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Abstract

The Zambezi River Delta on the Indian Ocean coast of Mozambique is a broad, flat alluvial plain, approximately 1.2 million ha in size. The delta includes a rich mosaic of wetland communities ranging from acacia and palm savanna on the delta periphery to seasonally flooded grassland, papyrus swamps, evergreen forests, and open water bodies on the low-lying delta plains to mangrove forest and mudflats bordered by dunes near the coast. The Zambezi Delta supports abundant wildlife, including African buffalo, African elephant, sable antelope, Lichtenstein's hartebeest, Livingstone's eland, and Endangered wild dog. Diverse waterbirds include a globally significant breeding population of Vulnerable wattled cranes, Endangered grey crowned cranes, numerous Palearctic and intra-African migrants, and immense breeding colonies of pelicans, herons,

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spoonbills, and other species. The Zambezi Delta has a vital role in the local, regional, and national economy of Mozambique through the ecological goods and services it provides. Although the delta is formally designated as a protected area and *Wetland of International Importance* under the Ramsar Convention, it faces serious threats including dams, dredging, mining, agricultural conversion, and overexploitation of many resources.

Keywords

Zambezi river · Wetlands · Delta · Biodiversity · Ecosystem services ·
Hydropower dams · Environmental flows · African buffalo · Wattled crane ·
Papyrus · Mangrove

Introduction

The Zambezi Delta is situated in Mozambique at the downstream terminus of the Zambezi River, the largest river system in southern Africa, where it discharges into the Indian Ocean (Fig. 1). The delta is a broad, flat alluvial plain, approximately 1.2 million ha in size. From its apex near the village of Mopeai, 120 km inland, the delta



Fig. 1 The Zambezi Delta. Landsat ETM satellite image acquired 1.12.03 (With permission of International Crane Foundation)

forms a large triangular area with a 200 km coastal frontage along the Indian Ocean. The Zambezi Delta is bordered to the west and north by the gently rising backslope of the rift escarpment. The delta supports a diverse mosaic of grassland, palm savanna, woodland, and mangrove communities and features some of the largest concentrations of wildlife found in African floodplain systems.

Hydrology

Rainfall over the delta is strongly influenced by the regional intertropical convergence zone (ITCZ), with most rainfall concentrated over the 4 month period between December and March and a prolonged dry season from May to November. Mean annual rainfall is approximately 1,150 mm but highly variable among years, with evidence of long-term cycles of relatively wet and dry years. Torrential rains and flooding may result from periodic cyclones, and severe droughts are a common phenomenon. Evaporation is high year-round and exceeds rainfall in all but the wettest months.

High flows from the Zambezi River arrive during the rainy season, with natural peak flows typically occurring between January and March. An intricate network of distributary channels conveys floodwaters from mainstem Zambezi River to the delta floodplains, and inundation of the entire delta occurs when the Zambezi River overtops its banks and spreads laterally across the floodplain. Zambezi floodwaters maintain shallow open water bodies and high water table conditions on the floodplain through most of the dry season. Groundwater contribution from the adjacent escarpment is a negligible component of the floodplain water balance but locally important for maintaining high water table conditions at the base of the escarpment.

Flooding patterns and processes in the Zambezi Delta are profoundly influenced by the upstream regulation of the Zambezi River for hydropower production, as well as local embankments constructed for roads, railroads, and flood protection. In the 28 years prior to Zambezi River regulation (1930–1958), the delta was inundated during all but one year, with an average flooding duration of 78 days above bankful discharge. Since construction of the upstream Kariba Dam (1958) and Cahora Bassa Dams (1974), flows have exceeded bankful discharge in only 54% of all years, for 26 days on average (Beilfuss 2001, 2012). As a consequence, floodplain water levels have declined by several meters, and the extent of permanent open water bodies and swamps has decreased.

Wetland Ecosystems

The Zambezi Delta is part of the Lower Zambezi Freshwater Ecoregion and includes a mosaic of wetland communities grading from acacia and palm savanna at the floodplain periphery to seasonally flooded grassland, papyrus swamps, evergreen forests, and open water bodies on the low-lying plains to mangrove forest and

mudflats bordered by dunes near the coast (Beilfuss et al. 2000, 2001). Major wetland vegetation associations include:

Floodplain Savanna Communities

- (i) Acacia savanna (140,000 ha): widespread at the periphery of the more elevated delta plain, rainfed, and dominated by *Acacia polyacantha* in association with *A. sieberana*, *A. xanthophloea*, *Cordyla africana*, *Kigelia africana*, and many other tree species. Midstory vegetation is sparse, and grass growth is vigorous, with a dense cover of *Hyparrhenia dichroa*, *Ischamum afrum*, *Panicum maculatum*, and other species.
- (ii) Borassus palm savanna (8,000 ha): conspicuous component of the floodplain margin on rainfed hydromorphic soils, with *Borassus aethiopum* occurring along the transitional zone from Acacia savanna to *Hyphaene* palm savanna and seasonally flooded grassland. Forms monotypic stands with increasing soil moisture, with vigorous grass growth.
- (iii) Hyphaene palm savanna (86,000 ha): monotypic stands occur over vast areas on the upper delta floodplain, *Hyphaene* palm is the first woody pioneer of the seasonally flooded grassland, persisting after short-duration inundation eliminates other woody invaders. Dense understory of tussock grassland species including *Hyparrhenia rufa*, *Imperata cylindrica*, *Setaria* spp., and other species.

Floodplain Grassland and Swamp Communities

- (iv) Rain flooded grasslands (115,000 ha.): bunch grasses on seasonally flooded floodplain vertisols (clay-rich soils that shrink and swell with changes in moisture content: during dry periods, the soil volume shrinks, and deep wide cracks form; during wet periods the clay absorbs water and increases in volume (swells). The alternate shrinking and swelling causes a mixing of vegetation and other surface matter into the subsoil and promotes a uniform soil profile). Grassland species are tall and rank, including various *Setaria* species, *Ischaemum afrum*, *Vetiveria nigriflora*, and others depending on elevation. Together with the acacia and palm savanna communities, supports large herds of sable antelope *Hippotragus niger*, Lichtenstein hartebeest *Alcelaphus lichtensteinii*, and diverse other species of ungulates.
- (v) River flooded grasslands (117,000 ha.): rhizomatous grasses and sedges on sites with prolonged inundation, on strongly expansive vertisols of the low-lying plains. Characteristic species include *Echinochloa pyramidalis*, *Cyperus digitatus*, *C. exaltatus*, *Leersia hexandra*, *Oryza longistaminus*, *Panicum maximum*, and many others. Supports vast herds of African buffalo *Syncerus caffer* and African elephant *Loxodonta africana*. Isolated patches of *Eleocharis acutangula* and *E. dulcis* are important for globally threatened (Vulnerable) wattled crane *Grus carunculatus* and other waterbirds.

- (vi) Papyrus swamps (84,000 ha.): occur along deep, permanently inundated waterways of the delta; on the delta northbank a vast *Cyperus papyrus* swamp covers more than 50,000 ha of the low-lying floodplain. Floating papyrus mats support a diversity of shallow-rooted vegetation.
- (vii) Phragmites reedswamps and saline grasslands (147,000 ha.): Dense stands of *Phragmites australis* occur in brackish water and saline soils near the coastal mangrove belt, occasionally with *Typha latifolia*, and often bordered by *Leersia hexandra-Cyperus digitatus* grassland on saline soils. Supports large mixed colonies of breeding waterbirds.
- (viii) Open water vegetation: shallow oxbow lagoons and swamp depressions in low-lying areas throughout the floodplain grasslands, mostly permanent flooded. Colonized by a variety of floating and submerged aquatic plants, including *Nymphaea caerulea*, *Nymphoides indica*, *N. nilotica*, and *Utricularia* spp. and free-floating plants including invasives *Eichhornia crassipes*, *Azolla filiculoides*, *Pistia stratiotes*, and *Salvinia molesta*.

Mangrove and Swamp Forest Communities

- (ix) Mangrove forest (100,000 ha.): part of the *East African Mangrove* ecoregion, a critically threatened and global biodiversity conservation hotspot, the delta coastline includes some of the most extensive mangrove forest on the Indian Ocean coast. Includes eight species of true mangrove, with conspicuous zonation – *Avicennia marina* and *Sonneratia alba* – are common pioneers on the exposed seaward front, with belts of *Rhizophora mucronata*, *Ceriops tagal*, and *Bruguiera gymnorhiza* moving inland.
- (x) Saline mudflats (45,000 ha.): large areas of hypersaline mudflats occur on the inland margin of the mangrove associations; sparsely covered with *Hibiscus tiliaceus*, *Salicornia* spp., and other succulents.
- (xi) Evergreen swamp forest (3,000 ha): evergreen “inland mangrove” thickets of *Barringtonia racemosa* and associated species occur on muddy alluvium at the margin of tidal influence. Supports large, mixed colonies of breeding waterbirds.

Biodiversity

The Zambezi Delta is an immensely productive wetland system, featuring many species of global conservation concern. The delta supports diverse and abundant large mammals, including one of the large concentrations of African buffalo on the continent and an “aquatic” African elephant population renowned for having pink pigment on their legs associated with prolonged exposure to flooded swamps. Other large herbivore species moving seasonally between the flooded grassland and adjacent savanna and woodland include waterbuck *Kobus ellipsiprymnus*, southern reedbuck *Redunca arundinum*, sable antelope, Lichtenstein’s hartebeest, and

Livingstone's eland *Taurotragus oryx*. A morphologically unique population of plains zebra *Equus quagga crawshayi*, referred to locally as "Selous zebra," occurs only in the delta region. African lion *Panthera leo*, leopard *Panthera pardus*, and globally threatened (Endangered) wild dog *Lycaon pictus* occur on the escarpment-floodplain periphery. Hippopotamus *Hippopotamus amphibious* are common in permanently flooded oxbow lagoons and other waterways (Beilfuss et al. 2010). Cape clawless otter *Aonyx capensis*, in regional decline, also occur here (Beilfuss et al. 2010).

The delta supports 73 waterbird species, including large breeding colonies of several species and numerous Palearctic and intra-African migrants (Bento and Beilfuss 1997). Species on the global Red List include wattled crane, grey crowned crane *Balearica regulorum*, and African skimmer *Rynchops flavirostris*. Thousands of pairs of great white pelican *Pelecanus onocrotalus* breed in the delta in addition to large breeding colonies of storks and herons, including African openbill *Anastomus lamelligerus*, African sacred ibis *Threskiornis aethiopicus*, grey heron *Ardea cinerea*, squacco heron *Ardeola ralloides*, African spoonbill *Platalea alba*, and *Egretta* spp.

Ninety-four fish species have been recorded in the Lower Zambezi River, of which 55 are primarily freshwater species and mostly floodplain dependent (Bills 2000).

Aquatic reptiles include the hinged terrapin *Pelusios castanoides*, Nile monitor *Varanus niloticus*, Nile crocodile *Crocodylus niloticus*, and various snakes (Branch 2000). Nineteen amphibian species are known to occur in the delta, with another five considered probable (Branch 2000).

Invertebrate studies are highly incomplete, but 18 gastropod and three bivalve mollusk species (Dudley 2000) and 25 species of Odonata (Kinvig 2000) have been recorded.

Conservation Status

Most of the south bank of the Zambezi Delta is protected through the Marromeu Buffalo Reserve, two forest reserves (*Reserva Floresta de Nhampacué* and *R.F. de Inhamitanga*), and four large hunting concessions. Other major land holdings in the delta include the large commercial agricultural lands (mainly sugar plantations) and community lands. Collectively, these lands are managed as the Marromeu Complex (1,127,200 ha) and were designated a *Wetland of International Importance* under the Ramsar Convention in 2003. In December 2015, the Government of Mozambique approved a major expansion of the Ramsar Site to include most of the north bank of the Zambezi Delta and local catchment, establishing one of the largest protected wetland complexes in the world – more than 1.2 million ha. (<http://www.ramsar.org/news/mozambique%E2%80%99s-zambezi-delta-joins-the-ramsar-list>).

Ecosystem Services

In addition to providing high biodiversity value, the Zambezi Delta has a vital role in the local, regional, and national economy of Mozambique through the ecological goods and services it provides. Guveya and Sukume (2008) estimate that the annual total value of ecosystem services in the Marromeu Complex ranges between US\$0.93 billion and US\$ 1.6 billion. Important goods and services provided by the delta include:

- Forest and woodland products (construction wood, fuel wood, wild fruits, honey, medicinal plants, and other forest and woodland resources)
- Carbon sequestration (woody species linked to voluntary carbon markets)
- Wetland products (papyrus and reeds used to make a variety of household items, palms used for palm wine, thatch grasses harvested from seasonal floodplain grasslands, and other resources)
- Grazing lands for livestock (grasslands of the floodplains, pans, and drainage lines, most notably late dry-season grazing lands supported by persistent high water table conditions)
- Nutrient-rich lands for flood-recession agriculture (floodplain agricultural lands receiving irrigation waters and nutrients from the natural ebb and flow of the mainstem Zambezi River and distributary channels)
- Riverine and floodplain freshwater fisheries (freshwater fisheries in the mainstem Zambezi, seasonal and permanent floodplain waterbodies, and pans and drainage lines on the escarpment)
- Clean and abundant freshwater (clean water supply for drinking, cleaning, bathing, and other household uses provided by surface water and groundwater recharge)
- Estuarine Penaeid shrimp fisheries (shrimp fisheries produced in mangroves and harvested off the Sofala Bank – an important source of export revenue for Mozambique)
- Storm surge and coastal erosion protection (mangroves and coastal dune vegetation that serve to stabilize coastal areas from erosion during cyclones and storm surge)
- Flood storage and mitigation (the capacity of the floodplain to store or attenuate large runoff events and reduce flood damage to settled areas)
- Diverse landscapes and wildlife for ecotourism (natural features of the landscape that contribute to the ecotourism potential of the region)
- Wildlife for sustainable trophy hunting and subsistence meat supply

Threats and Future Challenges

Although the Zambezi Delta enjoys significant institutional protection, the wetland faces a daunting range of conservation challenges. Adverse changes in the timing, volume, duration, and frequency of floodplain inundation are associated with the

upstream river regulation for hydropower production and compound the impacts of locally severe droughts. Dredging and canalization of the Zambezi River is proposed to transport coal from inland mines to coastal ports. The Zambezi Delta has been long considered a prospective source for crude oil, with prospecting and drilling operations by multinational oil companies dating back to 1937, and additional prospecting is underway for natural gas and other minerals. Agro-industrial drainage and pollution from commercial sugar expansion is resulting in eutrophication of floodplain waterways (Government of Mozambique 2011). On the open floodplain and savanna, uncontrolled fires – especially in association with reduced water availability – kill many smaller antelope, destroy nests, and reduce the dry-season carrying capacity of the floodplain. Floodplain woodlands are threatened by clear cutting for smallholder shifting agriculture, unsustainable logging for export and building materials, and charcoal production.

The prolonged civil war in Mozambique, and the Zambezi Delta region in particular, had a profound impact on wildlife. The African buffalo population was reduced by 95% to fewer than 2,000 individuals and waterbuck, hippopotamus, and plains zebra declined by >98%. During the postwar period since 1994, however, most wildlife species in the delta have undergone steady population growth. The current population of African buffalo now exceeds 18,000. African elephant numbers and most large herbivores are approaching their historic population levels, and hippo have reestablished several large pods on the floodplain (Beilfuss et al. 2010). Despite these gains, illegal hunting for the bushmeat trade is increasing and threatens many smaller antelope.

The delta also faces a range of daunting socioeconomic challenges, fueled by rapid population growth and immigration. The delta population lacks adequate primary health care, housing, sanitation, and safe drinking water. Food security is a chronic challenge, driving exploitation of delta resources. The region also lacks adequate primary and secondary education opportunities and employment alternatives.

Numerous programs are underway to address these challenges, including a regional effort to restore environmental flows in the Zambezi River basin through coordinated water releases from upstream dams (Beilfuss and Davies 2000; Beilfuss and Brown 2010). The Marromeu Complex Management Plan governs the administration and management of the delta, prohibited and regulated activities, and coordinated strategies for biodiversity conservation and sustainable livelihoods among agencies, academic institutions, concession operators, community-based organizations, and nonprofit conservation and social development organizations (Government of Mozambique 2011).

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