Appreciating tropical coastal wetlands from a landscape perspective

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Freshwater forested wetlands are often found just upslope from mangrove forests in both high- and low-rainfall areas in the tropics. A case study on the island of Kosrae, Federated States of Micronesia, demonstrates how important both wetland types are to each other hydrologically and to local economies as well. Together, these wetlands form a landscape that provides goods worth the equivalent of nearly two-thirds the median household income in the region. Elsewhere around the world, similar contiguous pairs of wetlands are extensively used by local populations. However, while the importance of mangroves is well recognized, goods and services provided by freshwater wetlands – which are also much threatened by coastal development – are not nearly so well documented. Because such landscapes provide sustenance for millions of people, the natural and socioeconomic roles that both types of wetlands play must be better understood and protected as plans for coastal development proceed.

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In many coastal landscapes throughout the tropics, freshwater forested wetlands lie just upslope from mangrove forests, sometimes grading into them. This juxtaposition of forested wetlands is most likely to occur where rainfall exceeds 200 cm per year (Saenger 2002), such as on the islands of the western Pacific and eastern Indian Oceans, along the western coasts of India and Myanmar, in western equatorial Africa, and along coastal Central and South America. Freshwater forested wetlands may also border mangroves in drier areas, where confining soil or rock layers collect rainfall and allow peat to accumulate. For instance, freshwater wetlands dominated by *Pterocarpus officinalis* are common in less rainy coastal areas of some Caribbean islands (Alvarez-Lopez 1990; Bacon 1990), including Grand-Terre (< 130 cm per year) and at least one part of Puerto Rico (< 80 cm per year), where the soil is saturated all year (Alvarez-Lopez 1990; Imbert *et al.* 2000). In spite of this widespread association, the relationships – especially water-flow patterns – between these two ecosystems are seldom recognized and therefore poorly understood.

In a nutshell:

- In many tropical regions, freshwater forested wetlands supply essential freshwater inputs to mangrove forests located downslope
- These wetlands may be just as important as mangrove forests to millions of people who depend on them for a subsistence lifestyle
- Both freshwater forested wetlands and mangrove forests are threatened by development, such as freshwater diversion and land-use conversion
- Coastal development plans must recognize the importance of the entire wetland landscape

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Mangrove forests are usually the focus of concerns about misuse and disappearance of tropical coastal wetlands. They are widely understood to be important to human subsistence and for protecting coasts from high waves. Mangrove atlases have been compiled (eg Spalding *et al.* 1997), and estimates of stand extent and rates of loss are being updated. Much less attention, however, has been given to documenting the global distribution of associated freshwater forested wetlands and their usefulness to local populations (but see Dugan 1993). The purpose of this paper is to describe hydrologic relationships between mangrove forests and freshwater forested wetlands, and to identify several examples from around the world where these two ecosystems are important to each other. For each instance, I will outline the importance of both ecosystems, indicate how they are valuable to indigenous people, and identify threats to their continued existence.

Hydrology of a coastal wetland landscape

The importance of freshwater inflows to mangrove forests has been recognized for decades (eg Wolanski and Gardiner 1981). Although none of the almost 70 species of mangroves that exist worldwide is believed to require saltwater to survive, individual species differ in their tolerances across a wide range of salinities (Duke *et al.* 1998). On an ecosystem scale, greater access to freshwater – from rainfall, surface flows, or groundwater – is associated with greater mangrove species richness, height, and productivity (Saenger and Snedaker 1993). On a community scale, five physiognomic types of mangrove forests commonly found in North America are differentiated on the basis of "local patterns of tides and terrestrial surface drainage" (Lugo and Snedaker 1974). Nevertheless, it is evident that many "ecologists and engineers (and environmental engineers) do not understand man-

Figure 1. *(a)* Terminalia carolinensis *is the dominant tree in most freshwater forested wetlands on Kosrae, Federated States of Micronesia. (b) In the Yela wetland landscape on Kosrae, a low, natural berm (1) separates mangroves (2) from a large freshwater wetland dominated by* T carolinensis *(3).*

grove hydrology" (Lewis 2005), and even well-intentioned restorers of mangrove forests often ignore the fact that they "[must] not interrupt essential upland or riverine drainage" (Lewis 2005). Changes in freshwater inputs to a mangrove forest, such as diverting water for irrigation, can lead, at first, to subtle changes in function and eventually to dramatic changes in species composition. These changes may not become apparent for years or even decades, but they may have important consequences for coastal food chains and for the socioeconomic benefits they extend to indigenous people.

River flooding is generally the most obvious and important source of freshwater to mangrove forests. In many tropical estuaries, rising tides drive a wedge of saltwater from the coastal ocean or sea upstream, forcing freshwater into the surrounding mangroves at the upper reaches. River flooding, along with terrestrial runoff directly into a mangrove forest, is generally more important at sites with high rainfall. Diversion of freshwater away from a river, such as for irrigation, may be the most common way in which a downstream mangrove forest is impacted, but changes in the timing of dam-associated discharges can be just as damaging. When a coastal river is dammed, mangrove species can be lost, because decreased inflow – even for part of a year – can expose them to salinity levels higher than they can tolerate (Colonello and Medina 1998). Even increases in freshwater in mangrove forests, such as discharge of water originally diverted from another site for irrigation or storage, may eventually lead to replacement of a long-established species complement by less-salt-tolerant species, affecting ecosystem services available to local communities (Dahdouh-Guebas *et al.* 2005).

Groundwater also seeps into many mangrove forests (eg Wolanski and Gardiner 1981; Semeniuk 1983; Mazda and Ikeda 2006). On the island of Kosrae, Federated States of Micronesia, in the eastern Caroline Islands of the western Pacific Ocean, freshwater forested wetlands dominated by *Terminalia carolinensis* (Figure 1a) often lie just upslope from mangrove forests, and in at least one site groundwater percolates through a natural berm (earthen embankment) that separates the two ecosystems (Drexler and Ewel 2001; Drexler and DeCarlo 2002; Figure 1b).

Unfortunately, disruption of groundwater flow in coastal areas can easily go unnoticed. Compaction of a berm separating two wetlands, for instance during road-building, would slow the groundwater flow to the mangrove forest, altering soil salinity and thereby changing tree species composition. Decreases in freshwater inflow could also increase sulfur concentrations, leading to increased anaerobic decomposition and peat loss rates (Snedaker 1993). Likewise, water impounded on the upslope side would result in subsequent vegetation changes in the freshwater forested wetland as well. Such a berm between two adjacent wetlands – and some of its effects – may be specific to Kosrae, resulting from local geophysical factors, but the disruption of groundwater flows – for whatever reason – would likely have similar results elsewhere.

■ Value of tropical forested wetlands

Wetlands provide a wide variety of goods and services to people, depending on the kinds of plants and animals that occur there; the characteristics of their carbon sequestration rates, as well as of the hydrologic and nutrient cycles; and the physical beauty of these ecosystems and the opportunities they provide for recreation and education (Table 1). However, the values of different types of wetlands, and even of individual wetlands within a given type, may vary considerably. For instance, the ways in which mangrove forests are valuable to local human communities have been documented in several studies (see Primavera [2000] for a summary), but even widely touted services, such as fish production, may not be provided by every forest as a result of variation in hydrology, nutrient cycles, and species composition (Ewel *et al.* 1998).

Goods and services provided by freshwater forested wetlands deserve attention separately from those of downslope mangroves (Table 1). For instance, wetlands dominated by *T carolinensis* in Kosrae can provide three times the direct economic return in harvested goods as

Table 1. Major categories of goods and services provided by coastal forested wetlands in the tropics (Ewel 1997; Ewel *et al.* 1998; see text for additional sources of information)

Categories	*Mangrove forests*	*Freshwater forested wetlands*
Biological		
Evolution of unique species	Trees, fish, mammals	Trees, all vertebrates
Habitat for wildlife	Shellfish, fish, birds	Fish, birds, mammals
Production of wood and other fibers	Timber, wood for carving and boat construction, firewood, charcoal, poles for fish traps, tannins, rattan, thatch, medicinal products	Thatch, rattan, timber, wood for carving and boat construction, latex, resins, tannins, dyes
Production of food other than meat	Leaves and propagules, fodder, honey, alcoholic beverages	Taro, fruit, honey, alcoholic beverages
Hydrological		
Water quality improvement	Denitrification, sediment and nutrient trapping	Wastewater processing
Flood mitigation	Shoreline protection	Water storage, shoreline protection
Biogeochemical	Peat accumulation, nutrient retention	Peat accumulation, denitrification, sulfur reduction
Social	Recreation and education	Recreation and education

that of mangrove forests, in large part because the former wetland type is the basis for a subsistence agroforestry system that requires no substantial hydrologic disruption (Drew *et al.* 2005; Figure 2). Products harvested from mangroves and freshwater forested wetlands collectively are worth the equivalent of nearly two-thirds of the median household income on Kosrae (US$6739 in the mid-1990s; Division of Planning and Statistics 1996; Naylor and Drew 1998; Drew *et al.* 2005; Table 2; Figure 3). Even when no understory crops are cultivated, freshwater forested wetlands in Kosrae support a diversity of harvestable trees and wildlife, some of them endemic, and they also supply groundwater and surface water to downslope mangroves. The Kosraean site shown in Figure 1b includes a large, intact watershed with a mature, 150-ha stand of *T carolinensis* and a productive downslope mangrove forest; it has been recognized as a "truly unique ecosystem [serving] as a valuable watershed that help[s] protect the reef from siltation [and] as a reservoir for biodiversity on the island" (Lorence and Flynn 2005). This site has been designated as a potential conservation area by national and international parties (TNC nd; Anonymous 2002).

In spite of the clear value of these two kinds of wetlands in Kosrae, the hydrologic importance of an intact landscape is not well recognized by Kosraeans (Drew *et al.* 2005). Similar landscapes with similar relationships may be found globally, where little appreciation is evident for the importance of either the separate ecosystems or the combined landscape. Kosrae is a useful case study for improving our ability to detect similar relationships in more extensive landscapes elsewhere. In the next sections, I review the characteristics of wetland landscapes similar to those of Kosrae, summarize what is known about their value to local communities, and describe the major known threats.

Example: Southeast Asian coastal wetlands

Approximately 10% of the world's peatlands are found in the tropics, mostly as forested wetlands. In Southeast Asia, these peat swamps cover a total of approximately 23 million ha, account for 62% of tropical peatlands, and are frequently found just inland from mangrove forests (Page *et al.* 2006). Because more than 70% of the Southeast Asian population lives in coastal areas, many of these wetlands have been lost to degradation, pollution, and land-use conversion.

In some Southeast Asian peat swamps, a single species of tree may dominate; elsewhere in the region, a forest may include a diversity of species endemic to the region (Rieley and Ahmad-Shah 1996). Trees may reach as high as 40 m in some places and can be a valuable source of most of the products listed in Table 1 (Lee and Chai 1996; Rieley *et al.* 1996). Fish from peat swamps are often an important source of protein for residents of local villages (Urapeepatanapong and Pitayakajornwute 1996; Vijarnson 1996). These wetlands also harbor rare and endangered animal species, some of which are endemic and others that occupy a shrinking refuge (Page *et al.* 2006).

The hydrology of coastal peat swamps, including interactions with subsurface groundwater flows, is complex. Peat swamps are believed to buffer coastal lands from saltwater intrusion (Andriesse 1988, cited in Rieley *et al.* 1996), and their saturated soils prevent acid sulfate soils from developing (Page 2006). In Aceh Province, on the island of Sumatra, peat swamps appear to have extinguished landward movement of the December 2004 tsunami (Cochard *et al.* 2008). In Sarawak, 70 000 people obtain their domestic water needs from peat swamps (Silvius and Giesen 1996).

Southeast Asian peat swamps are not likely to have been used by people as extensively for agriculture – as in the case of Kosraean *T carolinensis* forests – but local, shallow drainage systems have proven useful for some crops, more successfully in Indonesia and Malaysia with their plentiful rainfall than in Thailand, with its longer dry season (Vijarnson 1996). Over the past 30 years, many peat swamps have nevertheless been converted to permanent agriculture (plantation crops or perennial and seasonal crops) after commercial logging. This conversion has been accompanied by drainage, often leading eventually to peat shrinkage and sometimes to development of acid sulfate soils, which completely destroys the swamp's ability to provide goods and services for either local or export economies (Rieley *et al.* 1996).

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Figure 2. *On Kosrae, giant taro is often planted in small gaps in freshwater forested wetlands after a few* T carolinensis *trees are removed.*

In the Narathiwat Province of southern Thailand, half a million people live near the largest concentration of peatlands in the country. They value these areas highly, visiting them regularly to harvest fish, honey, and edible fruits, and occasionally timber (Immirzi *et al.* 1996). Accessibility to arable soils is limited there, but draining peatlands is not considered a useful strategy.

Almost 40% of the world's mangrove forests occur in Southeast Asia (Spalding *et al.* 1997), representing the most species-rich mangrove region in the world. In Indonesia, which has only 2.5 million ha of mangrove forest remaining from an estimated 4.25 million ha, traditional uses persist, including the harvesting of nearly all of the plant products mentioned in Table 1 (Soegiarto 2004). Net present value of mangrove forests to a village in Thailand is US$632–US$823 per ha (Sathirathai and Barbier 2001), slightly higher than that in Kosrae (US$426–US$640 per ha in 1996; Naylor and Drew 1998). As in Kosrae, resources harvested from mangrove forests include timber and non-timber products, as well as mangrove-dependent fisheries.

Table 2. Value of products harvested from forested wetlands on Kosrae, Federated States of Micronesia

Wetland type and product harvested	*Gross annual income (US$)*
Mangrove forests[1]	
Firewood harvested	287 500
Mangrove-dependent fish caught	170 000
Mangrove crabs (*Scylla serrata*) caught	550 000
TOTAL	1 007 500
Freshwater T carolinensis *forests*[2]	
Crops grown	2 460 000
Fish and wildlife caught	666 000
Canoes constructed	40 000
TOTAL	3 166 000

[1]Naylor and Drew (1998)
[2]Drew *et al.* (2005)

Both peat swamps and mangrove forests provide local populations in Southeast Asia with basic ecosystem services, but no formal valuation documents the importance of the former, which are just as widespread as the latter. Although economic valuations of these wetlands might not be enough to forestall further land-use conversion, they would at least bring attention to the impacts exacted on local people threatened with the loss of vital ecosystem services.

Example: the Niger Delta

The Niger Delta is a wetland-dominated region that covers an area of 40 000–70 000 km^2, approximately 3% of the total area of Nigeria. At the mouth of the delta, average annual rainfall ranges from 2480 to 3800 mm, and the dry season lasts only 1 month; at the northern end, more than 250 km inland, annual rainfall is closer to 2000 mm per year, and the dry season generally lasts for 6 months. Except where otherwise noted, the following discussion of ecological and socioeconomic issues involving coastal wetlands in the Niger Delta is based primarily on information from a comprehensive environmental impact statement (Imevbore *et al.* 1997).

Freshwater forested wetlands cover about half the Delta and represent the most extensive wetland of its kind in western and central Africa. Primary upland forest may still be found in the Delta as well. Because of low relief (less than 20 m above sea level; Onu 2003), freshwater moves very slowly through the Delta, and saltwater moves several kilometers upstream with each tide – as much as 70 km along one channel. Freshwater forested

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Figure 3. *(a) Firewood is collected from mangrove forests on Kosrae, especially for preparing food during funeral gatherings. (b) The roots of giant taro (as shown growing in Figure 2), as well as sugar cane and bananas grown around the edges of taro plots, are sold in a local market. (c) Outrigger canoes like this one are often made from* T carolinensis *logs.*

wetlands and mangrove forests are therefore hydrologically connected, with freshwater diluting salinity in the downslope forest and a saltwater wedge bringing a freshwater tide to parts of the upslope floodplain forest.

The freshwater fish fauna in the Niger Delta is very rich, with a high concentration of monotypic families, including one endemic family (Brown and Thieme 2005). Because such large areas are flooded, the Delta provides important seasonal nursery areas for fish. However, shallow water often limits transportation to dugout canoes, especially in the middle of the Delta, and as a consequence, access to fish populations is sometimes restricted when they are most abundant.

The freshwater swamp forest itself has been a bountiful source of renewable natural resources, and it provides habitat for a rich diversity of vertebrates. Several species of broadleaved trees are found there, and stands of *Raphia* palms are common. Palms have been important in local and regional trade relationships since the 19th century, in particular for producing gin and oils for food preparation.

Similar to those in Kosrae, the Nigerian wetlands – as well as the rich soils of the high ground around them – are farmed. River levees and coastal ridges are densely populated and support the most intensively cultivated lands in the area. Extensive flooding in the most interior part of the Delta has kept it one of the least-developed parts of the country. People who live there obtain their drinking water from the wetland, and water-borne diseases are common. The shallow, slow waters limit prospects for sustainable development in the most remote areas, and the entire region is vulnerable to both natural and anthropogenic changes in the hydrologic regime. In the river basins upslope from the Niger Delta, land-use changes (including irrigation as well as dams installed to provide hydroelectric power) have affected water levels, sediment loads, and patterns of erosion, thereby impacting both agriculture and living conditions.

Downstream, the mangrove forest in the Niger Delta is the largest in Africa and the third largest worldwide. At least five species of mangrove trees are found there, and other salt-tolerant shrubs and small trees are also common in cleared areas and on dredge spoils. Similar to those in Asia, these forests produce many benefits (Table 1). Both saltwater and freshwater wetlands have long been used by local populations, estimated at more than 6 million people in 1991. An extensive, traditional trade network, based on products from both types of wetlands, has existed for more than a century in the Delta.

However, Nigeria is the largest producer of crude petroleum in Africa, among the world's top 10 oil producers, and major port facilities associated with the petroleum industry are surrounded by mangrove forests. Both exploration and effluents have already caused considerable ecological damage (Onu 2003). Nevertheless, crude oil production and export account for 90% of Nigeria's total export earnings, and harnessing natural gas could contribute to even more degradation and fragmentation.

As important as the vast freshwater wetlands in the Niger Delta may be to the mangrove swamps and to the people who live there, they also make this remote area difficult to access, and inhabitants have few educational opportunities, in addition to inadequate water supplies and healthcare. Development of the Niger Delta, including projects such as the installation of more dams, could displace hundreds of thousands (or even millions) of people and will probably adversely affect mangrove forests and the people who depend on them for a living. This is a true dilemma, because leaving these ecosystems untouched would consign inhabitants of the more remote parts of the Delta to lives of continued deprivation. However, the lack of quantitative information about how much people depend on the wetlands makes comprehensive planning difficult.

Other similar settings

Similar landscapes occur worldwide, but little documentation exists about their hydrology or human use. Freshwater forested wetlands dominated by *P officinalis*, once a major type of wetland extending several kilometers inland behind mangrove forests in Puerto Rico and other Caribbean islands, now occur primarily adjacent to mangrove forests. Wetlands further upslope have been drained and converted to sugar cane fields and, more recently, abandoned to pasture (Eusse and Aide 1999). *Pterocarpus* wood was used during the 20th century for firewood (Imbert *et al.* 1999). Reports of consumption of *Rhizophora* propagules during times of famine by peoples indigenous to the West Indies, as well as the use of mangroves from the 1700s to the 1900s for numerous items listed in Table 1, are summarized by Walsh (1977). Coastal populations in Puerto Rico continued to use mangrove wood for timber and fence posts into recent times (Wadsworth 1959).

Palm swamps commonly occur landward of mangrove forests around the world, like the example of *Raphia* in the Niger Delta and like *Nypa fruticans*, which is transitional between mangroves and freshwater wetlands in Asia and the Pacific islands. In tropical parts of Central and South America, *Manicaria* spp characteristically extend from brackish to freshwater environments (Myers 1990; Ellison 2004). Other palms also grow just landward of mangroves, and still others grow in the "littoral zone close to the sea" (Jones 1995). The palms are used by indigenous communities in both New and Old World tropics in many different ways.

Finally, tropical peatlands, best documented for Southeast Asia and the Pacific islands, can be found in the New World tropics as well. For instance, San-San Pond Sak, Panama, which contains a peat dome dominated by *Campnosperma panamensis*, *Myrica* sp, and *Cyrilla* sp, is surrounded by a *Raphia* palm swamp, and is bordered to the west by mangroves (Ramsar 1993). This forested wetland has been used in the past for agriculture and hunting, supplies an aquifer that provides water for both consumption and crop irrigation to a local community, and is said to offer protection from coastal erosion; it is now an important area for bird conservation (Ramsar 1993).

Discussion

Hydrologic cycles in many mangrove forests include flows from upslope ecosystems, which are often freshwater forested wetlands. Whereas the importance of mangroves is commonly recognized, the values of freshwater forested wetlands, which may be as important or even more so to local indigenous communities, are seldom enumerated. Freshwater forested wetlands are also rarely valued by planners and decision makers involved in coastal development. Decisions on land use and land-use conversion, including conservation, must be based on an assessment of the entire wetland landscape, in order to predict the effects of potential developments on local communities.

A subsistence lifestyle provides both insurance for, and vulnerability to, a local community. Existing valuations of mangroves and freshwater forested wetlands indicate that both these types of ecosystems can be of substantial importance to coastal dwellers in less-developed countries, yet these populations lead a precarious existence, often with no alternatives when ecosystems are altered or lost. Landscapes where both types of wetlands occur collectively support millions of people. Although these areas may be remote, and quality of life may be poor, coastal development that modifies these ecosystems does not necessarily provide new livelihoods for displaced peoples. As plans for coastal development are made, attention is generally focused on mangrove forests. However, sharp eyes must also watch any adjacent wetlands to ensure the continued integrity of the entire wetland complex. Recognizing the existence of both parts of such a landscape is the first step toward making sure that the needs of the people, who live there or otherwise depend on those ecosystems, will be met as well.

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