10 Wetland-Based Agroforestry Systems: Balancing Between Carbon Sink and Source

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Abstract

Wetlands of India, estimated to be 58.2 million ha, are important repositories of aquatic biodiversity. The diverse ecoclimatic regimes extant in the country resulted in a variety of wetland systems ranging from high altitude cold desert wetland to hot and humid wetlands in coastal zones with its diverse flora and fauna. These ecosystems provide immense services and commodities to humanity. Wetlands perform numerous valuable functions such as recycle nutrients, purify water, attenuate floods, maintain stream flow, recharge ground water, and also serve in providing livelihood to local people in terms of fish, drinking water, fodder, fuel, and environmental services. With rapidly expanding human population, wetlands of India are threatened and facing severe anthropogenic pressures. There is obviously much ground to be covered in our conservation efforts of wetlands. Various agencies at local and government level need to join hands in making these viable, functional, and sustainable. Being diversified farming systems, agroforestry opportunities are abundant in rehabilitation of wetland systems. The nutrient-rich riparian zone provides a suitable site for harnessing the ecosystem services of tree-based farming in the flood plains and in the ecologically fragile hilly region. Ecologically, wetland use as a component in agroforestry may be more acceptable in areas which are facing frequent/seasonal or permanently flooding. It is envisaged that wetland agroforestry can alleviate poverty by making substantial contribution toward local economy in terms of fish and agricultural production.

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Introduction

A wetland is a land area that is saturated with water, either permanently or seasonally, such that it takes on the characteristics of a distinct ecosystem (Wikipedia- State of Florida, DoEP 2011). Primarily, the factor that distinguishes wetlands from other land forms or water bodies is the characteristic vegetation that is adapted to its unique soil conditions, which are hydric and support aquatic plants (Butler 2010). Wetlands include lands that are permanently or temporally flooded and many different habitats such as ponds, marshes, swamps, bogs, fans, and peat lands. The water found in wetlands can be salt water, fresh water, or brackish. Wetlands function as 'ecotones', transitions between different habitats, and have characteristics of both aquatic and terrestrial ecosystems. Thus, the biological resources tend to be highly productive. In India, wetlands are reported to occupy 58.2 million ha (Mha) (Prasad et al. 2002) under various categories (Table 10.1) which is about 17.7 % of the total geographic area. But, under National Wetland Conservation and Management Programme (NWCMP) only 3.02 Mha area covering 94 sites in different states are under wetlands (Table 10.2), out of which only 677 thousand ha area has been considered of International importance covering 25 (Ramsar) sites (MoEF 2007).

Mostly the wetlands are distributed across the floodplains and high hills. While 80 % human in the country depend on agrarian economy, still agroforestry in its diverse form become significant both at subsistence and semi-subsistence level (Asian Development Bank 2005). At systematic level, agroforestry opportunities are abundant in wetland systems. The nutrient-rich riparian zone provides a suitable site for harnessing the ecosystem services of tree-based farming in the flood plains and in the ecologically fragile hilly region. Ecologically, in wetland land use system agroforestry as a component may be more acceptable in areas which are facing frequent/seasonal or permanently flooding. It is envisaged that wetland agroforestry can alleviate poverty by making substantial contribution toward local economy in terms of fish and several agricultural products (Fig. 10.1). Nonetheless, the wetlands are continuing to be threatened owing to reveal the factors that are both ecological and anthropogenic.

Agricultural Perspective

India, with its annual rainfall of over 130 cm, varied topography and climate regimes support and sustain diverse and unique wetland habitats. Natural wetlands in India consists of the high altitude Himalayan lakes, followed by wetlands situated in the flood plains of the major river systems; saline and temporary wetlands of the arid and semi-arid regions; coastal wetlands such as lagoons, backwaters, and estuaries; mangrove swamps; coral reefs and marine wetlands, etc. In fact, with the exception of bogs, fens, and typical salt marshes, Indian wetlands

Table 10.1 Extent of wetlands in India

Wetlands in India	Area (million ha)
Area under wet paddy cultivation	40.9
Area suitable for fish culture	3.6
Area under capture fisheries	2.9
Mangroves	0.4
Estuaries	3.9
Backwaters	3.5
Impoundments	3.0
Total area	58.2

Source Parikh and Parikh (1999)

Table 10.2 State wise distribution of wetlands under National Wetland Conservation and Management Programme (NWCMP)

State/UT	Number of wetlands	Name of wetland	Area (ha)
Andhra Pradesh	1	Kolleru	90,100
Assam	2	Deepor Beel, Urpad Beel	4,504
Bihar	3	Kabar, Barilla, Kusheshwar Asthan	11,490
Chandigarh	1	Sukhna	148
Gujarat	8	Nalsarovar, Great Rann of Kachh, thol Bird Sanctuary, Khijadiya Bird Sanctuary, Little Rann of Kacch, Pariej, Wadhwana, Nanikakrad	12,70,875
Haryana	2	Sultanpur, Bhindavas	288
Himachal Pradesh	5	Renuka, Pong Dam, Chandratal, Kewalsar, Khajjiar	15,736
Jammu & Kashmir	7	Wular, Tsomoriri, Tisgul Tso & Chisul Marshes, Hokersar, Mansar-Surinsar, Ranjitsagar, Pangong Tso	1,17,325
Jharkhand	2	Udhwa, Tilaiya Dam	98,965
Karnataka	7	Magadhi, Gudavi Bird Sanctuary, Bonal, Hidkal & Ghataprabha, Heggeri, Ranganthittu, KG Koppa	4,250
Kerala	5	Ashtamudi, Sasthamkotta, Kottuli, Kadulandi, Vembnad Kol	2,13,229
Madhya Pradesh	12	Barna, Yashwant Sagar, Wetland of Ken River, National Chambal Sanctuary, Ghatigaon, Ratapani, Denwa Tawa, Kanha Tiger Riserve, Sakhyasagar, Dihaila, Govindsagar	3,59,814
Maharashtra	3	Ujni, Jayakawadi, Nalganga	40,298
Manipur	1	Loktak	26,600
Mizoram	2	Tamdil, Palak	285
Orissa	4	Chilika, kuanria, Kanjia, Daha	1,22,580
Punjab	3	Harike, Ropar, Kanjali	5648
Rajasthan	1	Sambhar	24,000
Sikkim	6	Khechuperi, Holy Lake, Tamze, Tembao Wetland Complex, Gurudokmar, Tsomgo	164
Tamil Nadu	3	Point Callimere, Kaliveli, Pallaikarni	46,283
Tripura	1	Rudrasagar	240
Uttar Pradesh	9	Nawabganj, Sandi, Lakh Bahoshi, Samaspur, Alwara, semarai Lake-Nagaria Lake Complex, Keetham Lake, Shekha, Saman Bird Sanctuary & sasai Nawar Complex	12,083
Uttaranchal	1	Ban Ganga Jhimli Tal	800
West Bengal	5	East Kolkata Wetlands, Sunderbans, Ahiron Beel, Rasik Beel, Santragahi	5,53,090
Total	94	Total wetlands (94)	30,18,795

Source MoEF (2007)

cover the whole range of the ecosystem types found. The various reservoirs, shallow ponds, and numerous tanks support wetland biodiversity and add to the countries wetland wealth. It is estimated that wetland alone support 20 % of the known range of biodiversity in India (Deepa and Ramachandra 1999, Prasad et al. 2002). The total number of aquatic plant species exceeds 1200 and a partial list of animals and avifauna has been given by Gopal (1995). This biodiversity may help in improving agricultural production including fish production having trees on boundaries of wetlands, which contribute toward shade, shelter, and nutrition as litter.

Fig. 10.1 Few wetland based agroforestry systems *Top* On the brink/slope of wetland, *Middle* fish pond surrounded by trees, *Bottom* On the bank (lowlying area) of wetland

Out of about 3.56 Mha of inland wetlands, north-eastern states and West Bengal cover about 370,000 ha and these areas fall under Indo-Burma global mega biodiversity hotspot and harbor large number of wetlands. Major wetland types are rivers, streams, lakes, ponds, waterlogged areas, ox-bow lakes, high altitude lakes, and reservoirs. Wetlands of this region are traditionally used for agriculture and fisheries since time immemorial.

Apart from the fishes, which are major produces from the wetlands, significant number of edible plant species such as *Alocasia cucullata*, *Euryale ferox*, *Hedychium coronarium*, *Lemanea australis,* and *Nelumbo nucifera* are also collected and sold in the local market.

Conversions of wetlands to agricultural land and for shifting cultivation have been projected as a severe environmental problem in the north-eastern region (Balasubramanian et al. 2011, Arunachalam et al. 2002). Recent reports do indicate that the natural wetlands are the largest sources of green house gases (GHGs) such as CO_2, CH_4, and N_2O that significantly contribute to global warming. Further, their loss and degradation of wetlands can result in releases of large amounts of GHGs into the atmosphere, negating gains made from emission reductions. It has been hypothesized that the wetland ecosystems could be a better carbon C sink if managed properly by plantation of multipurpose trees in and around the wetlands (Fig. 10.2). In brief eco-restoration of degraded wetlands could help protect their carbon stores and improve their ability to sequester more C in future. Contrarily, it may also increase the amount of methane released due to anaerobic microbial activity that is pronounced when water level rises. Feasibility analysis of wetland agroforestry as one of the C balancing technique, prescribes it as an alternative farming system in the fragile flood plain ecosystems, based on a few socio-eco-biological values.

Carbon Sequestration

In tree-based systems, carbon sequestration is a dynamic process and can be divided into phases. At establishment phase, many systems are likely to be source of GHGs. These follow a quick accumulation phase and a maturation period when tons of carbon are stored in boles, stems, and roots of trees and in soils. At the end of rotation period, when the trees are harvested and land returned to cropping (sequential systems), part of carbon will

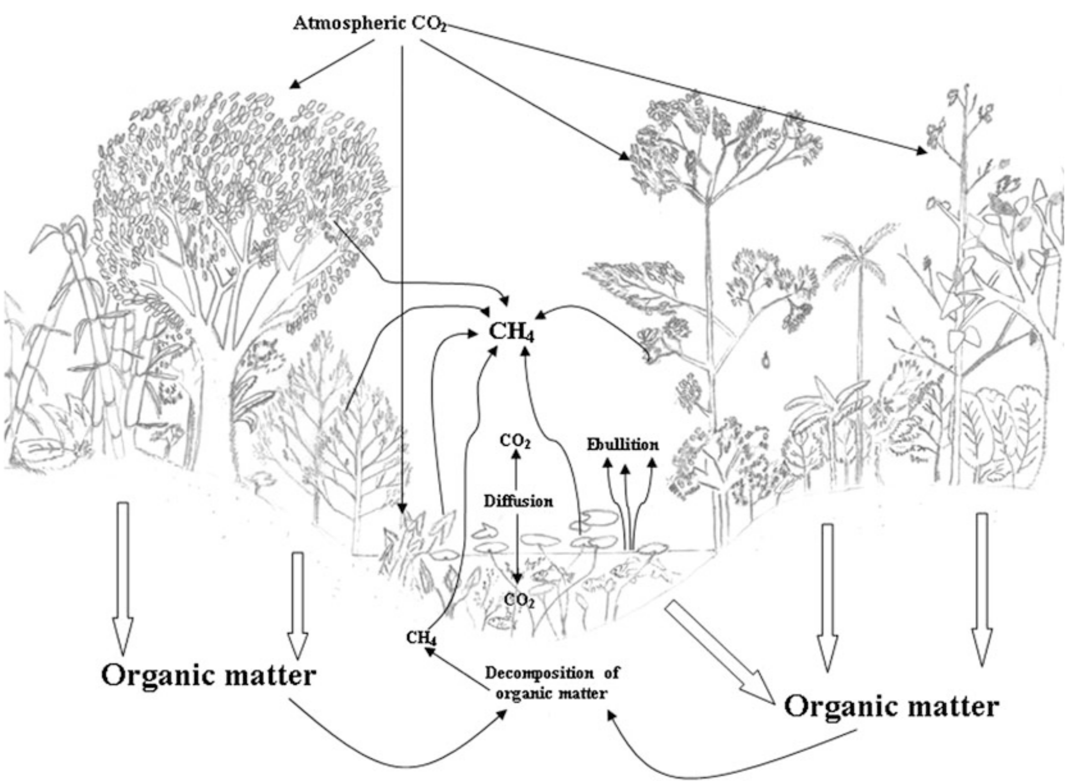

Fig. 10.2 Hypothetical structure of wetland agroforestry system and C balancing function

be released back to the atmosphere (Dixon 1995). In case of simultaneous systems like hedgerow intercropping, silvopastoral systems and agri-silviculture systems; fate of carbon will be different. Therefore, effective sequestration can only be considered if there is a positive net carbon balance from an initial stock after a few decades (Feller et al. 2001). In fact, practice of agroforestry system in and around the natural wetlands may be unique, which could lead to the irreversible alteration in the major ecological functions of wetlands (Box 1).

There are several mechanisms that influence the carbon storage capacity of a wetland ecosystem. For instance, wetland trees and other plants convert atmospheric carbon dioxide into biomass through the mechanism of photosynthesis. Hence carbon may be temporarily stored in wetlands as trees and plants and the living material which feed upon them, and detritus including fallen plants and animals which feed upon them. Many wetland plants are known to use atmospheric CO_2 as the C source, and their death/decay and ultimate settlement at a wetland bottom can have profound effect on C sequestration. This mechanism even varies along the latitudinal gradient where growth of vegetation is slow for high latitude wetlands with less sun, nutrient, and colder temperature.

Further, carbon-rich sediments are trapped and stored that are brought along floods, hurricanes or even drained from watershed sources. However, long-term storage is often limited due to rapid decomposition processes and rerelease of C to the atmosphere, such as in case of paddy fields. Hence, wetlands are dynamic ecosystems where significant quantities of C, both from wetland and non-wetland sources, could possibly be sequestered.

Box 1.

Poplar-based wetland agroforestry system in China: a case study (Fang et al. 2005).

Poplars are the major tree component of traditional agroforestry systems throughout the south temperate central area of China which includes all or portions of Jiangsu, Anhui, Zhejiang, Hubei, Henan, Shandong, and Shanxi provinces, an area of 600,000 km^2. In order to develop a poplar-crop inter-planting pattern in floodplain wetland areas, that is, economically viable, environmentally sound, technically workable, and socially compatible in wetland plain areas new poplar-crop inter-planting patterns were designed using the principle of edge effects and established in 1992 (Fang et al. 2005). The study site located at Hanyuan Forestry Farm, Baoying County, Jiangsu Province, P. R. China (33 °08 °N, 119 °19 °E), and a part of the Lixia River wetland experiences a warm temperate climate with an average growing season of 229 frost-free days.

The poplar-crop interplantations modified the microclimate by decreasing solar radiation, lowering air temperature, and enhancing relative humidity. Overall, the reduction of total solar radiation and illumination intensity in the interplantations ranged from 3.9 to 36.2 %, while relative humidity increased from 2.5 to 3.9 %, depending on phenological phases. The lower air temperature and higher relative humidity in the poplar-crop interplantations enabled the growth and development of winter wheat. Various poplar-crop interplantations have a great impact on plant morphology, wheat yields, and crop quality because of the modification in microclimate. The most dramatic impact on wheat quality between poplar-crop inter-plantation and agricultural monoculture was in protein content. For instance, protein content of wheat seed in the interplantations was increased by an average of 18.3 %. Starch content of wheat seed was also improved through the poplar-crop inter-plantation, varying from a minimum of 10.9 % to a maximum of 15.0 % (average of 12.1 %) depending on plant spacing. The results observed in this study highlight the importance of adopting a poplar-crop interplantations management system to improve crop quality, even though the system reduces some crop yields. The results indicated that the profits of the interplantations per unit are 20–47 % more than that of the agricultural monoculture. Hence, poplar agroforestry is a more profitable option for farmers at current prices, provided that the correct poplar-crop inter-planting patterns and cultivars are used.

Scope of Poplar in India

Poplar is a very prominent taxonomical group of tree species in agro (plantation) forestry in India. It occurs in natural forests also. However, its population in natural stands is small and is gradually declining. Bulk of the plantations is composed of *Populus deltoides*, an exotic species. Indigenous species of poplar occur in the Himalayan region in northern part of India. Other exotic species like *P. xeuramericana* and *P. xberolinensis* were introduced in India in 1950. Clones of *P. canescens, P.maximowiczii, P. trichocarpa, P. simonii, P. szechuanica, P. yunnanensis,* etc., were introduced in the subsequent years. *P. deltoides* performed better than all other exotic poplars in the plains of North India, and relegated most other exotic poplars to the status of anonymity in India. In the hills, *P.yunnanensis* and *P. xeuramericana* 'Robusta' proved better than other species.

Adoption of poplar (*Populus deltoides*) agroforestry in northern India, however, is occurring in areas where land and water are already intensively used and managed for agricultural production. Poplar-based agroforestry plantations in Saharanpur and Yamunanagar districts of northwestern India produce considerable amount of biomass, which helps the farmers in generating income. Poplar-based boundary and agrisilviculture systems account for 99–304 t ha^{-1} CO_2 assimilation at the rotation period of 7 years in the two districts (Rizvi et al. 2010). The potentials of promising poplar agroforestry are yet to be unleashed in mainstreaming livelihood security through intercropping.

The Mangroves

Mangroves are salt tolerant plants that occur between 32 °N and 38 °S latitudes (Ajai et al. 2013). According to a trend analysis conducted on available data by FAO (2007), 15.2 Mha of mangroves are estimated to exist worldwide as on the 2005, down from 18.8 Mha in 1980. Mangroves in India account for about 5 %of the world's mangrove vegetation and are spread over an area of about 4662 km^2 along the coastal States/Union Territories of the country (FSI 2011). Mangroves provide suitable opportunity for practicing tree-based farming systems in coastal areas due to their immense beneficial properties in both ecological and economical point of view (Box 2).

Box 2

Mangrove-based farming System for Coastal areas: case study in Kosrae (Conroy and Fares 2011, Drew et al. 2005).

On the island of Kosrae (Federated States of Micronesia), freshwater-forested wetlands dominated by *Terminalia carolinensis* are often found just upslope from mangrove forests, which appear to be hydrologically connected to them. Many of these *Terminalia* forests have been converted into agroforests (Conroy and Fares 2011, Drew et al. 2005). Kosrae's wetland agroforests have been in existence for approximately 1,350–1,500 years (Athens et al. 1996). In this type of agroforestry systems in coastal freshwater wetlands, with *Terminalia carolinensis* as a dominant overstory species, swamp taro (*Cyrtosperma chamissonis*), banana, and breadfruit are cultivated as main agricultural crops. Cultivation of *C. chamissonis* does not seem to alter the hydrological condition of the land, so that natural wetland conditions are maintained (Chimner and Ewel 2004, 2005). A survey of 10 % of the households on Kosrae showed that 89 % owned some *Terminalia* land. Most grew taro, bananas, and sugar cane, either in or immediately adjacent to *Terminalia* forests. Most owned canoes constructed of *Terminalia* logs, and nearly half had harvested trees from these forests during the past years: 64 % to clear land for agricultural purposes, 36 % for building canoes, and 31 % for other uses. *Terminalia* forests provided over $3.1 million worth of goods to Kosraeans, primarily from agricultural production (Drew et al. 2005). Approximately, 2/3 of those surveyed understood that *Terminalia* grows best in a wetland setting. Most thought that *Terminalia* forests provide erosion protection and improve water quality. However, very few were cognizant of the ecological links between *Terminalia* and mangrove forests. Kosraeans attached little importance to the fact that *Terminalia* is endemic to the eastern Caroline Islands. If human dependence on these wetlands increases, the integrity of *Terminalia* forests, as well as adjacent mangrove forests, could be at risk.

In most of the north-eastern India and coastal Kerala, one could see the cultivation of Taro (*Colocasia esculenta*) in wetland areas and buffer zone of fish ponds. It is suggested that root crops like Taro which grow well in wetland areas could be worthwhile in wetland agroforestry system along with the other tree crops. Coastal almond (*Terminalia catappa*), *Calophyllum inophyllum,* and species of *Pandanus* are very common behind mangroves in Andamans and *Nypa fruticans* along creeks of Andamans and Sunderbans; may be explored as commercial plantations. Cashew nut (*Anacardium occidentale*) *Pandanus* and *Casuarina* are cultivated along beaches and back spaces along Orissa coast.

Mangroves also play a significant role in sequestering of carbon and reducing greenhouse gases (Patil et al. 2012). The below-ground content of mangroves is 4–18 times higher than the carbon content of tropical rainforests (Tateda 2005). This indicates that positive action in mangrove conservation and rehabilitation would contribute immensely to sequestration of CO_2. The higher rates of carbon sequestration in salt marshes, soils of tidal salt, and lower methane emissions make coastal wetlands more valuable carbon sinks than other ecosystems in a warmer world. Dagar (2003, 2008) reported 38 species of exclusive mangroves and more than 180 species of associates of mangroves (including climbers, epiphytes, ferns, etc.) from India. In India, mangroves are mostly dominated by genera like *Aegiceras,Avicennia*, *Bruguiera,* *Ceriops*, *Excoecaria,Heritiera,Lumnitzera*, *Rhizophora,* *Sonneratia,* and *Xylocarpus*. *Nypa fruticans*, a mangrove palm is frequent in Sunderbans and Andamans only. Mangrove trees have been the source of firewood in India since ancient time. Because of the high specific gravity of wood, the species of *Rhizophora*, *Kandelia*, *Ceriops,* and *Bruguiera* are preferred for firewood. *Heritiera fomes* is used for boat building, while *Avicennia* and *Rhizophora* are used for brick-burning. Species of *Bruguiera* are used to make poles. All mangrove species are rich in tannin. Honey collection from the mangrove forest is a promising business in India. It has been estimated that Sundarbans mangrove alone produce 111 tons of honey annually. Honey collected from *Cynometra ramiflora* and *Aegialitis rotundifolia* has a good market value and is in demand. *Avicennia* spp., *Phoenix paludosa*, and *Sonneratia caseolaris* are used for human consumption and as cattle feed. *Nypa fruticans* is tapped for an alcoholic drink. Leaves of *Nypa* palm are used for thatching of roofs. The uses of mangrove and associate species have been dealt in detail by Dagar (2003, 2008), Dagar et al. (1991, 1993), and Dagar and Singh (2007). Further, mangroves can possibly provide a gene bank for cultivating salt tolerant species of crops.

Backwater Farming in Kerala

The backwaters (or '*Kaayals*' in Malayalam) in Kerala are a chain of brackish lagoons and lakes lying parallel to the Arabian Sea coast (also known as the Malabar Coast). The network includes five large lakes linked by canals, both manmade and natural, fed by 38 rivers, and extending virtually half the length of Kerala state. It is estimated that the total area of these backwaters has shrunk from 440 km^2 in 1968 to 350 km^2 due to the population and extended agricultural activities (Namboothiry 2000). The nutrient-rich upland area of backwaters with perfectly balanced tropical climate is very conducive for practicing tree-based farming system. The upland backwater area with expansion of mangrove forests provides suitability for growing paddy fields and coconut (*Cocos nucifera*) based agroforestry systems which are practiced traditionally by the upland communities. The coconut plantations contain a carbon stock of about 30–70 t ha^{-1} depending on the agro-climatic and soil conditions (Ranasinghe 2012).

Cultivation of Colocasia (*Colocasia esculenta*) under the coconut trees are major economic activities in backwater area. Fruit crops

Table 10.3 Potential indigenous plant species for wetland agroforestry system based on their socio-ecological properties

Plant Species	Ecological/Agroclimatic Zone	Selection Restraints/Criteria		C Stock (t ha^{-1}) (Reference)
		Ecological Services[a]	Economic Services	
Albizia procera	TSEF; TMDF; DTF; NSBLF	Y, H	Y, L	0.95 (Ullah and Al-Amin 2012)
Alnus nepalensis	A; B; C	Y, H	Y, L	30.20 (Ranabhat et al. 2008)
Areca catechu	K; Q; R; S	N	Y, H	NA
Artocarpus heterophyllus	HT; HST; NT	N	Y, H	2.26 (Alamgir and Al-Amin 2007)
Aquilaria malaccensis	Subtropical; Sub-temperate	Y, L	Y, H	NA
Bambusa balcooa	Tropical; Subtropical; HST	Y, H	Y, H	2.22 (Nath and Das 2011)
Bambusa pseudopallida	Tropical; HT; HST	Y, H	Y, H	NA
Bombax ceiba	Tropical; Subtropical	Y, H	Y, H	0.09(Ullah and Al-Amin 2012)
Cassia fistula	Tropical; Subtropical	Y, H	Y, M	0.64(Ullah and Al-Amin 2012)
Castaniopsis indica	Tropical; Subtropical; Sub-temperate	Y, H	Y, M	0.05(Ullah and Al-Amin 2012)
Dalbergia latifolia	Tropical	Y, M	Y, L	NA
Dendrocalamus strictus	Tropical; Subtropical; Temperate	Y, H	Y, H	NA
Duabanga grandiflora	Tropical; Subtropical;	Y, M	Y, M	0.07(Ullah and Al-Amin 2012)
Eucalyptus tereticornis	Tropical; Subtropical; Temperate	Y, H	Y, M	98.27 (Devi el al. 2013)
Grevillea robusta	Warm temperate; Subtropical	Y, H	Y, H	NA
Livistona jenkinsiana	TEF; NSBLF	Y, L	Y, H	NA
Mangifera indica	Tropical; Warm temperate	N	Y, H	0.03 (Chavan and Rasal 2011)
Phyllostachys assamica	Tropical; Temperate; Assam Plains	Y, H	Y, H	NA
Piper nigrum	Tropical; Pantropical; Temperate	Y, M	Y, H	NA
Populus deltoides	Temperate; Warm temperate; Tropical	Y, H	Y, H	31.95 (Rizvi et al. 2010)

TSEF – Tropical Semi-Evergreen Forests; *TMDF* – Tropical Moist Deciduous Forests; *DTF* – Dry Tropical Forests; *NSBLF* – Northern Subtropical Broad-Leaved Forests; *TEF* – Tropical Evergreen Forests; *HT* – Humid Tropical; *HST* – Humid Subtropical; *NT* – Near Tropical

A, *B*, *C* Western, Central and Eastern Himalayas respectively. *K*, *Q*, *R*, *S* – Deccan Plateau, Bengal and Assam Plains, Western Coastal Plains, Eastern Coastal Plains respectively.

Y – Yes; *N* – No; *L* – Low; *M* – Medium; *H* – High, *NA* – Not Available.

[a] Based on the assumption of C sequestration potential of particular plant species.

like banana, mango, jackfruit, and pineapple also grown in this system. Plantation crops like cocoa and coffee are also cultivated for cash generation activities. Paddy-cum-fish cultivation (locally known as '*Pokkali*') practice is a unique traditional farming system in backwater area of Kerala. The rice crop cultivated is highly resistance to salinity and very productive without addition of manure/fertilizers.

The Way Forward

Appropriate choice of plant species is necessary for successful wetland agroforestry system. While selecting tree species for the wetland agroforestry, the factors such as adaptation to highly fluctuating flooding condition, water level, salinity, nutrient enrichment, etc. are important Planting trees for agroforestry around wetlands may help to extract and remove excess nutrients. Trees may be even more effective than some forage species, by using more extensive and deeper root systems to recapture deep leached nutrients. A major concern with growing trees in this part of the landscape is the risk of flood damage. This depends on the risk of a flood event, the duration of flooding and soil saturation, the flood tolerance of the tree species, and the expected harvest interval of the tree crop. A few potential trees for wetland agroforestry system with both ecological (mainly C storage) and economic importance have been identified (Table 10.3). A thorough surveying of woody perennials that could be managed under short-rotation forests is warranted for diversifying the species specific to different agro-climatic condition with intricate work plan, such tree-based system in wetland could yield substantial economic return while reducing management costs. Further, carbon loss from the wetlands could also be significantly balanced by the trees which capture and fix the atmospheric carbon in the form of biomass and return to the soil subsequently by decomposition. Thus, wetland agroforestry provides tremendous potential for carbon storage by balancing C between its sink and source, and help to achieve sustainable livelihoods in source rich and wet northeast India.

References

Ajai BA, Chauhan HB, Sarma KS, Bhattacharya S, Ashutosh S, Pandey CN, Thangaradjou T, Gnanppazham L, Selvam V, Nayak SR (2013) Mangrove inventory of India at community level. Nat Acad Sci Lett 36(1):67–77

Alamgir M, Al-Amin M (2007) Organic carbon storage in trees within different geopositions of chittagong (south) forest division, Bangladesh. J For Res 18(3):174–180

Arunachalam A, Khan ML, Arunachalam K (2002) Balancing traditional Jhum cultivation with modern agroforestry in eastern Himalaya-A biodiversity hot spot. Curr Sci 83:117–118

Asian Development Bank (2005) Federated states of Micronesia economic report toward a self sustainable economy. Asian Development Bank, Manila, The Philippines, Pacific Studies Series. http://www.adb.org/sites/default/files/pub/2005/fsm-economic-report.pdf Accessed on 19 Feb 2013

Athens JS, Ward JV, Murakami GM (1996) Development of agroforest on a Micronesian high island: prehistoric Kosraean agriculture. Antiquity 70:834–846

Balasubramanian D, Arunachalam A, Arunachalam K, Das AK (2011) Nutrient accumulation pattern of *Eichhornia crassipes* Mart. (Solms.) in natural wetlands with different trophic condition. In: Malik DS, Kumar S, Bharti U (eds) Water pollution and management. Biotech Books, New Delhi, pp 30–56

Gopal B (1995) Biodiversity in freshwater ecosystems including wetlands, biodiversity and conservation in India. A status report, vol 4. Zoological Survey of India, Calcutta

Butler S (ed) (2010) Macquarie concise dictionary, 5th edn. Macquarie Dictionary Publishers Ltd., Sydney

Chavan BL, Rasal GB (2011) Potentiality of carbon sequestration in six year ages young plant from university campus of Aurangabad. Global J Res Eng 11(7):15–20

Chimner RA, Ewel KC (2004) Differences in carbon fluxes between forested and cultivated Micronesian tropical peatlands. Wetland Ecol Manage 12:419–427

Chimner RA, Ewel KC (2005) A tropical freshwater wetland: II. Production, decomposition and peat formation. Wetland Ecol Manage 13:671–684

Conroy NK, Fares A (2011) A snapshot of agroforestry in *Terminalia carolinensis* wetlands in Kosrae, Fed States Micronesia 41(2):177–195

Dagar JC (2003) Biodiversity of Indian saline habitats and management and utilization of high salinity tolerant plants with industrial application for rehabilitation of saline areas. In: Alsharhan AA, Wood WW, Gouie AS, Fowler A, Abdellatif EM (eds) Desertification in the third millennium. Swets and Zeitlinger Publishers, Lisse, pp 151–172

Dagar JC (2008) Indian mangroves : Status, management and their plausible benefits for livelihood security. J India Soc Coast Agric Res 26(2):121–128

Dagar JC, Mongia AD, Bandyopadhyay AK (1991) Mangroves of Andaman & Nicobar Islands. Oxford & IBH Publishing Co. Ltd., New Delhi, p 166

Dagar JC, Singh G (2007) Biodiversity of Saline and Waterlogged Environments: Documentation, Utilization and Management. NBA Scientific Bulletin Number - 9, National Biodiversity Authority, Tamil Nadu, India, p 78

Dagar JC, Singh NT, Mongia AD (1993) Characteristics of mangrove soils and vegetation of bay islands in India. In: Lieth H, Al Masoom A (eds) Towards the rational use of high salinity tolerant plants, vol 1, Kluwer Academic Publishers, The Netherlands, pp 59–80

Deepa RS, Ramachandra TV (1999) Impact of Urbanization in the interconnectivity of wetlands. In: Proceedings of National Symposium on Remote Sensing Applications for Natural Resources: Retrospective and perspective, Indian Society of Remote Sensing, Bangalore

Devi B, Bhardwaj DR, Panwar P, Pal S, Gupta NK, Thakur CL (2013) Carbon allocation, sequestration and carbon dioxide mitigation under plantation forests of north western Himalaya, India. Ann For Res 56(1): 123–135

Dixon RK (1995) Agroforestry systems: sources or sinks of greenhouse gases. Agrofor Syst 31:99–116

DoEP (2011) Glossary. Department of Environmental Protection, state of Florida (http:www.dep.state.fl.us/evergladesforever/about/glossary.html)

Drew WM, Ewel KC, Naylor RL, Sigrah A (2005) A tropical freshwater wetland: III. Direct use values and other goods and services. Wetlands Ecol Manage 13:685–693

Forestry Paper 153 (2007) The worlds mangroves 1980–2005: a thematic study prepared in the framework of the global forest resources assessment 2005. FAO, Rome, p 77

Fang S, Xu X, Yu X, Li Z (2005) Poplar in wetland agroforestry: a case study of ecological benefits, site productivity, and economics. Wetlands Ecol Manage 13:93–104

Feller C, Albrecht A, Blanchart E, Cabidoche YM, ChevallierT, Hartmann C, Eschenbrenner V, Larre-Larrouy MC, Ndandou JF (2001) Soil carbon sequestration in tropicalareas: general considerations and analysis of some edaphicdeterminants for lesser antilles soils. Nutr Cycl Agroecosyst 61:19–31

FSI (2011) India state of forest report 2011. forest survey of India, ministry of environment and forests, government of India, Dehra Dun, pp 286

MoEF (2007) Conservation of wetlands in India: a profile. Ministry of environment and forests, government of India, New Delhi, pp56

Namboothiry SS (2000) Romancing with Kerala Backwaters. http://pib.nic.in/feature/feyr2000/fjun2000/f220620002.html Accessed 02 February 2013

Nath AJ, Das AK (2011) Carbon storage and sequestration in bamboo-based smallholder homegardens of Barak valley, Assam. Curr Sci 100(2):229–233

Patil V, Singh A, Naik N, Seema U, Sawant B (2012) Carbon sequestration in mangroves ecosystems. J Environ Res Dev 7(1A):576–583

Parikh J, Parikh K (1999) Sustainable Wetland. Environmental Governance – 2, Indira Gandhi Institute of Development Research, Mumbai

Prasad SN, Ramachandra TV, Ahalya N, Sengupta T, kumar A, Tiwari AK, Vijayan VS, Vijayan L (2002) Conservation of wetlands in India–a review. Trop Ecol 43:173–186

Ranabhat S, Awasthi KD, Malla R (2008) Carbon sequestration potential of *Alnus nepalensis* in the mid hill of Nepal: a case study from Kaski district. BankoJanakari 18(2):3–9

Ranasinghe S (2012) Potential impacts of climate change on coconut. http://climatenet.blogspot.in/2012/07/potential-impacts-of-climate-change-on.html. Accessed 02 Feb 2013

Rizvi RH, Dhyani SK, Yadav RS, Singh R (2011) Biomass production and carbon stock of poplar agroforestry systems in Yamunanagar and Saharanpur districts of northwestern India. Curr Sci 100(5):736–742

Tateda Y (2005) Estimation of CO_2 sequestration rate by mangrove ecosystem, http://criepi.denken.or.jp/en/publications/annual/2005/05juten16.pdf. Accessed on 02 Feb 2013

Ullah MR, Al-Amin M (2012) Above- and below-ground carbon stock estimation in a natural forest of Bangladesh. J For Sci 58(8):372–379