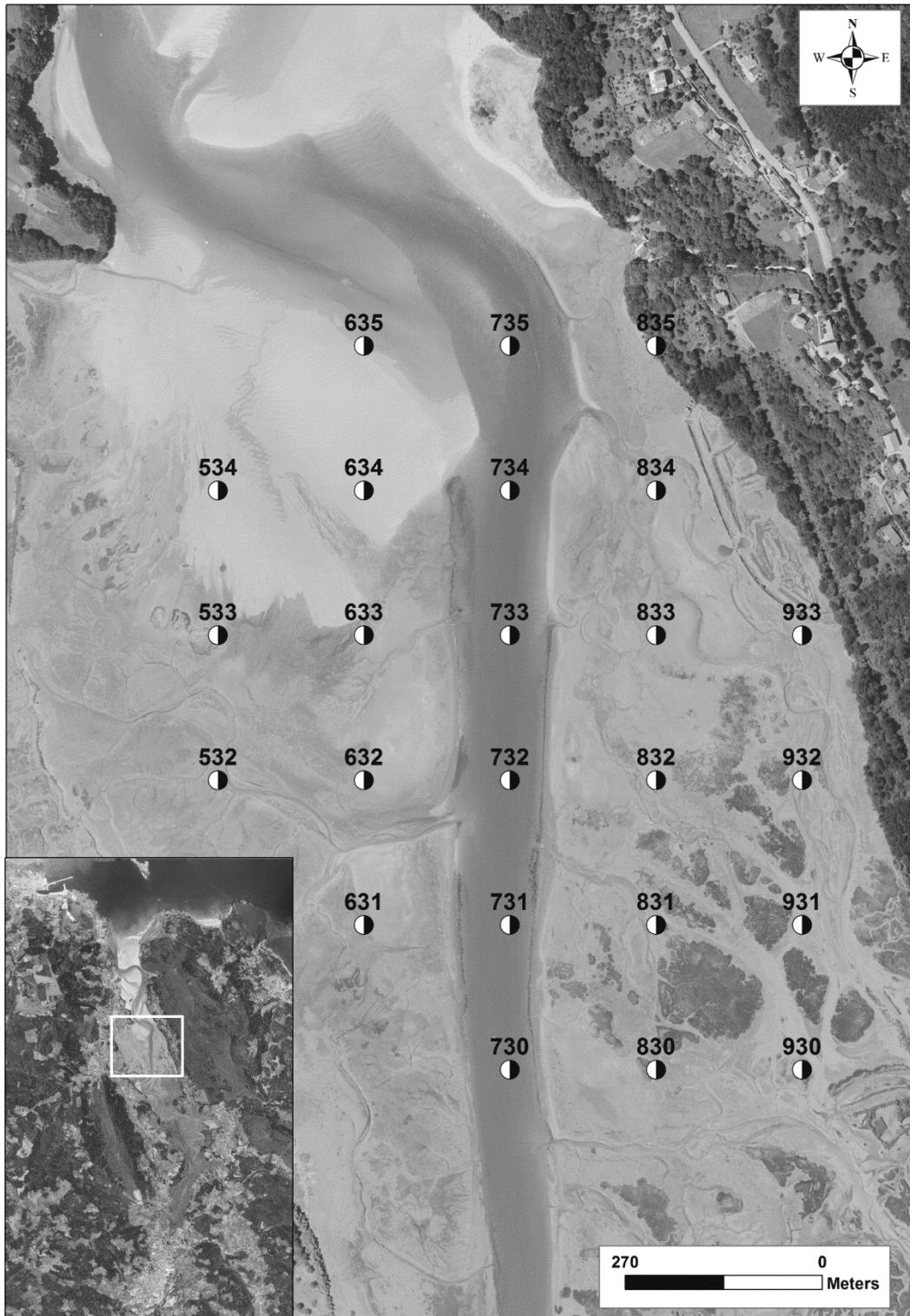
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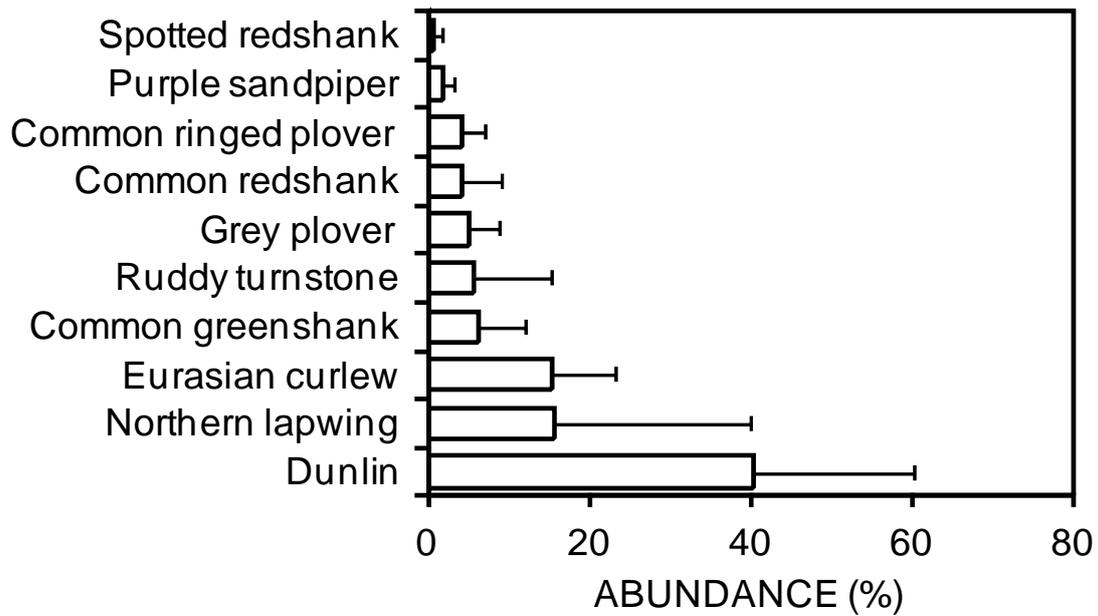
Fig. 1. Location of the sampling points considered to sample sediment characteristics all along the intertidal mudflats at Urdaibai.



466

467

467
468 Fig. 2. Relative abundance (mean \pm SD) of the ten most abundant shorebirds that
469 overwinter at Urdaibai, period 1992-2011. Ruddy turnstones and spotted redshanks
470 showed a median population size <10 individuals per winter for the period 1992-2003,
471 and were not included in the analyses.
472

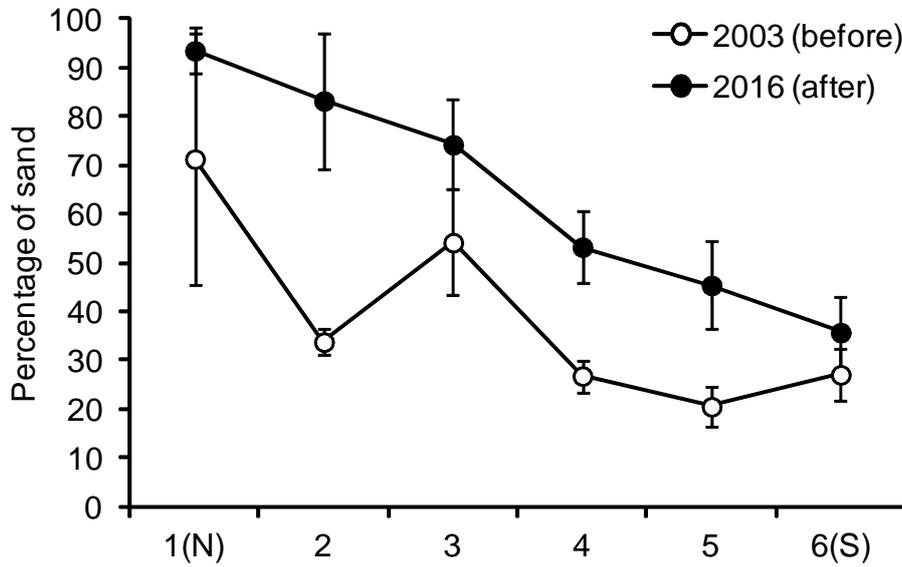


473
474

474

475 Fig. 3. Mean (\pm SE) percentage of sand along a north-south axis (1 stands for the
476 sampling points 635-835 in Fig. 3; 2 for the points 534-834, etc.) of those samples taken
477 to characterize the sediment of the intertidal mudflats at Urdaibai.

478



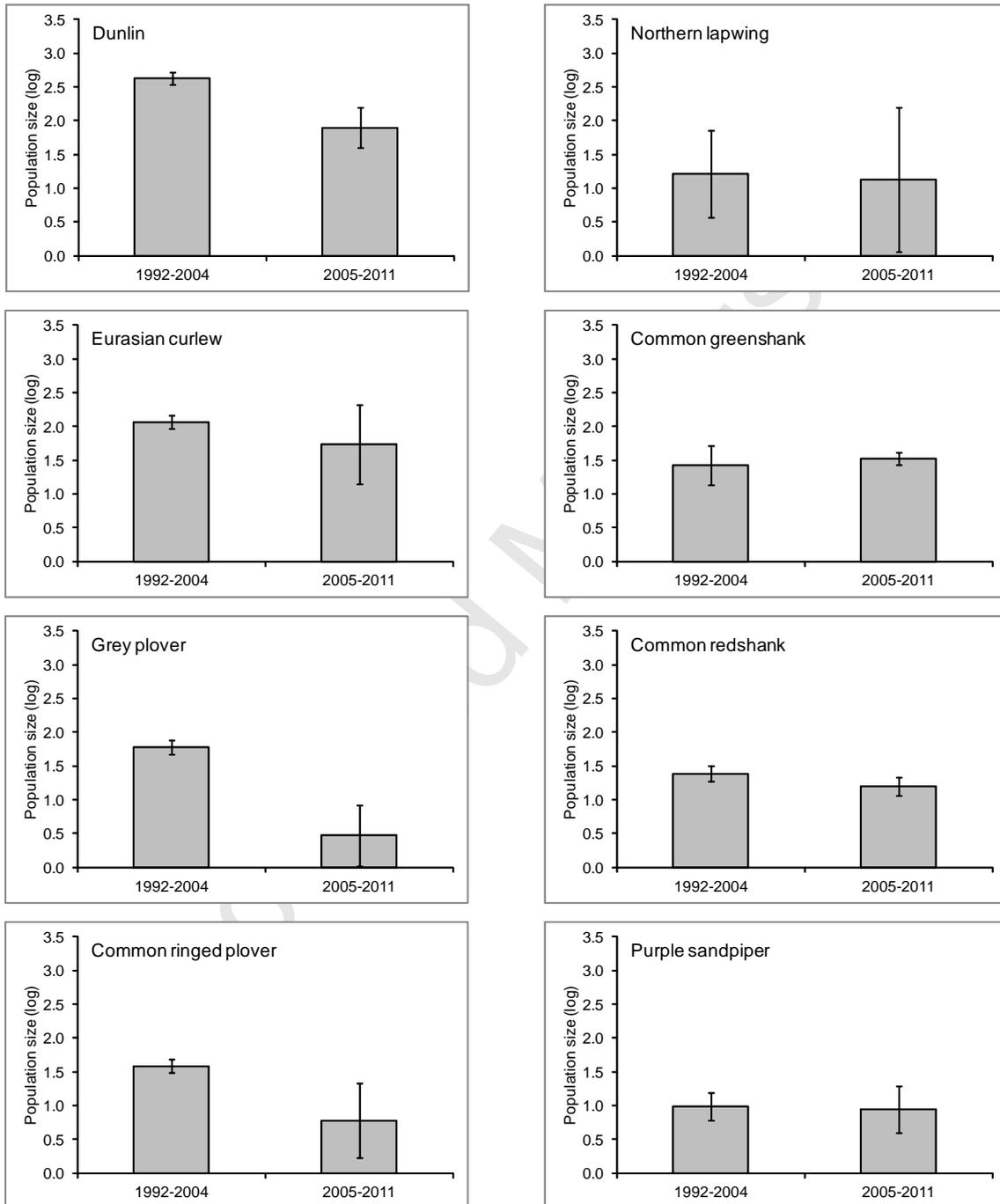
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482 Fig. 4. Mean ($\pm 95\%$ confidence interval) population size (log-transformed) of
483 shorebirds before and after the dredging and dumping actions of 2003 at Urdaibai, in
484 northern Iberia.

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