MANAGEMENT OF WETLANDS FOR BIODIVERSITY

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Summary

Wetlands have been the cradle of human culture, but their ecological functions are still of extreme importance, as testified by the adoption of the Ramsar Convention on Wetlands of International Importance. According to the first article of the Convention: "Wetlands are areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water the depth of which at low tide does not exceed six meters." They accomplish physical and ecological functions of primary importance for humankind, such as flood control, shoreline stabilization, storm protection, and climate-change mitigation. They also provide many products that sustained, and still sustain, human communities over the centuries, such as rice, fish, building material, and fuel material, as well as valuable areas for recreation and tourism. This is mainly due to the fact that some wetlands, such as estuaries, coral reefs, and mangroves, are among the most productive environments in the world. Their primary productivity supports a very

diverse animal community. Such is the case with the freshwater ecosystems, which cover only 1% of the total world surface, but hold ~40% of the world's species. Wetlands are utilized by visitor species as well, which increase the overall biodiversity of wetlands. Wetlands are, in fact, the favored feeding and resting station along migratory flyways for ducks, shorebirds, and waders, which, in their turn, attract large numbers of raptors, making them real reservoirs of biodiversity. At the beginning of the third millennium, these reservoirs of biodiversity can be considered among the most threatened ecosystems of the world. A holistic overview of wetlands and serious management planning at the local, national, and international level are the only way of preventing their total degradation and destruction.

1. A Brief History of Cultural Heritage and Sustainable Management of Wetlands

The term "wetlands" is a recent one; however, some of the habitats and ecosystems that are now encompassed by this term have been the cradle of humankind since the start of the agricultural revolution.

Wild rice was, and in some parts of the world is still, a common wetland plant before Chinese people started to domesticate varieties as crop plantations ~7500 years ago, making it one of the oldest crop plantations in the human history. Today; rice is still the most eaten crop in the world, being the staple diet for over half of the world's population, and rice cultivation still depends on wise use of inland wetlands. Although the main crop was wheat, not a truly wetland crop, agriculture in the Middle East started 6000 years ago in the valleys of the Tigris, Euphrates, and, a bit later, Nile rivers. For centuries, before the domestication of cattle, which provided the power needed to till harder soils upland, the floodplains of these rivers where the only tillable soils for early farmers, and thus these wetlands gave birth to some of the first cultures in human history. Those floodplains are still considered the cradle of human culture and, in some parts of the world, entire populations still depend on such floodplains to till and harvest for crop plantations. In the Middle Ages, the search for peat for fuel, the harvesting of reeds and marsh hays, and the use of wetlands as summer pasture for cattle were the main means of support for large Northern Europe communities. Today, many European estuaries and other wetlands are the result of centuries of manipulation and management by local communities, and they are still among the largest reservoirs for biological diversity in this continent.

Wetlands gave birth to important civilizations, but their ecological and cultural functions are not finished; they are of extreme importance at the beginning of the twenty-first century as well, as testified by the adoption of the Convention on Wetlands of International Importance, signed at Ramsar, an Iranian town, in 1971. The Ramsar Convention was the first of a number of conventions and treaties on ecological and environmental matters stipulated in the 1970s and it remains the only international convention that concentrates on a particular kind of habitat—wetlands —rather than on species or other ecological units.

2. Wetlands: Definition and Classification

According to the first article of the Ramsar Convention: "Wetlands are areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water the depth of which at low tide does not exceed six meters." This definition is probably the broadest ever adopted and it encircles extremely different environments, ranging from shallow marine areas, such as coral reefs, to river courses and temporary ponds or frozen tundra. Although the term wetlands is a relatively new one, its definition has gone through many stages and the above-cited Ramsar definition is not universally accepted; for instance many researchers and scientists don't wish to include coral reefs within the term wetlands.

Why is it so difficult to formulate a precise definition of wetlands? The difficulty is implied in the physical and ecological characteristics of wetlands themselves, as can be understood by simply examining their main features. In ecological terms, wetlands are transitional environments; the natural ecotones between land and water; and they naturally form a large continuum of community types and microhabitats whose boundaries are difficult to delineate. Thus, it is not a real contradiction to describe them as "natural boundaries with no boundaries," and it is often a matter of pure interpretation where wetlands become true marine or freshwater environments.

However, it is possible to summarize the different definitions and classifications developed in the late twentieth century, focusing on three main characteristics used in all wetland definitions:

- wetlands are characterized by the presence of water, static or flowing;
- wetlands often have peculiar soils, different from adjacent uplands;
- wetlands support vegetation adapted to the wet conditions and, conversely, are characterized by the absence of flood-intolerant plants.

Thus, the minimum essential characteristics of a wetland system are recurrent inundation or saturation at or near the surface and the presence of physical, chemical, and biological characteristics reflective of recurrent inundation or saturation.

Given the above definitions and characteristics, the term wetlands includes environments to be found in every continent, with the exception of Antarctica. It comprises:

- riparian wetlands along rivers and streams, seasonally flooded forests, and brackish swamps typical of all latitudes;
- bogs, fens, peatlands, and tundra of the humid cool regions;
- salt marshes, mud flats, mangrove forests, and coral reefs of the temperate, subtropical, and tropical shores;
- inland salt flats and vernal pools of the arid regions.

As a whole, wetlands, comprising habitats from rice paddies to shallow continental water bodies hosting coral reefs, are estimated to cover from 6% to 7.7%–from about 8 to 11.5 million km^2–of the existing land area. In contrast with what was thought in the 1970s, they seem not to be concentrated in subtropical and tropical regions, but are distributed homogeneously throughout the world, with the percentage of boreal and temperate wetland systems almost equal to that of the subtropical and tropical regions.

3. Ecological Functions of Wetlands

The list of ecosystems presented in the last section shows how the definition of wetland can encompass a composite group of ecosystems sometimes strongly differing from each other. However, some ecological features remain constant across all wetlands and are based on the complex interaction between their fundamental components: water, soil, and biotic communities. They consequently accomplish physical and ecological functions of primary importance for humankind. The most important and critical functions are flood control, groundwater replenishment, shoreline stabilization, storm protection, sediment and nutrient retention and export, climate change mitigation, "greenhouse" gas production, and water purification.

Moreover, they provide many products that have sustained, and still sustain, human communities over the centuries, as well as valuable areas for recreation and tourism. Although not every wetland type performs all the above functions, most types perform many functions; such is the case with mangrove swamps.

3.1. Mangroves: An Example of a Multifunctional Wetland

Mangrove is the general name for ~60 species belonging to different families of plants colonizing gently sloping intertidal zones of tropical and subtropical sheltered coastlines. The term is applied to both the individual and the ecosystem, the latter of which is also termed mangal. These forests are restricted to tropical and subtropical areas, where the average minimum temperature is never lower than ~20 °C. Throughout the centuries, mangroves have provided coastal communities with valuable products such as building material, fishery grounds for fish and shellfish, and timber for shipbuilding. Unfortunately, at the beginning of the twenty-first century, they must be considered endangered ecosystems, at least in parts of their geographical distribution, due to increasing human population and, in some cases, thanks to poor management. The depletion of these wetlands is actually acting as a natural experiment; it is now revealing that mangroves, once looked upon as worthless mosquito-infested areas, perform most of the general physical and ecological functions ascribed to wetlands. They act as a buffer between the sea and the land, being crucial in flood control. Moreover, it has been demonstrated that they are primary barrier against coastal erosion and play a major role in shoreline stabilization, even of adjacent ecosystems, and storm control. Mangroves act both as nutrient and sediment traps, building up meters and meters of new land from the sea each year, and as nutrient exporters, supplying nutrients to other ecologically important shallow-water wetlands, such as seagrass beds and coral reefs. Their high productivity plays a role also in "greenhouse" gas production and the high rate of chemical and degradation processes occurring in their soil proved to be efficient in purification of wastewater and sewage coming from urban areas. Last, but not least, the beauty of their landscapes and the quantity of bird species they shelter make them important areas for recreation and ecotourism in various parts of the world.

4. Productivity and Biodiversity of Wetlands

4.1. Productivity

Productivity levels of many wetland ecosystems are among the highest in the world. An example of high productivity among inland wetlands are the papyrus (*Cyperus papyrus*) swamps of Lake Naivasha, Kenya, which proved to produce a harvestable standing crop of 30 t ha^{-1} y^{-1}, about double that produced, in terms of grass, by the best European pastures. Annual productivity of marshes is very high as well, being estimated at 9 t km^{-2}, and this is probably about half of what estuaries can produce yearly. Intertidal and marine ecosystems, such as mangrove forests and coral reefs, represent other examples. The former have levels of primary production comparable to the most intensively mechanized agricultural production of the Western countries, while the latter, if properly managed, can produce up to 15 t km^{-2} y^{-1} of fish and seafood.

Table 1 provides the production rates known for some plant communities of selected wetlands. It is possible to ascertain that estimated primary production varies significantly, as expected, among the different regions and among the different communities. However, on average, productivity remains high and it scores some astonishingly high values in ecosystems such as tropical freshwater marshes and seagrass beds.

Wetland/community	**Region**	**Production ($t\ ha^{-1}\ y^{-1}$)**
Bogs		
Sphagum spp. carpet	Arctic/temperate	1–4
Sedges, shrubs, and fens	Arctic/temperate	2–10
Bog forest	Temperate	5–15
Marshes		
Freshwater emergent plants (reeds, e.g., *Phragmites australis*, *Typha* spp.)	Temperate	50–70
Freshwater floating plants (e.g., *Eichhornia crassipes*)	Subtropical	40–60
Freshwater emergent plants (papyrus, C*yperus papyrus*)	Tropical	60–90
Submerged plants	Temperate	5–10
Submerged plants	Tropical	20
Phytoplankton		15–30
Riparian forest	Subtropical	15
Marine ecosystems		
Mangroves	Subtropical/tropical	12
Tidal salt marsh	Subtropical/tropical	14
Seagrass bed	Tropical	70

Table 1. Productivity of plant communities in selected wetlands

4.2. Reservoirs of Biodiversity

Although productivity figures of wetlands can be surprisingly high, the estimates of wetland biodiversity can be even more spectacular, and there are many reasons for this.

Of course, highly productive ecosystems can support a very diverse animal community. The enormous primary productivity of freshwater ecosystems allows them to be called, without exaggeration, the world's reservoirs of biodiversity. In fact, they cover only 1% of the total world surface, but they hold ~40% of the world's species and 12% of all animal species. Spectacular concentrations of biological diversity can be found in Lake Tanganyika, which hosts 1470 animal species, 632 of which are endemic to the lake, and in the Amazon river, hosting 1800 species of endemic fish in its basin.
Moreover, wetlands have such an abundance of food resources that they are utilized by both permanent residents and "visitor species," which increase their overall biodiversity. These include both invertebrate and vertebrate species spending only a particular stage of their lifecycle within the wetlands and vertebrate species taking advantage of seasonal variations in water level, characteristic of many wetlands, to feed on the wetland's resources. In tropical ecosystems, the first group of visitor species is typically represented by many marine shrimp and shallow-water marine fish, which rely on the mangrove swamps as nursery grounds for newly hatched larvae and young. The latter group of "wetland visitors" in the temperate and semiarid regions is represented by grazers, including livestock, which move to the wetland basins during the dry seasons to forage on the abundant resources.

The productivity of wetlands and, consequently, the large availability of food make them a favored feeding and resting station along migratory flyways for ducks, shorebirds, and waders, which, in turn, attract large numbers of raptors, increasing the biodiversity of wetlands. As a result, the concentration of bird life in wetlands can be impressive. Two million shorebirds are estimated to visit both the Banc d'Aguin National Park, Mauritania, and the Wadden Sea, Northern Europe; while the St. Lucia estuarine system (a Ramsar site in South Africa) supports 350 species of birds.

There are reasons other than productivity which account for the high biological diversity of wetlands. As previously pointed out, in fact, wetlands include a large number of ecosystems, each of them characterized by its own communities and species. Thus, the overall species diversity we actually refer to when considering wetlands is enormous, for it ranges from marine to freshwater communities.

Another important source of abundance of species regards the above-stated topographical and ecological characteristics of these boundaries between land and water. As ecotones, wetlands are complex ecosystems, often encompassing various habitats and numerous microhabitats, each one hosting peculiar, composite, and rich communities. In fact, they are subjected to ecological and topographical gradients, which influence the distribution patterns and zonation of invertebrate fauna and vegetation. In both inland and coastal wetlands, a gradient between almost truly terrestrial locations to permanently flooded plateaus can be found and soil infauna, macrobenthic fauna with limited mobility, and vegetation are distributed according to the topographical features determining the gradient itself. Rather than this spatial distribution being a distinct and linear zonation pattern or a complex mosaic of patchily distributed communities, the whole wetland ecosystem is actually a composite macrohabitat were single and peculiar microhabitats are strongly linked to form a biologically diverse environment.

4.2.1. An Integrated Biodiversity Reservoir: The Arabuko-Sokoke–Mida Creek Wetlands System in Kenya

The wetland system, formed by the part of the Arabuko-Sokoke coastal forest and Mida Creek (03° 21' S, 39° 59' E), is located ~80 km north of Mombasa, Kenya, and, in administrative terms, it belongs to the Malindi District. From a management point of view, the area is under the authority of different departments, such as the Forestry Department, the Agricultural Department, and the Fisheries Department (all acting under the coordination of the Ministry of Agriculture and Livestock Development), assisted by the Kenya Wildlife Service (KWS). In particular, the whole Arabuko Sokoke Forest Reserve, 358 km^2 of coastal forest (declared the second most important forest in Africa for bird conservation and currently under consideration for the rank of World Heritage Site) together with the northwestern part of the Mida Creek mangrove forest, is managed by the Forestry Department, while the rest of the mangrove swamps, the intertidal mud flats, the seagrass beds, and the coral patches are part of the Watamu Marine Park and Reserve and are managed by KWS. This split between two administrative units has been recently solved with the institution of the Arabuko-Sokoke Forest Management Team (ASFMT), a joint team between the Forestry Department and KWS.

The lowland wetlands of Arabuko-Sokoke forest and Mida Creek represent an ecological continuum of wetland habitats of different natures. This system comprises the forested wetlands and freshwater ponds of the lowland coastal part of the Arabuko-Sokoke forest, dominated by *Brachystegia spiciformis* and *Hibiscus tiliaceus*. Where the sea starts to exhibit its influence, freshwater ponds disappear and stagnant brackish and hypersaline pools are dominant. Here, only highly specialized succulent herbs, such as *Arthrocnemon indicum* and *Salicornia pachystachya*, can resist. More seaward, in the intertidal belt, forested areas and major and minor creeks of a huge mangrove swamp are dominant. Eight species of salt-tolerant trees can be found here, the commonest of which are the grey mangrove (*Avicennia marina*), the red mangrove (*Rhizophora mucronata*), the yellow mangrove (*Ceriops tagal*), the large-leafed orange mangrove (*Bruguiera gymnorrhyza*), and the mangrove apple (*Sonneratia alba*). All these trees evolved aerial roots of different kinds, known as prop, peg, knee, and pencil roots according to their shape, to survive the strong anoxia of the soil they inhabit. These dense aerial root systems, commonly flooded at high tide, represent the microhabitat of the intertidal algae *Bostrychia tenella* and *Catenella caespitosa*, and these algae form carpets that host dense and diverse communities rich in algal species and marine invertebrates. The lower intertidal belts are characterized by rocky, sandy, and muddy bare intertidal platforms, depending on the type of substratum and on the topography of the different areas, each of them colonized by substantially different assemblages of algae and macrobenthic species. In the shallow subtidal, seagrass beds, dominated by the seagrasses *Thalassodendron ciliatum* and *Cymodocea* spp., form one of the most productive environments in the world, where annual production is estimated at 70 t ha^{-1}

y^{-1}. The seagrass beds host a huge number of species of epiphytic algae and sessile invertebrates, which represent an essential food source for numerous mobile invertebrates, fish, and turtles. Finally, where the current is slightly stronger and the water concentration of suspended matter is lower, patches of coral blocks are present; these host a diverse algal flora and invertebrate and fish fauna. Each of these single environments hosts highly diverse communities constituted by very specialized species that could not survive in other habitats of the creek itself. Examples can be taken from the crab fauna of Mida Creek.

In the Arabuko-Sokoke forest ponds and forested wetlands, freshwater crabs are common, such as *Potamonautes obesum*, *Varuna litterata*, and *Deckenia imitatrix*. The latter represents a highly specialized species with a very peculiar capability; like lungfish, it is capable of surviving within dug mud dens when the system of temporary freshwater ponds it inhabits dries up. This species, although fairly common in the temporary ponds of Mida Creek, could never colonize the mangrove forest, where, on the other hand, a numerous, both in terms of biomass and species diversity, community of crabs is present. It is worth noting that the species assemblage of crabs living in Mida Creek, as well as in the other East African creeks colonized by mangroves, is second, in terms of species, only to the astonishing assemblage of crabs colonizing coral reefs. Of all the leaf-eating crabs common in East African mangroves, the climbing crab *Sesarma leptosoma* lives in this creek in higher numbers than are known from any other mangrove swamp in East Africa. This highly specialized crab climbs the mangrove trees every day and feeds on the canopy of various species. In turn, the mangrove crabs never venture in the subtidal habitats, where box crabs (*Calappa* spp.) and swimming crabs belonging to various genera colonize the seagrass beds, hunting for molluscs and other prey. Finally, along the coral patches, decorator crabs (family Majidae) and colorful pebble crabs (family Pilumnidae) form a dense and active community, which could not live in any of the other adjacent habitats.

In this way, the macrobenthic fauna of Mida Creek is very diverse, ranging from freshwater to semiterrestrial and marine species and communities. However, even if it is fractionated in many environmental units, Mida Creek still acts, in ecological terms, as a unique wetland macrohabitat, interlinked in its single parts. In fact, no stream input is present in this creek and mangrove swamps could not survive without the groundwater replenishment to the freshwater ponds of Arabuko-Sokoke, and both coral patches and seagrass beds are dependant on the nutrient flow coming from the mangroves. The composite nature of this wetland ecosystem also provides different environmental conditions, which can be important in different parts of the lifecycles of many marine species. For instance, coral reef fish colonizing the Mida corals find in the mangroves of the very same creek both nursery habitats and feeding grounds for their newly hatched young, thanks to the spatial complexity and the availability of small-scale shelter the mangrove aerial roots can provide. Once grown, young fish can rely on Mida seagrass beds, within which they still can find shelter and feeding grounds. The same is true for sea turtles, such as the green turtle (*Chelonia midas*), and the olive Risley turtle (*Lepidochelys olivacea*), which can rely on seagrass bed coral patches as feeding grounds and on the inner sandy shores, dominated by the grey mangrove (*Avicennia marina*), as sheltered breeding grounds.

Finally, the great biodiversity of Mida Creek, considered as a single wetland continuum, provides food and shelter for larger animals such as birds and mammals. They can either rely on part of the resources offered by this habitat or range freely through the various habitats searching for different sources of food. The former group can be represented by species such as the forest elephants (*Loxodonta africana cyclotis*), which feed in the freshwater ponds and forested wetlands, and the Crab Plover (*Dromas ardeola*); one of the world's largest populations of this highly specialized shallow-water crab predator is actually feeding on the Mida Creek plateaus during their nonbreeding season. On the other hand, representative of the species that exploit a large variety of habitats of Mida Creek, are, among mammals, the yellow baboon (*Papio cynocephalus*) and the blue monkey (*Cecopitecus mitis*), and, among birds, the African Fishing Eagle (*Haliaeetus vocifer*), various species of storks, such as the African Open-billed Stork (*Anastomus lamelligerous*) and the Yellow-billed Stork (*Mycteria ibis*), and herons, such as the Goliath Heron (*Ardea goliath*) and the Squacco Heron (*Ardeola ralloides*).

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Biographical Sketches

Stefano Cannicci, PhD, is a Post-Doctoral Research Fellow in the Department of Animal Biology of the University of Florence. He has been involved in ecological field research since 1993. He has been mainly working within two ecological frames: the ecology of mangroves in East Africa, since 1992; particularly food chain and flora and fauna distribution in relation to environmental parameters; and the ecology of Mediterranean coastal habitats, since 1996.

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