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Alteration of wetland hydrology in coastal lagoons: Implications for shorebird conservation and wetland restoration at a Ramsar site in Sri Lanka

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A B S T R A C T

Many of the world's lagoons and estuaries, representing the most important habitat for shorebirds, are increasingly degraded, often associated with dramatic declines in shorebirds, particularly in Asia. We investigated effects of hydrology on shorebird communities of two coastal lagoons of a Ramsar site in south-east Sri Lanka. One of the lagoons (Bundala) experienced natural water level fluctuations, while the other (Embilikala) had high stable water levels (>10 cm), maintained by inflows from irrigated agriculture. These inflows dramatically affected composition and abundance of shorebird communities and their prey. Tactile and visual foraging shorebirds were consistently more abundant on Bundala than Embilikala lagoon. Their feeding efficiency was significantly (50%) higher on Bundala, where large (500 μm) benthic prey were more abundant than on Embilikala. Contrastingly, small (60 μm) planktonic prey dominated the hydrologically stable Embilikala lagoon where pelagic foraging shorebird species dominated the shorebird community. On both lagoons, visual and tactile species foraged predominantly in shallow water (1–10 cm). Pelagic shorebirds also foraged in water depths >10 cm but 20% less efficiently than in shallower water. Effective shorebird conservation depends on reducing anthropogenic impacts that detrimentally affect functional processes and habitat value. The detrimental effect of altered hydrology on Embilikala lagoon could be reversed by diverting drainage water. Re-establishing a natural hydroperiod, would increase the productivity of the lagoon for foraging shorebirds. Restoration of shorebird habitat on this Ramsar site could also improve other ecosystem services such as fisheries and tourism. Changes to the hydrology of coastal lagoons elsewhere may be similarly affected.

1. Introduction

Coastal and marine ecosystems are among the most productive, yet threatened, ecosystems in the world (Halpern et al., 2009), with impaired natural functions (Agardy and Alder, 2005), because this is where 60% of global human populations live (UNESCO, 1993). Such coastal areas are particularly affected in Asia with its burgeoning population growth, unsustainable resource use, escalating agriculture and urban development. Unfortunately, understanding interactions with the ecology of wetlands in developing countries lags well behind well resourced parts of the world (Galbraith et al., 2005).

Many anthropogenic impacts on coastal ecosystems originate upstream (Pringle, 2000; Fabricius, 2005). Agricultural pollutants drained into coastal waters cause eutrophication, hypoxia or anoxia (Rabalais et al., 2002). Damming of rivers, levees, channels and diversion of water have altered hydrology, increased sedimentation rate, salinity and erosion, detrimentally affecting functions of many coastal estuaries (Dudgeon, 2000; Gillanders and Kingsford, 2002).

Much of this understanding of coastal impacts relates to effects on hydrodynamic, physical and biological characteristics of estuaries, rather than coastal lagoons, common along continental coasts of most continents and occupying about 13% of the world's coastline (Boynton et al., 1996). Morphological and functional differences between estuaries and coastal lagoons mean impacts also may differ (Kjerfve and Magill, 1989). Nutrient, sediment and freshwater input from agriculture may be particularly detrimental to coastal lagoons, with limited tidal exchange, compared to estuaries (Kjerfve and Magill, 1989; Boynton et al., 1996).

Many coastal lagoon systems provide critical habitat for migratory shorebirds (Ferreira et al., 2005; Alfaro and Clara, 2007), whose global populations have declined dramatically with coastal degradation (Stroud et al., 2006), particularly in Asia (Delany et al., 2010). Some shorebird populations (e.g. Curlew sandpiper (*Calidris*

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ferruginea)) of the Central Asian Flyway have declined by more than 70% at major wintering grounds along the east coast of India (Point Calimere, Balachandra, 2006) and in Sri Lanka (Li and Mundkur, 2004), the southernmost point of the flyway. Causes and drivers for decline in the flyway remain unclear (Balachandra, 2006) mainly because little is known of shorebird ecology, even though it has the greatest number of globally threatened waterbirds (Mundkur, 2006).

Long-term resilience of wetlands and the biota they support around the world is seriously compromised by water resource development (Kingsford et al., 2006; Vörösmarty et al., 2010). The key international agreement meant to mitigate such impacts is the Ramsar Convention with the listing of wetlands of international importance around the world (www.ramsar.org). A key objective of the Ramsar convention is to avoid change of ecological character in a wetland due to anthropogenic impacts (Ramsar, 1993; recommendation 5.2 article 3; Finlayson et al., 2011). Ecological character is defined as: "the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time" (Ramsar Bureau 2002, Resolution X.15) where ecosystem benefits are "the benefits that people receive from ecosystems" (Ramsar Bureau 2002, Resolution IX.1. Annex A, n 11) including wildlife resources; fisheries; forage resources; agricultural resources and water supply. Maintaining the ecological character of a wetland should therefore translate in maintaining a healthy wetland that supports a rich biodiversity and people livelihoods and is not affected by anthropogenic impacts. Measuring impacts of people on wetlands is often difficult, given paucity of data and natural stochastic variability of these ecosystems. Pressure for water resource development is particularly acute in Asia (Dudgeon, 2000; Li and Ounsted, 2007) and safeguarding ecosystems services for people and biodiversity, through sustainable development and conservation of wetlands is a challenge.

We investigated the relationship between shorebird ecology and hydrology on two brackish water (0.05–3% ppt) coastal lagoons that form a Ramsar site in south-east Sri Lanka. The two coastal lagoons have different flow regimes: altered (from irrigated agriculture) (Embilikala Lagoon) and natural (Bundala Lagoon) (Smakhtin and Piyankarage, 2003). There has been an alarming decrease in the abundance of shorebirds and other waterbird species such as the flamingos (*Phoenicopterus ruber*), an iconic touristic attraction, at the Ramsar site over the last decade (Perera, 2008; Bellio et al., 2009).

We tested for differences in shorebird abundance, community composition, prey abundance and foraging efficiency to cycles of flooding and drying patterns of the two lagoons. This has implications for rehabilitation of the lagoon with altered flow regimes. Habitat restoration and rehabilitation are considered to play a pivotal role in recovering degraded or destroyed ecosystems (Finlayson et al., 2001; Roni et al., 2005).

2. Methods

2.1. Study site

Four coastal lagoons (Embilikala 430 ha, Bundala 520 ha, Malala 650 ha, Koholankala 390 ha) form part of the wetland system of Bundala National Park, on the south-east coast of Sri Lanka (Fig. 1). Under the Ramsar criteria, wetlands should be selected for the Ramsar List on account of their international significance in terms of the biodiversity and uniqueness of their ecology, botany, zoology, limnology or hydrology. The Ramsar status was granted to Bundala National Park because of the outstanding ecological significance of its coastal lagoons (Bambaradeniya, 2001). The lagoons system supports 324 species of vertebrates which include 32 species of fish, 15 species of amphibians, 48 species of reptiles, 197 species of birds and 32 species of mammals and 52 species of butterflies are among the invertebrates. Shorebird species include 10 residents and 34 migratory palaearctics (including seven vagrants) which spend the Northern Hemisphere winter (non-breeding season) on the Bundala wetlands in internationally significant numbers (>21,000, Bambaradeniya, 2001; Bellio et al., 2009). In particular curlew sandpipers and black-tailed godwits, regularly winter at the Ramsar site of Bundala, are among the long distant migrant populations suffering dramatic declines along the Central Asian flyway.

The climate is hot and dry (Cooray, 1984), with a mean annual temperature of 27.1 °C and an average annual precipitation of 1074 mm. There is one dry season (July–September) and two wet seasons: the north east monsoon (October–March) when rainfall is highest in November (IIMI, 1995) and the south west monsoon (April–June). These seasons produce two rice (*Oryza sativa*) cultivation seasons (called Maha and Yala seasons respectively).

The lagoons' natural hydrology depended on seasonal rainfall, inflow and seepage of seawater through the sand bars of two narrow inlets (Fig. 1), connecting Bundala and Malala coastal lagoons to the Indian Ocean (CEA and Euroconsult, 1993). Flow regimes have changed in Embilikala since 1989, where freshwater drainage flows in from an upstream irrigation scheme (Kirindi Oya Irrigation Settlement) (drainage canal, Fig. 1) (Jayawardena, 1993; Smakhtin and Piyankarage, 2003). This has decreased salinity (conductivity in Bundala 9732–669 msm^{-1}, Embilikala 973–63.4 msm^{-1}; Bellio et al., 2009) and increased turbidity (CEA and Euroconsult, 1993; Amarasinghe et al., 2001; Bellio et al., 2009). Water levels in the impacted lagoon have also increased after irrigation development (water level fluctuations range before (0–1.5 m) and after (1–2.2 m)) (Jayawardena, 1993; Smakhtin and Piyankarage, 2003), preventing the lagoon drying out after the monsoon. Contrastingly, Bundala lagoon retains natural drying (post monsoon season) and filling (monsoon seasons) sequences, reflecting rainfall. We recorded water level (cm) on both lagoons at least every two weeks from 2006 to 2007.

2.2. Shorebird habitat

Most shorebirds feed and roost within the shallows of a wetland (water depth <30 cm), where prey availability and accessibility is mediated by prey behaviour (Zwarts and Wanink, 1993) and species' specific bill and neck morphology, leg length and body size (Zwarts and Wanink, 1991). We categorised all habitats used by shorebirds related to water depth: dry margins (D) (0–1 cm), shallow water (S) (1–10 cm) and high depth (*H*) (11–30 cm). These were further subdivided on the basis of vegetation/algal cover which were generally more developed on Embilikala lagoon than on Bundala lagoon (Bellio et al., 2009).

We identified five mutually exclusive habitat types on Embilikala lagoon: two on dry margins (dried grass (DG) and bare soil (DS)); two in shallow (1–10 cm) water (sandy bare soil (SS) and water with vegetation (SV)) and one in high (11–30 cm) water depth with aquatic vegetation (HV), including submerged and emerged plant species. Dominant submerged plant species included water thyme (*Hydrilla* spp.), pondweed (*Najas* sp.), hornwort (*Ceratophyllum demersum*), duck lettuce (*Ottelia alsimoides*) and emergent species included water lettuce (*Pistia stratiotes*), cattails (*Typha* spp.), the floating fern salvinia (*Salvinia molesta*), sedges (*Cyperus* spp.), and water couch (*Paspalum* spp.).

Bundala lagoon had submerged macroscopic algae (*Nitella* ssp.) and microscopic blue green algae (*Microsystis, Nostoc and Oscillatoria* sp.), creating thick algal mats when water levels were shallow (1–10 cm) but no aquatic vascular plants (CEA and Euroconsult,