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TOPIC 9

Wetland Functions and Values

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WETLAND FUNCTIONS AND VALUES

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Why are wetlands important ?

Wetlands are intimately linked with the ecological balance and socio-economic well-being of human population in Asia, where the oldest civilizations developed along river courses and coastlines and built largely on the basis of wetland resources. The vast majority of people depends on wetlands for sustenance. Wetlands and their conservation have been an integral part of the Asian culture.

Wetland ecosystems provide a wide range of benefits – which may be tangible or intangible – to people living in the vicinity. Wetlands provide the basic needs : foods and water, housing materials and shelters, medicines, and enhance the occupation and income of rural and urban inhabitants, and therefore are essential to the health, welfare and safety of people.

The South China Sea is a strategic body of water, surrounded by nations that are currently at the helm of industrialization and rapid economic growth in the Asia-Pacific Region. The South China Sea has always been central to issues of economic and political stability in Southeast Asia and adjacent regions. Wetlands bordering the South China Sea are of global importance. Their richness in flora and fauna contributes to the area's high natural rates of primary and secondary production. Capture fisheries from the South China Sea contribute 10 % of the world's total landed catch (UNEP, 2005).

Types of wetland benefits

Each wetland is composed of a number of physical, biological and chemical components such as soils, water, plant and animal species, and nutrients. Processes among and within these components allow the wetland to generate, provide, perform and possess certain benefits, roles, importance and value to people, wildlife, natural processes and systems as a whole.

Wetland benefits can be classified into 3 major types (Dugan, 1990; Chan et al., 2001; http://www.ramsar.org/ram/ram_rpt_50e.htm).

(a) Products or goods : Wetlands generate a wide range of products which can be harvested and directly used by population and communities. Products generated by wetlands include fisheries; forest resources; wildlife resources; forage resources; agricultural resources; and water supply. These products are generated by the interaction between the biological, chemical and physical components of a wetland. Most wetlands are important in augmenting the diet and, through the harvest and sale of wetland produce, the income of rural inhabitants and households. This type of wetland benefits is defined as "**direct use values**" by economists.

(b) Functions or services : Activities or actions, which occur naturally in wetlands, are a product of the interactions between the ecosystem structure and processes. Wetland ecosystems potentially and actually support or protect human activities and human properties without being used directly, or support or protect natural systems and processes. Functions include flood water control; nutrient, sediment and contaminant retention; food web support; shoreline stabilization and erosion control; storm protection; and stabilization of local climate conditions, particularly rainfall and temperature. This type of wetland benefits is defined as "**indirect use values**" by economists.

(c) Attributes or qualities : Wetland ecosystems possess special and unique characteristics, quality or properties which do not necessarily support a use or provide a function, but are valued by a group within society at the ecosystem scale**.** Attributes of a wetland include biological diversity and unique cultural and heritage features. These attributes may lead to certain uses or derivation of particular products, but they may also have intrinsic, unquantifiable importance.

It is the combination of these benefits : products or goods, functions or services, and ecosystem attributes that make wetlands important to society.

What products or goods do wetlands provide ?

Wetlands have abundantly diverse and varied resources. The list of harvestable products from wetlands exploited by humans is immense. The dynamic characters, especially the hydrological regime, of most wetlands lead to the seasonal availability of resources, products and goods. Exploitation is being carried out at all levels of intensity from subsistence to cottage industries and commercial scale. Harvesting that respects the annual and seasonal production rates, supportive and regenerative capacity of wetland species and ecosystems can generate great benefits to human society.

Forest resources

Direct harvest of forest resources from wetlands yields various important timber and non-timber products, ranging from firewood and charcoal; timber for construction; fencing and housing materials; materials for making fishing gears; fibers; barks; tannin; resins; honey; bee wax; dyes; raw materials for cottage industries, handicrafts, and compost.

Timber and other forestry products which are found in great abundance in swamp forests number among the main export products of Indonesia. In 1988, these forests

provided 10% of the exported timber i.e. a revenue of US$ 290 million; as for rattan, swamp forests represented 25% of exports, generated US$ 14 million. In Peninsular Malaysia, the 460,000 ha of swamp forest were valued in 1990 at around US$ 100 million. The figure included 3 forestry products i.e. timber, rattan and bamboo stems (Roggeri, 1995). The *Melaleuca* forest ecosystems provide *Melaleuca leucadendron* timber for construction which is valuable due to its strength, durability and resistance to insect and fungi attacks, and other products such as oil and honey. In the *Melaleuca* swamp forest of Telong in Malaysia, a family with three charcoal ovens earns a monthly revenue of around US$ 800 (Roggeri, 1995). Mangroves are a vital source of firewood for the coastal communities. Species, which are important source of charcoal production and domestic fuel, include *Rhizophora sp.* (with high calorific value and little smoke), *Bruguiera sp.*, *Ceriops sp.*, *Sonneratia caseolaris* and *Acrostichum aureum.* In Thailand the value of charcoal obtained from mangroves was estimated at US$ 30-400 per ha per year depending on the intensity of harvest (Dugan, 1990). Mangrove species like *Aegiceras corniculatum* is a source of honey. Stems of *Avicennia sp.* and *Sonneratia sp.* are usually exploited and sold to the brick-kilns.

Wildlife resources

Wild foods are harvestable from wetlands and vital for local nutritional status and sources of augmented diets and income. Wetland wildlife such as several species of amphibians e.g. frogs *Rana tigrina, R. vittigera, R. limnocharis*, *Kaloula pulchra*; crustaceans e.g. crabs and shrimps; paddy rats *Rattus rattus*; mollusks and pond snails e.g. *Filopaludina doliaris*, *Vicisara doliaris*; snakes; insects; birds; soft-shelled turtles; and ant eggs are important sources of supplementary protein and are not only consumed domestically but also sold in local markets providing an additional household income source.

Some animals such as crocodiles and snakes are exploited for food and skins. The international trade in crocodilian skins is worth US$ 500 million per year. Many countries now operate exploitation programmes that encourage the sustainable use of crocodiles through a mixture of controlled hunting, ranching (which involves bringing eggs or hatchlings from the wild and raising them in captivity) or captive breeding.

It should be stressed that amphibians, reptiles, birds, insects and many others are also vital to agro-ecosystems and to rural economy as they play an importantly ecological role in food web / food chain, predator-prey cycle, rodent and insect pest control. An example in ricefield ecosystems in Thailand and probably some other countries in Southeast Asia is Asian open bills versus Golden apple snails.

Flora resources

Wetlands abound in natural products of plant origin which are used by local communities for a variety of purposes. Through the harvest and sale of wetland produce, wetlands provide daily income and economic opportunities for many unemployed and under-employed inhabitants.

In the swamps of Tasek Bera in Malaysia, the essential oil produced from the resin extracted from *Dipterocarpus kerii* is sold at around US$ 8 per litre. In Thailand,

Vietnam and many other Asian Countries, wetland plants such as water hyacinth *Eichhornia crassipes*, Cypress species e.g. *Scirpus grossus,* Typha species e.g. *Typha angustifolia,* and *Lepironia* are harvested and used as raw materials for cottage industries. Fibers from creeper plants such as *Stenochlaena palustris* are used for making ropes; fibers from *Lepironia sp.* emergent aquatic plants are used for making mats and handicrafts. Certain plant species in wetlands provide a whole range of products, such as Nipa palm *Nypa fruticans*, providing leaves, thatch, fodder, fruits, alcohol, vinegar and sugar. It is estimated that this palm can produce 3 tons of sugar per hectare (Maltby, 1986; Ramsar Bureau, 2001).

Aquatic plants and vegetables such as morning glory *Ipomoea aquatica,* Neptunia *Neptunia natans,* Lotus or Tropical water-lily *Nymphaea lotus,* Asiatic Pennywort *Centella asiatica, Limnocharis flava, Colocasia esculenta* are harvested for food. *Ipomoea aquatica* is not only consumed by the people of the region of Lake Tempe in Indonesia, but fishermen also plant it for the protection that its hanging roots offer young fish (Roggeri, 1995). Sacred Lotus *Nelumbo nucifera* is harvested and used in religious and cultural activities in many countries in Southeast Asia and South Asia.

Several kinds of wetland plants such as duckweed *Lemna sp.,* and water hyacinth *Eichhornia crassipes*, are harvested for animal feed and for sale.

Medicinal resources

Aksornkoae (1989) lists some mangrove species which can be used for medicinal purposes, including *Rhizophora apiculata, Ceriops tagal, C. decandra, Avicennia alba, A. officinalis, Xylocarpus granatum, X. moluccensis, Excoecaria agallocha, Clerodendrum inerme, Derris trifoliata, Acanthus ilicifolius, A. ebracteatus, Thespesia populnea,* and *Hibiscus tiliaceus.*

Agricultural resources

Wetlands can be used for agriculture and yield substantial benefits to rural communities. Several factors make wetlands particularly suitable for agriculture, including the humidity of the soil or the presence of water during the dry season, the sediments and nutrients annually brought by the floods and the alternation of dry and wet conditions. The natural irrigation and fertilization of the land make low-cost agricultural production possible. In seasonal wetlands, production costs are reduced as aquatic weeds are killed by exposure to desiccation when the flood recedes. Alternating wet and dry phases often constitute a natural form of pest control.

Rice which is a staple food for population of many countries in Asia and major export of Thailand and Viet Nam is grown in wetlands. The Mekong Delta provides 50% of total rice production of Viet Nam. Floodplains of the Chao Phraya River of Thailand is named the “Rice and Water Bowl of Thailand”. Floating rice is the best known crop associated with the rise of the flood. This type of cultivation is practiced in several areas including the Mekong Delta, the drawdown zone of the Great Lake of Cambodia, and the Irrawaddy Delta in Myanmar.

Swamp agriculture includes swamp-rice and sago palm cultivation. Sago palm *Metroxylon sagu* is a very common swamp palm, grown extensively throughout

Southeast Asia. Its annual protein production can reach 3.5 tons/ha. The sago obtained from the starch of its pith is the main food staple for a quarter of the population of Irian Jaya in Indonesia (Roggeri, 1995). Other cash crops such as Taro *Colocasia esculenta*, Lotus *Nymphaea lotus* and *Nelumbo nucifera* are also produced from wetlands.

Forage resources

Wetlands contain grasslands and trees that can be grazed by livestock which are important to pastoral communities. Fodder can be collected for sale or use as a dry-season animal feed. Livestock and poultry production depends very much on wetlands. Some emergent aquatic plants provide food for water buffaloes.

Fisheries

Wetlands are nutrient-rich, sheltered habitats for fish and aquatic species, and are important to their life cycles as feeding, spawning, hatching and nursery areas. Wetlands is the main source of low-cost and high quality animal protein for rural populations. Fisheries is significant to the local as well as national economies, providing occupation and income-earning opportunities, particularly for the unemployed and under-employed. The majority of rural families are either part-time or full-time fishermen or fish farmers.

At Don Hoi Lot intertidal mudflats on the Gulf of Thailand, a major producted harvested - razor clam (*Solen regularis*) is an economic mollusk species, important source of fisheries production, occupation and income. There are 200-300 mollusk harvesters harvesting 1,360-3,025 kg/day and earning 2.5 USD/kg of fresh flesh.

At Xuan Thuy Natural Wetland Reserve of Vietnam, human uses include fishing and aquaculture yielding up to 10,300 tonnes per year.

The Lower Mekong Basin supports one of the largest inland fisheries in the world, producing an annual yield of over 500,000 tons in Cambodia and Vietnam alone, and providing some 40-60 % of the animal protein intake of the people (Scott, 1991; Chan et al., 2001). The total annual catch of the Lower Mekong River Basin (Cambodia, Lao PDR, Thailand and Viet Nam) is estimated at 1.6-1.8 million metric tons which is a value of approximately over US$ 1.4 billion (Mekong River Commission, 2001).

There are various estimates and reports on fish yields and socio-economic values derived from different wetland types, sizes and locations. The countries bordering the South China Sea are significant producers and consumers of captured and cultivated fish.

Water supply

Humans, plants and animals may use water directly from wetlands for consumption. Streams, rivers, ponds and lakes are major sources of water supply for rural households. As reservoirs, wetlands are major sources of water supply for public, agricultural, and industrial consumption. In Sumatra of Indonesia, communities living

close to the Berbak National Park depend on this swamp forest for their supply of freshwater (Roggeri, 1995). In the Southern Thailand, local people living around Phru Khantulee swamp forest depend on the forest for water supply for their orchard farms.

Energy supply

The Mekong River has high hydropower potential. The Mekong mainstream and its major tributaries are important for development of hydroelectric energy and have an estimated potential hydropower generation capacity of 285,400 GWh per year (Mekong River Commission, 1997).

The plant biomass of wetlands can be a source of renewable energy. The water hyacinth *Eichhornia crassipes* may be used as fuel, an important source of biogas. In India, a ton of partially dried water hyacinth can provide up to 4,000 litres of gas (Roggeri, 1995). Sago palms can be used for alcohol production. Peat can be extracted from peat swamps for energy production.

Clay, sand, salt, mineral resources

Clay, sand, salt, and mineral resources can be harvested from wetlands for pottery, brick making, and construction materials.

What functions do wetlands perform ?

Functions or services of wetlands are the roles of wetlands in numerous natural phenomena and processes which normally are not measurable in monetary terms but benefit all inhabitants living near, and those using wetland sites.

Groundwater recharge

In areas surrounding wetlands, groundwater is generally close to the surface and shallow wells supply many communities with drinking water. This function occurs when water moves from the wetland down into the underground aquifer. By the time it reaches the aquifer and remains as part of the shallow groundwater system, or it may eventually move into the deep groundwater system, the water is usually cleaner than when it began to filter down from the wetland, providing a seasonal or long-term water resource (medium or deep wells). Once in the aquifer, water is clean and may be drawn up again for consumption by nearby communities especially in dry season.

Recharge is also beneficial for flood storage because runoff is temporarily stored underground, rather than moving swiftly downstream and overflowing.

Agricultural, livestock, aquacultural, recreational, urban and industrial sectors also rely on surface and underground water withdrawals.

Groundwater discharge

This function occurs when water that has been stored underground moves upward into a wetland and becomes surface water. Wetlands that receive most of their water from groundwater discharge usually support more stable biological communities, because water temperatures and water levels do not fluctuate as much as in wetlands which are dependent upon surface flow. Some wetlands are sites of groundwater discharge at one time of the year and then act as sites of recharge to the groundwater at another, depending on the rise and fall of the local groundwater table.

Flow regulation, flood control and protection

Wetlands can act as buffers to store excess amounts of water which may occur during heavy rainfall or high flows in rivers. Chan et al. (2001) describes two processes which result in flow regulation and flood control :

- Flood water can be stored, either in the soils or retained as surface water in lakes, marshes, etc.. This reduces the volume of immediate downstream flood water and prevents possible flooding downstream. Some of this water may be discharged from the storage site over days, weeks or months, and some is removed from the flow regime through evapo-transpiration and percolation to groundwater.
- Wetland vegetation slows down the flow of the flood water, so that not all of it arrives downstream at the same time.

The effect of both processes is that downstream flood heights are reduced and stream and river flows are maintained for a longer period each year than would be the case without the wetland.

Freshwater swamp forests and peat swamp forests play an important role in the mitigation of flooding in adjacent areas by acting as natural reservoirs that absorb and store excess water during the rainy season.

The Great Lake and Tonle Sap River act as natural flood regulators for southern Cambodia and the Viet Nam Delta by decreasing flood peak during the beginning of the flood season and increasing low flow in the dry season. When the Mekong overflows, it pours part of its water into the Tonle Sap, to fill the Great Lake and its surrounding swamp forests, and the surface area of the Great Lake increases. During flood recession, the lake discharges into the Mekong. Downstream, river floods are therefore limited – the lake stores a large volume of water during the wet season, while dry-season flows partly originate from the lake (Mekong River Commission, 1997).

By retaining rainfall and runoff, wetlands decrease the destructive flooding impacts downstream, avoiding the expensive construction of dams, reservoirs, and flood control structures, as well as the socio-economic loss. Loss of wetlands, e.g. floodplains to agriculture and human habitation, means the reduction of this capacity. Construction of levees and dams on rivers for flood control have often had the reverse effects. Floodplain restoration and removal of structures is providing a partial solution in many countries. In Viet Nam, local authorities in Dong Thap Province of the Mekong Delta opposed drainage and, instead, initiated a wetland rehabilitation

programme designed to maintain a range of wetland functions, including flood storage (Scott, 1989; Dugan, 1990).

Floods have long been associated with disasters. However, hundreds of thousands of inhabitants, farmers, fishermen and cattle breeders in 4 countries of the Lower Mekong Basin have another way of looking at floods. Indeed, in many cases, wetland functions and values actually depend on floods caused by the overflowing of rivers or heavy rainfall. Human-beings themselves seem to be at the origin of some flood disasters. Farmlands, houses, villages, industries locate on the floodplains where the hydrological data recorded over decades of floodings. Protection against exceptional flooding may be necessary in some regions where rapid population growth requires the development of new lands. This may not necessary be the case for natural floods in wetland areas.

Prevention of saline water intrusion and acidification

The outward flow of freshwater from a river or a stream, usually limits the entry of seawater into that watercourse. With reduced freshwater flow (due to over-extraction or drainage of surrounding wetlands or blockage of rivers by dams), seawater is able to intrude further upstream, so depriving people, agriculture, industry and ecological communities of the freshwater that they need.

In some cases, the characteristics of river channels and coastal vegetation help prevent the flow of tidal waters into a river. Straightening, deepening or clearing the vegetation of the channel may result in greater penetration of saline water into the river, especially at peak tides.

In low lying coastal areas where the underlying substrate is permeable, a wedge of freshwater frequently overlies deeper saline water. The existence of this freshwater wedge is frequently maintained by coastal freshwater wetlands. Removal or reduction of the freshwater wedge allows the deeper saline water to move upwards towards the land surface, where it can affect water supplies to ecological communities and to people. It is, therefore, very important to retain the freshwater wedge in low-lying coastal areas, as it ensures a supply of drinking, washing and irrigation water to local communities and agriculture, and prevents salinisation of the soil.

The regulation of river water salinity by wetlands ensures the supply of freshwater necessary for the functioning of estuary systems. For the Mekong Delta, due to the Great Lake and the floodplains of the Mekong Basin, the dry-season flow of the river is sufficient and saltwater intrusion in the delta is limited.

Many wetlands are in areas which were once marine. In many cases, pyrite-rich marine clays were laid down during the marine phase. When these clays are exposed to the air, or when a wetland is drained, they oxidise and produce strongly acidic sulphate compounds. These compounds acidify both the soil and the water which pass through it. In the natural state these clays are often overlaid by wetlands. This prevents exposure of pyrite-rich sediments to air, and thus prevents oxidation and the development of acidic conditions and acid sulphate soils. Therefore, keeping the wetland intact, especially the natural hydrological regime which maintains the waterlogged soil conditions, ensures that acidity does not develop.

Storm protection, windbreak, shoreline stabilization and erosion control

Coastal wetlands play a critical role in protecting coastal land from the influence of violent coastal weather by providing a buffer against storm surges and protecting coastlines from erosion.

Wetland vegetation absorbs the energy of waves, currents, storms and other erosive forces. Chan et al. (2001) describes the three main processes that occur.

- Binding and stabilisation of substrates by vegetation and plant roots and deposited vegetative matters.
- Dissipation of wind, wave and current energy.
- Trapping of sediments.

These processes stabilize, reduce and prevent shorelines, estuaries, canal and river banks from erosion. These also prevent the damage of agricultural and residential land and properties.

Mangrove areas provide shelter from the wind and storm. Mangroves help dissipate the force and lessen the impact of coastal storms. The mangrove forests of the Sundarbans in India and Bangladesh, for example, breaks storm waves which often exceed 4 metres in height (Dugan, 1993). The mangrove forests of the Sundarbans in Bangladesh play an important role in protecting the densely populated agricultural hinterlands from cyclones and tidal storms. The Sundarbans have acted as a buffer against calamities and loss has been minimal in areas north of the Sundarbans when compared to other unprotected areas along the coast (Chan et al., 2001). Aftermath of the Asian Tsunami at the end of 2004 revealed that mangroves played a significant role in saving people life and protecting coastal communities and properties in several countries. Cutting of mangroves leads to exposure to storms. The value of intact mangrove swamps in Malaysia for storm protection and flood control alone has been valued at US$ 300,000 per kilometre – the cost of replacing them with rock walls. Reforestation is a costly process. In Thailand, replanting costs amounted to US$ 946 per hectare compared to only US$ 189 per hectare for protecting existing mangroves.

Predicted effects of climate change over the next 50-100 years will place both coastal and inland wetlands under a great deal of pressure through increased prevalence of tropical storms, changing patterns of precipitation, and sea level rise. This wetland function will become crucial to riverine and coastal zone management.

Sediment retention

Sediment is often the major water pollutant in many river systems. Wetlands may serve as pools where sediment can settle. The physical properties of some wetlands, such as size, water depth, and vegetation, tend to slow down the flow of water and increase sediment settling. This is especially true of swamps, marshes and floodplains. Vegetation of wetlands acts like sieves that retain sediments in water. This facilitates the deposition, and therefore the removal of sediment. In some cases, wetlands may actually help to build up land by trapping sediment.

Retaining sediment in upstream wetlands will lengthen the lifespan of downstream reservoirs and waterways and reduce adverse effects on coastal water quality and ecosystems. Sediment removal by wetlands may benefit agriculture in those wetlands by renewing nutrients and soils.

Wetlands, however, do not have an inexhaustible capacity. If there is drastically increased sedimentation due to increased soil erosion in the catchment of the wetland, the excess deposition may have adverse effects on the receiving wetland. Their capacity to further absorb sediments will be considerably reduced in addition to causing water quality problems in lakes and reservoirs. Therefore, rather than relying on wetlands alone to buffer excess sediments, it is far better to ensure that land practices within the catchment keep the input of sediments into wetlands to a minimum.

Nutrient retention

Nutrients are often associated with sediments and can be deposited at the same time. The Mekong River deposits between 10-30 mm of fertile silt each year during the flood season on lowland forests and floodplains in Cambodia and Viet Nam (Mekong River Commission, 1997). This is important for enriching the alluvial soils for agricultural productivity.

Nutrients may be from a wide variety of sources, but are commonly run-off of fertilizer from agricultural areas, human wastes and industrial discharges. When the sediment is deposited, the nutrients may be stored in the sub-soil and water, taken up by wetland vegetation or transformed by chemical and biological processes. Uptake by wetland vegetation and aquatic species does not ensure the nutrient's removal from the water since the nutrients can be released again through decay of the plants and animals. Harvesting biomass from the wetland such as grasses and sedges for thatch and fishes for food means the nutrients are taken out of the system in a useable form.

Inorganic phosphorus and nitrogen are the most significant nutrients which are removed, stored or transformed by chemical processes in wetlands. Nitrates can be removed by the process of denitrification in which bacteria found in oxygen-poor wetland soils convert nitrates and nitrites into molecular nitrogen which diffuses into the atmosphere. Phosphates can be bound to inorganic ions in mineral soils of wetlands.

This is important in preventing eutrophication further downstream, a process that leads to rapid plant and algal growth followed by depleted oxygen levels that affect other species. This is also important in preventing high concentrations of these nutrients reaching groundwater supplies or other water sources that may be used for drinking water. Moreover, the cost and investment on water treatment facilities can be reduced. However, it should be noted that the assimilative capacity of wetlands is limited. Under certain circumstances, wetlands can be used for treatment of domestic wastewater from small non-industrial communities and as tertiary wastewater treatment facilities.

There is a large number of research carried out on the function and capacity of wetland plants as well as wetland ecosystems in nutrients retention. Among the efficient aquatic plants include *Eichhornia crassipes, Neptunia natans, Typha angustifolia, Scirpus sp., Pistia stratiotes, Salvinia cucullata, Nymphaea lotus, Azolla pinnata, Lemna trisulca.* Some plants e.g. water hyacinth *Eichhornia crassipes* can remove over 95% of nutrients from domestic wastewater under appropriate conditions and so can help purify water.

Toxicant retention

Many wetland plants have the capacity to remove toxic substances which come from pesticides, industrial discharges and mining activities. Some wetland plants have been found to accumulate heavy metals in their tissues at 100,000 times the concentration in the surrounding water and so can detoxify certain kinds of effluent (Davies and Claridge, 1993). Water hyacinth *Eichhornia crassipes,* some *Typha* and *Phragmites* species have been used to treat effluents from mining areas that contain high concentrations of heavy metals such as cadmium, zinc, mercury, nickel, and copper. Some other wetland plants can help remove grease and oil.

However, nature has its limitation. It would be wrong to consider that wetlands can deal with whatever waste concentrations humans can produce. Wetlands should not be used as immediate wastewater treatment facilities, but should be used for tertiary treatment rather than primary or secondary treatment.

Biomass transport

Like other plants, wetland plants fix inorganic carbons into organic matter. The net primary production can be measured in terms of biomass. This in turn feeds into the wetland ecosystem. Phytoplankton is the base of the food web, and fallen leaves also provide food for aquatic animals. Nutrients and biomass can be transported along with water and runoff, distributing fertility to nearby wetlands. Annual flooding dominates the biotic production of wetlands by releasing nutrients from the soil, vegetation and inundated organic debris. Water, thus enriched, supports a bloom of plankton, fish and macro-vegetation. Fish populations utilize inundated habitats like flooded forest for reproduction and replenishment of fish stocks. The nutrient rich sediments are also transported downstream to inundation plains where they are deposited in fields and swamps.

Koh Kapik and associated islets in Cambodia, estuarine waters and intertidal mud, sand, saltflats, play a critical role in providing a nutrient source supporting coastal fishery in the near-shore and off-shore waters of Cambodia (http://www.ramsar.org).

In Bangladesh, it is estimated an average of 20 metric tons/ha of fallen leaves, twigs, and bark of mangroves enters the marine food chain every year. This leads to the estimate of 14 million tons of raw material is supplied by mangroves to the marine food chain of Bangladesh annually (Chan et al., 2001).

Micro-climate stabilization

The overall hydrological, nutrient and material cycles and energy flows of wetlands may stabilize local climatic conditions, particularly temperatures, humidity, and rainfall (Dugan, 1990). This has an influence on agricultural or wetland resource-based activities as well as the stability of wetland ecosystems.

Wetlands may store as much as 40% of global terrestrial carbon. Peatlands and forested wetlands are particularly important carbon sinks. Conversion to agricultural use and destruction of wetlands will release large quantities of carbon dioxide, a greenhouse gas, the gas that accounts for at least 60% of the global warming effect. While wetland restoration and creation will increase the sequestering of carbon.

Water transport

Wetlands have been important routes for transportation since the ancient time. Wetlands may serve as a convenient alternative to normal forms of road transport with effective, low cost and less environmental effects.

In the floodplains of Bangladesh, a large flood is the occasion for a woman to visit her family, largely because navigation is easier. Like the Deepar Beel in the plain of the Brahmaputra River in India, most shallow lakes are important communication routes for local communities.

The Mekong River and its tributaries are the lifelines and also important means of transportation. There are major inland ports as well as smaller and less developed ports on the Mekong River and its tributaries. For a landlocked country like Lao PDR, the Mekong River is the lifeline and is also an important means of transportation of goods and the public.

Recreation and tourism

Tourism in wetlands can be economically significant. Because of their natural beauty, scenery, presence of water, cool climate, and the diversity of plant and animal life, wetlands make them ideal locations for tourists and have long been popular for recreation. Rivers and streams especially ones with rapids, waterfalls and beaches, are prime tourism spots. Many of the finest sites are protected as National Parks, World Heritage Sites, Ramsar Sites, or Biosphere Reserves and are able to generate considerable income from tourism and recreational uses. In many Asian countries, the revenue from wetland recreation and tourism is a significant component of the local and national economy. Activities include water sports, swimming, boating, diving, canoeing, sport fishing, bird-watching, nature photography, sailing, etc..

At Bangpakong River Estuary, a coastal wetland bordering the South China Sea, local people benefit 668 Baht/trip on average from taking tourists on their fishing boats for dolphin-watching during November-February (4 months a year), with the Net Benefit 8,394 Baht/household/year (Phuviriyakul, 2007).

Education and research

Wetlands which have not undergone the influence of human beings are ecosystems “in their natural state”. They are particularly favourable “natural laboratories” for all groups, levels, and all walks of life, for scientific studies of the processes which ensure the functioning and evolution of ecosystems, e.g. plant succession. The educational potential of wetlands is linked to the possibility of studying history and observing botanical, zoological, ornithological, ecological or environmental phenomena and processes.

Usually being low-lying “sinks” of pollutants and waste, wetlands often provide important clues. Wetlands host several organisms which, living in the transitional zone between aquatic and land ecosystems, are sensitive to any changes in surrounding natural conditions. A slight change in the ecosystem can lead to a reduction in their population or their disappearance. Observing these biological indicators offers two major advantages. First, a biological indicator reacts to a disturbance before the functioning and functions of the ecosystem are visibly modified, therefore permits the setting-up of an early warning system, allowing corrective measures to be taken in time. Second, chemical and physical analyses are only significant at the moment and the place where they are carried out, while a biological indicator can often inform us about the average stage of the ecosystem over a longer period.

Wetlands offer ideal locations for involving the general public and schoolchildren in hands-on learning experiences, in a recreational atmosphere, to raise awareness of environmental issues. There are many wetland education centres and programmes, nature study centers, and nature trails that involve the general public and schoolchildren in practical activities in their local wetland environments.

What special attributes or qualities do wetlands have ?

The special attributes of a wetland are not necessarily directly or indirectly used, but are seen to have a value in themselves, enhanced by maintaining the wetland "intact" or "preserved" (Dugan, 1990).

Biological diversity and gene pool

Wetlands support a significant diversity of wildlife. Freshwater ecosystems cover only 1% of the Earth’s surface, but they hold more than 40% of the world’s species and 12% of all animal species. For marine ecosystems, coral reefs are among the most biologically diverse ecosystems on the planet. Although they cover only 0.2% of the ocean floor, coral reefs may contain 25% of all marine species.

The Mahaweli Ganga, the most extensive floodplain system in Sri Lanka is the marsh area of the Mahaweli Ganga, the largest river in Sri Lanka. The floodplains provide a migratory corridor between wet and dry season feeding grounds for the largest concentration of elephants *Elephus maximus* and they are home also to the highest density of large mammals in the country, including the endangered leopard *Panthera pardus*, toque macaque *Macaca sinica* and sloth bear *Melursus ursinus*. Reptiles

include the threatened python *Python molurus*, estuarine crocodile *Crocodylus porosus*, marsh crocodile *C. palustris* and the endemic lizards *Calotes zeylonensis* and *Otocryptis weigamanni*, while amphibians include the palm-frond frog *Hylerana gracilis*. Most of the 250 resident species of birds have been recorded from this floodplain system, as well as 75 species of migratory birds (Dugan, 1993).

The Sundarbans, the single most extensive mangrove forests in the world, straddling the border between India and Bangladesh, covering around 6,000 sqkm, is threaded with a complex network of rivers, creeks and canals which flood twice daily as the tide rises, creating a rich habitat for the many species of fish and invertebrates that move into the forest with the tides. There are at least 27 species of mangrove tree growing in this dynamic system. It supports a diverse fauna of 35 species of reptile, over 270 birds and 42 mammals. Most famous among the mammals is the Royal Bengal Tiger *Panthera tigris* for which the Sundarbans is the last remaining stronghold. It is estimated that 350-450 tigers are still present in the Bangladesh portion of the forest, with a further 250-300 in India (Dugan, 1993).

Berbak Nature Reserve on the east coast of Sumatra consists mostly of peat swamp forest and contains an amazing diverse flora. The forests also supports a remarkably diverse mammal fauna, including Sumatra tigers *Panther tigris sumatrae*, clouded leopards *Neofelis nebulosa*, Malayan tapirs *Tapirus indicus* and Sumatran rhinoceroses *Dicerorhinus sumatrensis.* Over 160 species of bird are known to live in the reserve, and it may be one of the last remaining strongholds of the rare crocodilian, the false gavial *Tomistoma schlegelii* (Dugan, 1993).

In the Mekong Delta, at least 23 species of mammals, 386 species of birds, 35 species of reptiles, 6 species of amphibians, and 260 species of fish are recorded. Five species of dolphins have been found (Mekong River Commission, 1997).

Many endemic, rare and endangered species depend on wetlands to complete their life cycle. Many species can only live in wetlands. Loss of wetlands will eliminate wetland dependent species.

Wetlands are an important storehouse of plant genetic materials that have considerable economic potential in the pharmaceutical industry and in commercial agriculture. A wide range of floral species are found in wetlands. Wild rice in wetlands is an important source of new genetic materials in developing disease-resistant and higher-yield strains. The flooded forest is central to the overall ecology of the Great Lake and Tonle Sap River system in Cambodia and to its biological productivity. Over 140 species of floodplain plants and over 60 species of mixed scrubland can be found in the inundated forest around Tonle Sap Lake (Parr et al., 1996).

The flooded forest surrounding Tonle Sap Lake supports one of the world's most significant populations of the globally threatened White-winged Duck *Cairina scutulata*, and the most significant populations of breeding Greater Adjutant Stork *Leptoptilos dubius* in the world (Parr et al., 1996). The Great Lake is of major significance as breeding and feeding habitats for many other large water birds including rare and endangered species, Oriental Darter *Ahinga melanogaster*, Spot-billed pelican *Pelecanus philipensis*, Lesser Adjutant *Leptoptilos javanicus*, Black-

necked Stork *Ephippiorhynchus asiaticus*, Asian Openbill *Anastomus oscitans*, Painted Stork *Mycteria leucocephala*, Milky stork *Mycteria cinerea*, Black-headed Ibis *Threskiornis melanocephalus*, White-shouldered Ibis *Pseudibis davidsoni*, Giant Ibis *Pseudibis gigantea*, and the sarus crane *Grus antigone sharpii*. Critically endangered Giant Ibis *Pseudibis gigantea* is also found along the Xe Kong and Mekong Rivers in southern Lao PDR. The Mekong Delta of Vietnam is of international importance as habitat for the endangered Eastern Sarus Crane *Grus antigone sharpii* and other rare water birds. Within a small area of 9,000 ha of the Tram Chim Nature Reserve in Viet Nam, 92 bird species have been identified. The Reserve has a rich food base, particularly the aquatic grass *Eleocharis dulcis* with its tubers, which attracts the Eastern sarus crane *Grus antigone sharpii*. The population of this species has stabilized at around 800 individuals (Mekong River Commission, 1997).

An estimated 1,700 different species of fish are known to inhabit the waters of the Mekong mainstreams, tributaries, and associated wetlands (Mekong River Commission, 2001). Important fish species include the globally endangered endemic Mekong Giant Catfish *Pangasianodon gigas* the world's largest freshwater fish, *Boraras micros* the world's third smallest fish inhabiting swamps of the Mekong floodplain, critically endangered globally Leaping Barb *Chela caeruleostigmata* and Dwarf Botia *Botia sidthimunki*, Jullien's Carp *Probarbus jullieni*, Golden Arowana *Scleropages formosus*, an endemic freshwater herring *Tenualosa thibaudeaui*, and another at least 30 endangered endemic fish species. Many fish migrate seasonally, sometimes across more than 2,000 km, e.g. the Giant Catfish *Pangasianodon gigas*, to place themselves at the beginning of the flood wave at their reproduction time. In this way, the fry can be swept on downstream floodplains when the river overflows.

Rapids and deep pools of the Mekong River and tributaries are habitats for many endemic fish species which are not found elsewhere such as *Chitala blanci*, *Chitala lopis*, *Wallago leeri*, *Pangasius sanitwongsei*, *Mekongina erythrospila*, *Bangana behri*, *Mystus wyckioides*, Giant gouramy *Osphronemus sp.*, *Channa marulius*, and also are shelters and spawning ground for riverine species such as *Pangasius sp.*, *Cirrhinus microlepis*, and *Cyprinid sp.* Rapids and deep pools of the Mekong River between Phnom Penh and the Khone Falls in southern Lao PDR and the Xe Kong River are habitats of the critically endangered freshwater Irrawaddy Dolphin *Orcaella brevirostris.*

In the Great Lake of Cambodia, at least 850 fish species have been recorded. More than 215 fish species are known to originate in the Lake, of which nearly 70 species are of commercial value. Fish migrations from the Lake into the Mekong River help restock fisheries as far upstream as Yunnan and many tributary rivers along the way. During the flood season, the Plain of Reeds supports a large number of fish species which move from upstream areas for breeding and nursing. Juvenile individuals of shrimp and fish find food and protection in the aquatic plant communities. When floodwater recedes, mature shrimp and fish move with water to numerous ponds and swamps inside the areas, and to large rivers outside. This is when fish are harvested in large quantities.

Wetlands are not only known as bird and fish habitats. Wetlands in Cambodia, for example, the Stung Sen area supports a great variety of grazing animals, including the

endangered Kouprey *Bos sauveli*, Banteng *Bos javanicus*, Gaur *Bos gaurus*, Eld's deer *Cervus eldi*, as well as elephants, wild water buffalo *Bubalus arnee*, Lowe's Otter Civet *Cynogale lowei*, tigers and leopards (Mekong River Commission, 1997). The critically endangered Siamese Crocodile *Crocodilius siamensis* is found in southern Lao PDR and Cambodia.

Uniqueness to culture and heritage and importance to history

Wetlands played a large part in development of human history. The major cradles of civilizations were all located along river valleys. Many historical and cultural relicts, e.g. Angkor Wat in Cambodia, are located not far from wetlands, major rivers and lakes. This was probably because of the ease of transportation, the availability of water and the abundance of wetland products.

Local inhabitants may have a strong spiritual attachment to a wetland site because their family or community has used the site for many generations, or because it is associated with aspects of their culture. In many cases it is impossible to compensate the loss of a site which has this value because such sites are unique.

In Thailand, wetlands are involved with Thai history, legends, culture, traditions, national identity, religion, and way of life. Settlements, floating markets, temples and religious establishments can be seen along waterways and on riverbanks. Many wetlands are religious sites or highly respected or have spiritual values according to the local beliefs (e.g. Don Pu Ta). In northern and northeastern Thailand and in Lao PDR, the Giant Mekong Catfish is believed to be a sacred fish and this affects the way of people's exploitation of this fish. Some wetlands are archaeological sites. Many Thai traditions, culture and festivals in the Mekong River Basin in Thailand are centered on wetlands, such as Loy Kratong, Festival of Lights, Illuminated Boats Procession, Rockets Festival, and Boat Racing.

Many wetlands are unique environments where human activities have evolved to make best use of the resources available. These activities include specialised fishing methods, methods of collecting fruits, resins and other forest products, and methods of using unproductive soils. In many cases, these activities demonstrate sustainable use of valuable resources.

Trans-boundary significance

Wetlands bordering the South China Sea have transboundary significance and play a great role buffering and reversing the degradation trends of the South China Sea. Almost all coastal wetland sites bordering the South China are parts of the East Asian-Australasian Flyway.

The Mekong River and its associated wetlands are of international importance and of transboundary significance, especially in terms of biodiversity, economic, socio-culture and politics. The Plain of Reeds is a good example of a true transboundary wetland ecosystem of transboundary significance, covering some 700,000 ha in Viet Nam and 300,000 ha in Cambodia. This is an important production region in terms of agriculture, forestry and fisheries resources.

The multiple values of wetland ecosystems

Whether a wetland performs certain functions or services, yields specific products or goods, or possesses certain attributes, is determined by the interaction of the physical, biological and chemical characteristics of that wetland site and type. Not all characteristics are present in each wetland, so few wetlands provide all benefits and not all benefits are provided equally by each wetland. Furthermore, the role that different wetlands can play in a given process may vary considerably, both in significance and quality.

One thing for sure is that, benefits which a society can obtain from wetlands, especially the intact or preserved ones, usually come with the following unique characteristics :

- **Enormous**
- **Diversed, multiple**
- **Simultaneous**
- **Regular, continuous, and long-term**
- **Direct and indirect**
- **Tangible and intangible**
- **Marketable and non-marketable**
- **Naturally increasing, without high cost or large investment**
- **Harvestable by local/traditional technology or local wisdom**
- **Available for public at large or communities, not for specific groups or a few individuals**

These unique characteristics of wetland benefits should be bourne in mind and considered whenever and wherever a natural or semi-natural wetland site will be reclaimed and converted to other single economic use.

While no single wetland provides all benefits, all wetlands yield multiple benefits. Most development projects, on the other hand, concentrate intensively on one aspect, such as the agricultural or aquacultural yield. Full development of the single-use approach often requires major investments of capital, manpower, technology, and inputs such as fertilizer, as well as substantial annual investment in maintenance. Wherever conversion is attempted, the ability of natural wetlands to sustain alternative development is generally found to be low. Such conversions usually involve hidden costs and, if development is to be sustainable, require far more sophisticated management than is generally available to the average rural community.

There is today a growing appreciation that the potential of wetlands for meeting development needs lies in maintaining their functional integrity, and not in converting them to single-purpose use. In other words, if managed properly, wetlands can, in their natural conditions, provide a wide range of benefits.

However what many planners tend to forget are :

- many groups of people benefit, both inside and outside a wetland, from the goods and services that it provides;
- these goods and services vary according to the season; and
- any modification to a wetland ecosystem can lead to a series of effects, the consequences of which may be felt far beyond the actual limits of the wetland itself, by a large range of the population and by different sectors of the provincial, national or regional economy.

Therefore, assessing the benefits – be they direct or indirect, economic or spiritual – gained from wetlands requires a holistic vision.

The needs for maintenance of wetland benefits

Many of the benefits provided by wetlands are essential to communities and the public at large. Loss of wetlands will remove these benefits. Maintenance of wetlands as functioning ecosystems will often ensure that their important contributions to sustainable development are maintained.

The multiple roles of wetland ecosystems and their value to humanity have been increasingly understood and documented. This has led to massive expenditures to restore lost or degraded hydrological and biological functions of wetlands or even to create wetlands.

Why did not we maintain our wetland ecosystems and benefits, at the first place ?

Examples

Valuation of wetlands of different types

Wetland types	Total value (US$/ha/yr)
Estuaries	22,382
Seagrass / algae beds	19,004
Coral reefs	6,075
Tidal marshes / mangroves	9,990
Swamps / floodplains	19,580
Lakes / rivers	8,498

Source : Ramsar Bureau, 2001.

Values of wetland functions

Functions	Estimated values
Flood control	**US$ 17 million/yr** : the estimated cost of flood damages that would result if 3,800 ha of intact wetlands along part of the mainstream of the Charles River in USA were drained.
Groundwater replenishment	**US$ 25 million/yr** : the role of a 223,000 ha swamp in Florida, USA, in storing water and recharging the aquifer, direct removal of water from aquifers for agriculture, million cu.m..
Shoreline stabilisation & storm protection	**US$ 300,000/km** : the cost of replacing intact mangroves in Malaysia with rock walls for storm protection. **US$ 425/m of bank** : loss of vegetation along river banks in UK – the cost of maintaining artificial bank reinforcement to prevent erosion. **US$ 137,000 – 1.2 million/km of coral reef over a 25 year period** : the economic value of storm protection, fishing and tourism.
Sediment & nutrient retention and export	**US$ 45/1,000 cu.m.** : of water of floodplain in Nigeria for fishing, agriculture, fuelwood, livestock, tourism; in contrast to US$ 0.04 of diverted water for irrigation. **US$ 264 million in 1989** : value of Louisiana fishery threatened by degradation of the Mississippi delta. **US$ 5 million** : cost of efforts to restore floodplain in Cameroon over 8 year period.
Water purification	**US$ 3-8 billion** : cost of new wastewater treatment plants which New York City could avoid, by investing US$ 1.5 billion buying land around wetland for free water purifying.
Reservoirs of biodiversity	**US$ 343 million** : annual income of WWF, comes from individuals members who pay to conserve wildlife they may never see.
Wetland products	**US$ 4.4 million/yr** : value of wetland products from 1 million ha of a wetland reserve in Brazil. **US$ 500 million/yr** : value of international trade in crocodile skins. **US$ 13 million** : value of crab, shrimp, salmon in 1991 at landings in USA. **US$ 4,850/ha** : value of marketable fish caught from mangroves in Australia. **15 tons/sqkm** : of fish and seafood produced from well-managed coral reefs.
Recreation / tourism	**US$ 540 million, 1.6 million visitor-days** : at the Great Barrier Reef Marine Park. **US$ 800,000** : annual income of Kakadu National Park

	US$ 20 billion : annual income from economic activities generated by 60 million bird-watchers and 3.2 million bird-hunters in Canada, Mexico, USA.
Cultural value	**US$ 150 million** : investment on a dam construction in Portugal abandoned in 1995 after Palaeolithic engravings were unearthed.

PRESENT USES OF WETLANDS

Uses of wetlands differ according to wetland types and sizes. All cases contribute substantially to the national and local economies. Uses of many wetlands are of marginal value but for significant subsistence.

Rivers and streams are used mainly for fisheries, water supply for domestic consumption, agriculture and livestock, transportation, recreation and tourism. Many rivers contribute to hydropower generation.

Riverine floodplains are used mainly for agriculture, livestock grazing, and fisheries.

Marshes and swamps are used for domestic water supply, for agriculture in the seasonally inundated peripheral areas, and for fisheries in the central perennially-inundated areas. Harvesting of natural products, such as woods, edible plants, plants of medicinal value, and utilizing peripheral areas for grazing, livestock and cattle, besides being habitats for animals and birds, are major uses.

Lakes and reservoirs are mainly used for water supply and storage, flood prevention, fisheries, irrigation, agriculture and livestock, transportation, recreation and tourism.

References and suggested further readings :

Barbier, E.B., Acreman, M. and Knowler, D. 1997. ***Economic Valuation of Wetlands A Guide for Policy Makers and Planners.*** Ramsar Convention Bureau.

Chan, S., Benstead, P., Davies, J. and Grubh, R. 2001. ***The Wetland Management Handbook for South East Asia.*** Ministry of the Environment, Japan. 121 pp.

Choowaew, S. 2003. ***Classification and Inventory of Wetland/Aquatic Ecosystems in the Lower Mekong River Basin of Thailand.*** Final Report submitted to the Thai National Mekong Committee Secretariat and the Mekong River Commission Secretariat. April 2003. 100 pp.

Claridge, G.F. (compiler) 1996. ***An Inventory of Wetlands of the Lao PDR.*** IUCN, Bangkok.

Davies, J. and Claridge, G.F. (eds.). 1993. ***Wetland Benefits. The Potential for Wetlands to Support and Maintain Development.*** Asian Wetland Bureau Publication No. 87; IWRB Special Publication No. 27; Wetlands for the Americas Publication No. 11.

Dugan, P.J. (ed.). 1990. ***Wetland Conservation : A Review of Current Issues and Required Action.*** IUCN, Gland, Switzerland. 96 pp.

Dugan, P.J. (ed.). 1993. ***Wetlands in Danger.*** A Mitchell Beazley World

Conservation Atlas. Mitchell Beazley – IUCN.
Haab, T.C. and McConnell, K.E. 2002. ***Valuing Environmental and Natural Resources.*** Edward Elgar Publishing Limited. Cheltenham, UK. 326 pp.
Hong, Phan Nguyen and Hoang Thi San. 1993. ***Mangroves of Vietnam.*** IUCN, Bangkok, Thailand. 173 pp.
International Center for Living Aquatic Resources Management (ICLARM). 1999. Programme/Project Document. ***The Legal and Institutional Framework, and Economic Valuation of Resources and Environment in the Mekong River Region : A Wetlands Approach***. 31 March 1999.
Kent, D.M. (ed.). 2001. ***Applied Wetlands Science and Technology.*** Lewis Publishers. New York. 454 pp.
Maltby, E. 1986. ***Waterlogged Wealth.*** Earthscan. 200 pp.
Mekong River Commission. 1997. ***Mekong River Basin Diagnostic Study. Final Report.*** MKG/R. 97010. Mekong River Commission, Bangkok.
Mekong River Commission. 2001. ***Local Knowledge in the Study of River Fish Biology : Experiences from the Mekong***. Mekong Development Series No.1. July 2001.
Office of Environmental Policy and Planning. 1999. ***Inventory of Wetlands of International and National Importance of Thailand.*** Ministry of Science, Technology and Environment. Bangkok, Thailand. 414 pp.
Parr, J.W.K., Eames, J.C., Sun Hean, Chamnan Hong, Som Han, Vi La Pich and Kim Hout Seng. 1996. ***Biological and Socioeconomic Aspects of Waterbird Exploitation and Natural Resource Utilization at Prek Toal, Tonle Sap Lake, Cambodia***. IUCN Species Survival Commission. IUCN, Bangkok, Thailand.
Pearce, D. and Moran, D. 1994. ***The Economic Value of Biodiversity.*** IUCN The World Conservation Union. Earthscan Publications Ltd. London. 172 pp.
Phuviriyakul, S. 2007. ***Economic Valuation of Mangrove Forest : a Case Study of Klong Tam-Ru Sub-district, Muang District, Chonburi Province, Thailand.*** MSc Thesis (Technology of Environmental Management), Faculty of Graduate Studies, Mahidol University.
Prapamontol, N. 2001. ***The Contingent Valuation Method Applied to Conservation of Fishery Resources in Bung Lahan Wetland, Chaiyaphum Province.*** M.Sc. (Technology of Environmental Management) Thesis. Faculty of Graduate Studies. Mahidol University. 222pp.
Ramsar Bureau. 2001. ***Wetland Values and Functions Folder.*** http://ramsar.org/
Roggeri, H. 1995. ***Tropical Freshwater Wetlands : A Guide to Current Knowledge and Sustainable Management.*** Kluwer Academic Publishers. 349 pp.
Scott, D.A. (ed.). 1989. ***A Directory of Asian Wetlands.*** IUCN, Gland, Switzerland.
Turner, K. and Jones, T. (eds.). 1990. ***Wetlands : Market and Intervention Failures.*** Organization for Economic Co-operation and Development. Earthscan Publications Ltd. London. 202 pp.