Barisal University Journal Part 1, 4(2):271-290 (207) ISSN 2411-247X

IS MANGROVE FOREST AN ASSET OR A LIABILITY?: A REVIEW

M Hasinur Rahman*

Department of Soil and Environmental Sciences, The University of Barisal, Barisal 8200, Bangladesh

Abstract

Background: Mangroves are intertidal wetland forests which could be considered as an "eco-efficient agro-forest" since they grow in marginal soils (viz. acid sulfate soils, saline soils, sodic soils, contaminated soils, swamp and marsh soils, intermittent submerged soils etc.) without any agricultural inputs. **Objectives:** This review discloses current status of mangrove forests, elucidates the services and functions provided by mangrove forests to the human society, marine and coastal ecosystems and states the obligation of conservation of mangrove forests. **Results:** Despite the great impact on environment the mangrove forests in tropical and subtropical regions are declining sharply. The tidal mangrove forests inhabit the interface between land and sea, and reduce the risk of waves, tsunamis as well as storm surges. This biologically significant mangrove forests act as usual barriers, also provide nursery grounds and breeding sites for marine and pelagic species, supply woods and sustain accumulation of sediments, nutrients and contaminants. Biodiversity conservation and management as well as biotechnological potential of mangrove forests are well documented. Mangroves contribute to a significant degree of terrestrial and marine carbon sequestration and consider as a dynamic ecotone between terrestrial and marine habitats. In salt water marshes, epiphytic red algae and mangrove interaction have produced the mycosporine like amino acids, which are considered to be biochemical photoprotectants against exposure to UV radiation. Mangrove grows in salt water marshes are subjected to influx of ions except sodium and chloride. Alternatively, mangroves growing in brackish waters have special uptake mechanism for inorganic salts. While halophytic mangroves are under water stress, they inactivate uptake or storage of inorganic sulfate present in sea water, through conjugation with phenolic compounds, particularly with flavonoids in plants. Mangrove species can produce novel metabolites which help to regulate salts and accumulate or synthesize other solutes to maintain osmotic balance. **Conclusions:** The mangrove forests have positive impact on managing and/or reclamation of problematic soils like acid sulfate soils, saline soils, sodic soils, contaminated soils in seashore and deterioration of these forest associations may negatively influence the terrestrial and marine ecosystems. However, a few environmental scientists still considered mangrove ecosystem as swamps which is very unhygienic, inhospitable and dangerous as many harmful animals lived into there. It is therefore very important to do 'pros and cons' analysis on mangrove forests and mangal associates which has not been conducted yet.

Keywords: Agro-forest, Carbon sink, Eco-efficient, Ecological stability, Global estimator, Mangrove forest, Secondary metabolites.

1. INTRODUCTION

The mangrove forests are located in the intertidal region between the land and the sea. Macnae (1968) first introduced the provisos ‘mangrove’ and ‘mangal’ to quote ‘plants’ and ‘mangrove plant communities’, respectively. Mangroves are biologically diverse forests composed of 9 orders, 20 families, 27 genera and approximate with 70 species (Alongi, 2002). Mangrove forests can extend irrespective of agro-ecological zones. Nevertheless, tropical mangroves differ from temperate mangroves with their distinct ecology and physiology (Ellison, 2002). Mangrove forests are well established between 30°N and 30°S with few exceptions in Bermuda (32°20′N), Japan (31°22′N), Australia (38°45′S), New Zealand (38°05′S) and South Africa (33°04′S). About one-fourth of mangrove forests located in North and Central America (15%) and South America (11%) (Giri et al., 2011). Mangrove forests grow on marginal soil without any agricultural inputs (viz. seeds, fertilizers, pesticides, insecticides, water management, agro-implements, phytohormones etc.) Mangrove forests grown on the tidal flats of wide range of soils viz. mineral soils (sulfaquents, organic soils (sulfafemists), acid sulfate soils, and saline soils associated with bioclastic and coralline sands. Sediments along with mangrove forests are mostly saline with brown or reddish brown mottles when leached at the surface. Seaward mangrove forests are generally grown on acid sulfate soils which contain iron sulfides (Lacerda et al., 2002). The mangrove forests are important ecosystems as they (i) provide important and unique ecosystem goods and services to human society and coastal and marine systems (ii) protect shorelines (iii) reduce the devastating impact of natural disasters (iv) provide breeding and nursing sites for marine and pelagic species, (v) catch metals and nutrients, (vi) trap sediments (vii) supply food, medicine, fuel and building materials for local communities (Giri et al., 2011). Intense mangrove forests have significantly contributed to guard human habitation, lives, properties and agricultural crops next to the coastline commencing extreme weather events resulting from climate change (Rahman et al., 2015).

Mangroves forests play potential role in carbon cycle and recognised as carbon sink. Studies conducted by Dittmar et al. (2006) stated that mangrove forests could sequester approximately 22.8 million metric tons of carbon each year including associated soils. In contrast, mangrove areas have been declining sharply and their long-term survival is at great risk (Duke et al., 2007). Mangroves growing in or near the sea or in salt water marshes are subjected to influx of other ions besides sodium and chloride and it is conceivable that adaptation to other inorganic salts present in brackish waters may be necessary for survival of plants in such habitats. One such ion present in sea-water in some quantity is inorganic sulfate; one possible route for inactivation or storage is through conjugation with naturally occurring phenolic compounds, and particularly with flavonoids and remarkably enough, such compounds occur principally in plants which are subject to water stress, and especially in halophytic mangrove. Even some mangrove species synthesize few nitrogen compounds, the protein amino acid proline and the quaternary nitrogen compound glycine betaine which help to regulate salts and accumulate or synthesize other solutes to maintain osmotic balance (Bandaranayake, 2002).

Recently, scientists have examined the importance of mangrove forests on plant diversity for ecosystem stability in terrestrial ecosystems, especially grasslands where the dominant vegetation lies low to the ground and is easy to manipulate experimentally. Stability was conferred by species richness, both within and among functional groups (Wardle et al., 2000). Therefore, this review will give a brief momentous of mangrove forests on terrestrial and marine ecosystems with the special emphasis of its existence and protective capacity, biodiversity conservation and management, carbon sequestration in mangrove ecosystems, and their socio-economic values.

2. PAST, PRESENT AND FUTURE STATE

On the Global scale, mangrove forests have been declining very sharply. FAO estimated 18.8 and 15.2 m ha of mangroves in 1980 and 2005, respectively (FAO, 2007a). According to the survey report of FAO, 3.6 m ha of mangrove has lost in worldwide which stand for around 20% loss of mangrove forests within 25 years. Defying the size, Bangladesh have the world’s largest uninterrupted tidal halophytic mangrove forests named as Sundarbans is reduced to the area of about 6,000 sq km from 6500 sq km within the last two decades. The Chakaria Sundarbans in Bangladesh was established in 1903 with a command area of 8510 ha which was considered as one of the oldest mangrove forests in the subcontinent has been cleared due to the heavy human interference in 1996 (Hossain et al., 2008). If the present rate as well as trend of loss continues then the existing mangroves could be lost in next hundred years. Mangrove forests decrease is proportional to the increase in population as the subsequent demand of foods and shelter increases (Alongi, 2002). Apart from this, factors such as flooding, land reclamation, sedimentation, pollution, saline water intrusion due to sea water level rise, expansion of commercial navigation as well as commercial activities and lack of agitation are responsible for the disappearance of mangrove forests. The disappearance of mangroves definitely have pessimistic impact on the atmospheric composition and climate change and on transfer of materials into the marine (Giri et al., 2011) and terrestrial ecosystems. However, there is a quantitative research gap on how mangrove forests loss alters the ecosystem function in marine and terrestrial ecosystems as well as mangrove themselves.

3. NATURAL BARRIER AND PROTECTIVE CAPACITY

Due to abrupt climate change natural challenges are becoming more frequent and devastating worldwide and it is well known that mangrove forests protect those natural calamities by acting as a buffer zone. It is well documented that these natural disasters have already killed millions of people and still billions of people are currently living with a high risk. The Indian Ocean tsunami that took place on 26 December 2004 causing the loss of about 225,000 people and the destruction of property costing millions of US dollars was particularly one of the worst events in the account of natural calamities. Although the magnitude of the tsunami waves was high along the affected coasts, human losses and the amount of damage to inland property and infrastructure were less in healthy mangrove or coastal forests areas like in Nicobar and Andaman Islands and few places of Tamil Nadu, India (Osti et al., 2009). The protective power of mangrove forest has been well documented in the event of Indian Ocean tsunami in 26 December 2004. Effective mitigation of such disasters is possible via healthy coastal forests, which can reduce the energy of tsunamis. In recent years, mangrove forests which work as the natural barriers have declined due to adverse human and natural activities. It is essential to recover them to use as a natural barrier against a tsunami and, in addition, as a resource to obtain optimum ecological, socio-economic, and environmental profits (Osti et al., 2009). The role of mangrove forest in mitigating the outcomes of a tsunami disaster, especially in 2004, is covered in the study by Selvam (2005). His laboratory experiments showed that 30 trees per 100 square metres might reduce the maximum flow of a tsunami by more than 90 per cent. A numerical simulation of Hiraishi (2005) as well showed that the reduction of tsunami flow pressure by increasing the density of the planted zone. Kathiresan and Rajendran (2005) used linear regressions to identify the value added by mangrove forests in reducing per capita mortality in India due to the 2004 tsunami.

Based on the 1998 tsunami that destroyed parts of the north coast of Papua New Guinea a model simulation was made to predict the attenuation of tsunami energy by mangroves (Hiraishi and Harada, 2003). The model output suggests a 90% reduction in maximum tsunami flow pressure for a 100-m wide forest belt at a density of 3000 trees ha^{-1}. Model results obtained by Harada and Imamura (2005) for various types of coastal vegetation, including mangroves, were very similar. Tanaka et al. (2007) modelled the relationship of species specific differences in drag coefficient and in vegetation thickness with tsunami height, and found that species differed in their drag force in relation to tsunami height, with the palm, *Pandanusodo ratissimus*, and *Rhizophora apiculata*, being more effective than other common vegetation, including the mangrove *Avicennia alba*. These data point to the importance of preserving or selecting appropriate species to act as wave barriers to offer sufficient shoreline protection.

Mangrove forests can attenuate wave energy, as shown by various modelling and mathematical studies (Quartel et al., 2007). They concluded that the magnitude of the energy absorbed strongly depends on forest density, diameter of stems and roots, forest floor slope, bathymetry, the spectral characteristics (height, period, etc.) of the incident waves, and the tidal stage at which the wave enters the forest. Mazda et al. (2006) found that waves were reduced in energy by 50% within 100 m into Sonneratia forests. They also showed that another important factor is vegetation type, for example, the percentage of forest floor area covered by either prop roots or pneumatophores, as the drag coefficient of these structures is related to the Reynolds number which differs for each species depending on diameter and aboveground root architecture.

4. BIODIVERSITY AND BIOTIC-ABIOTIC PROCESSES

Mangrove forests have direct as well as indirect impact on conservation and management of biodiversity and it is proved by the scientists that due to climate change there is a dreadful loss on biodiversity and extinction of species have already been occurred worldwide. Species diversity has very strong impact on ecosystem functioning through productivity and stability by sharing different resources. Stability of any ecosystem was conferred by the species richness between and among the functional groups (Wardle et al., 2000). Scientists have raised the necessity of plant diversity for ecosystem stability in terrestrial ecosystems. Mangroves provide protective habitat for spawning, nursery, and feeding ground for juvenile fish and crustacean species that spend part of their lives in these habitats. Mangroves contribute many different functional ways to fisheries. These include contributing nutrients to support an elaborate food web within the mangroves, exporting-derived nutrients offshore to enhance fisheries, or providing habitat to fauna for shelter and nursery grounds (Robertson et al., 1992). Mangroves also provide shelter to a wide variety of mammals, amphibians and reptiles. Many other animals such as birds, marine and terrestrial mammals use or visit the mangroves for roosting, nesting, or feeding on a daily or seasonal basis. Wetlands biodiversity is influenced by factors ranging from the evolutionary history to the current environmental pollution and pollutants. Gopal (2006) predicted that various socio-cultural, economic and political factors may affect the biodiversity directly as well as indirectly. Mangrove forests may alter abiotic factors including sedimentation rate, organic matter content in sediments, temperature, light intensity and nutrient availability which may change in turn impact associated mangrove communities and adjacent habitats (biotic factors). Granek and Ruttenberg (2008) stated that even a small scale clearing of mangrove forests showed significant changes in the abiotic and biotic conditions of the local environment. Abiotic and biotic factors can alter mangrove forests through the changes of the microbial community structure and composition. Plant species diversity can lead to increase the number of microbial species richness and expand their composition. Species diversity and specific species traits control the decomposition rate and nutrient turnover as different species utilize their resources with different magnitudes and times. The factors involved are shown in Fig. 1.

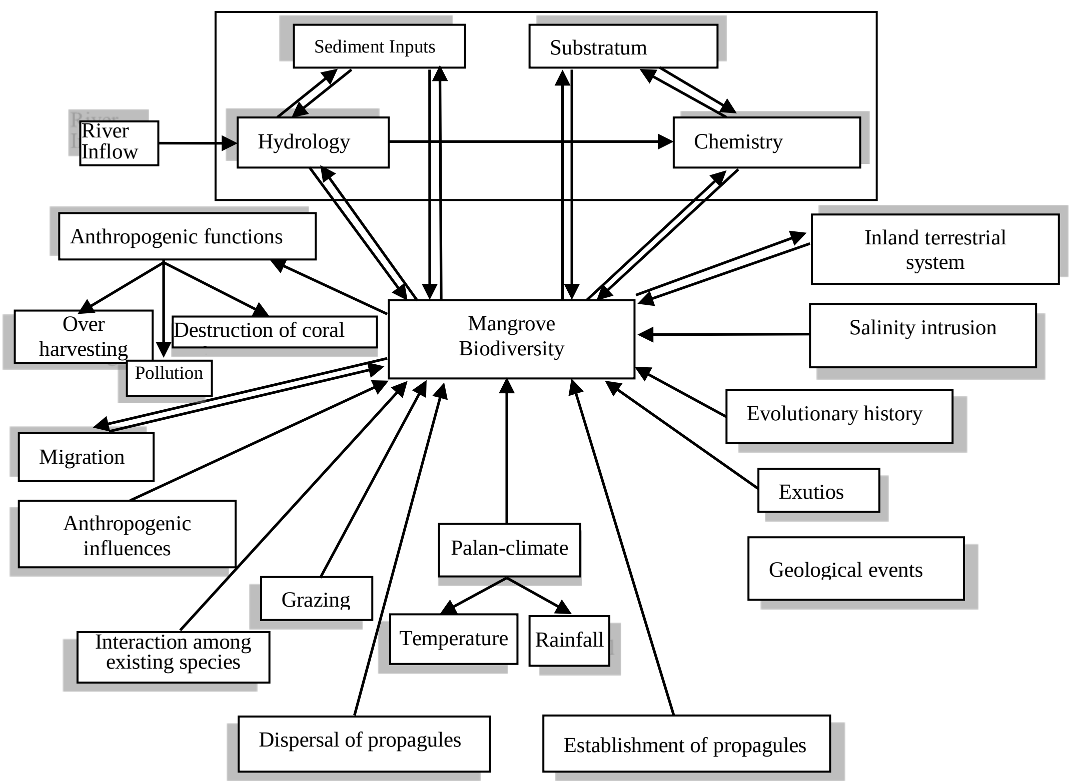

Fig. 1. Factors affecting biodiversity in mangroves (modified from Gopal, 2006).

5. BIOMASS GENERATION

Mangroves are rapid growing plants of marginal lands. Measurement of the biomass (both for above-ground and below-ground) of mangroves is quite difficult as they are not in homogeneous conditions. Biomass quantification is therefore based on indirect methods. Biomass production depends on factors including plant itself (plant species, ecotype etc.) and their growing media and macro- and micro-climates. Woodroffe (1985) estimated above ground biomass of *Avicennia marino* of Tuff Crater basin in New Zealand was 104.1 t ha^{-1} and 6.8 t ha^{-1} for more than 4 m and less than 1 m tall trees, respectively, with an average of 55.5 t ha^{-1}. Study confirmed that the standing above ground biomass of *Rhizophora apiculata* was 159 t ha^{-1} in Thailand (Puket Island) mangrove forests (Christensen, 1978). In Malaysia, above ground biomass accumulation for *R. Apiculata* ranged from 270 to 460t ha^{-1} with a mean of 409 t ha^{-1} (Putz and Chan, 1986). Studies in different mangrove forests of Malaysia indicated that standing above ground biomass in Matag mangrove (*Rhizophora apiculata*) was 185.3 t ha^{-1} (Gong and Ong, 1990), in Pulau Langkawi (*Bruguiera parviflora*, *Rhizophora mucronata*, *Bruguiera gymnorrhiza*, *Ceriops tagal and Xylocarpus granatum)* was 115.6 t ha^{-1} (Norhayati and Latiff, 2001), in Kuala Selangor (*Bruguiera parviflora*) was 144.5 t ha^{-1} (Hossain et al., 2008). In contrast, Khan et al. (2009) estimated 80.5 t ha^{-1} of above ground biomass for mangrove forests (*Kandelia obovata)* in Okinawa, Japan. It is more difficult to measure below ground biomass compared to the above-ground biomass. Therefore, a few studies estimated both above- and below-ground biomass in mangrove forests. Komiyama et al. (2000) estimated the above- and below ground biomass of *Ceriops tagal* in southern (Satun) Thailand and found 92.3 and 87.5 t ha^{-1}, respectively. For *Avicennia germinans* in south-western Florida, the above- and below-ground biomass was178.2 and 146.3 tha^{-1}, respectively (Twilley, 1982). Limited data sets as discussed above concluded that the biomass production depends on mangrove species as well as ecological zones. Irrespective of ecological zones, the above ground biomass was in the order of *Rhizophora apiculata>Avicennia germinans>Bruguiera parviflora>Ceriops tagal>Kandelia obovata>Avicennia marino.* On the other hand, regardless of species mangrove forests in Malaysia stand the highest above ground biomass followed by USA south-western, Thailand and Japan, and lowest was in New Zealand. Research results as well indicated that irrespective of mangrove species and ecological zone the above ground biomass is more than below ground biomass. As stated by Twilley et al. (1992), the dispersal of biomass accumulation all over the tropical regions indicated that elevated values occur at lower latitudes. As biomass production inversely related to latitude a regression model was fitted as $Y = -7.291X + 298.5$ ($R = 0.75$), where X is latitude and Y is predicted biomass in Mg ha^{-1}. Cintrón and Schaeffer-Novelli (1984) found a significant positive correlation between latitude and tree height they established a regression equation as: Y = 45.8-1.28X (r^2 = 0.75); where Y is the tree height in meter and X is latitude north or south. Cintrón et al. (1978) found that tree height of Puerto Rico mangroves is inversely related to soil salinity by the equation: Y = -0.20 + 16.58 (r^2 = 0.72); where X is soil salinity in ppt and Y is the tree height in meter. All these models are based on species-specific within definite ecological zones. It is therefore necessary to do validity test of those models before apply to any other mangrove forests. More precisely multiple regression model should be developed including as many as factors involved in mangrove forest ecosystems.

6. BIOMASS CONTENT, LITTER SYSTEM AND CARBON SEQUESTRATION

Seasonal changes have a significant influence on above-ground biomass deposition as well as their decomposition. Mangrove forests are widely recognized for litter production, carbon and nutrient cycling and contribution to the food chain through leaf detritus pathway in coastal and marine ecosystem. The rate and variability of litter export and detritus in mangrove zones can be affected by species, tidal height, rainfall, feeding activities of marine invertebrates, temperature (Woitchik et al., 1997). The carbon and nutrient cycle is depends on litter decomposition process. The potential carbon sequestration highly dependent on litter quality as well as microbial community structure and composition involved in litter system. Litter qualities vary with carbohydrate, lignin, acid detergent fibre, phenol-protein complexes, tannin, amino acids, fatty acids, triterpenoids etc. Additionally, during litter systems the specific microbial community have specific respiration pattern for producing specific organic and organo-mineral compounds which may enhance or reduce the litter decomposition rate.

Marine ecosystems considered as a massive reservoir for carbon sink. The huge amount of blue carbon is captured by marine ecosystems which represent more than 55% of green carbon or biological carbon captured globally. The carbon captured by living organisms in marine ecosystems is stored in the form of biomass and sediments from mangrove forests, salt marshes and sea grasses. Some 93% of the earth's CO_2 (40 Tt) is stored and cycled through the oceans. The ocean's vegetated habitats, in particular mangroves, salt marshes and sea grasses, cover <0.5% of the sea bed. These create earth's blue carbon sinks and makeup more than 50%, possibly a maximum of 71%, of all carbon storage in ocean sediments. Although they encompass only 0.05% of the plant biomass on land, they stock a comparable amount of carbon each year and therefore rank among the most strong carbon sinks on the planet (Nellemann et al., 2009).

Mangrove forests play an important role for carbon assimilation and turn to sinks. The carbon assimilation depends on litter system (i.e. quality of litter inputs, accumulates and decomposes). Wood or leaf based and grassy inputs differing with physic-chemical composition. Therefore, carbon cycle in mangrove forests is species specific. In AoSawi mangrove forests, Thailand, Alongi et al. (2001) found that carbon mineralization ranged from 7.0 to 16.4 mol C m^{-2} $year^{-1}$. Above-ground biomass, surface litters, below-ground biomass and soil function as carbon store in mangrove ecosystems. Alongi (2012) stated higher below- and above-ground carbon mass ratios in mangroves compared to terrestrial trees. Mangroves are among the most carbon-rich biomes, containing an average of 937 t C ha^{-1}, which facilitate fine particles and sediment accumulation (~5mm yr^{-1}). Mangroves account for only approximately 1% (13.3 Gt C yr^{-1}) of carbon sequestration by the world's forests but as coastal habitats they account for 14% of carbon sequestration. Green-house gas emission may acutely increase with mangrove carbon stocks disturbance. There is lack of research for inorganic carbon investigations in mangrove forests.

Simple model for the carbon cycle is shown in Fig. 2 as from Smith and Smith (2003).

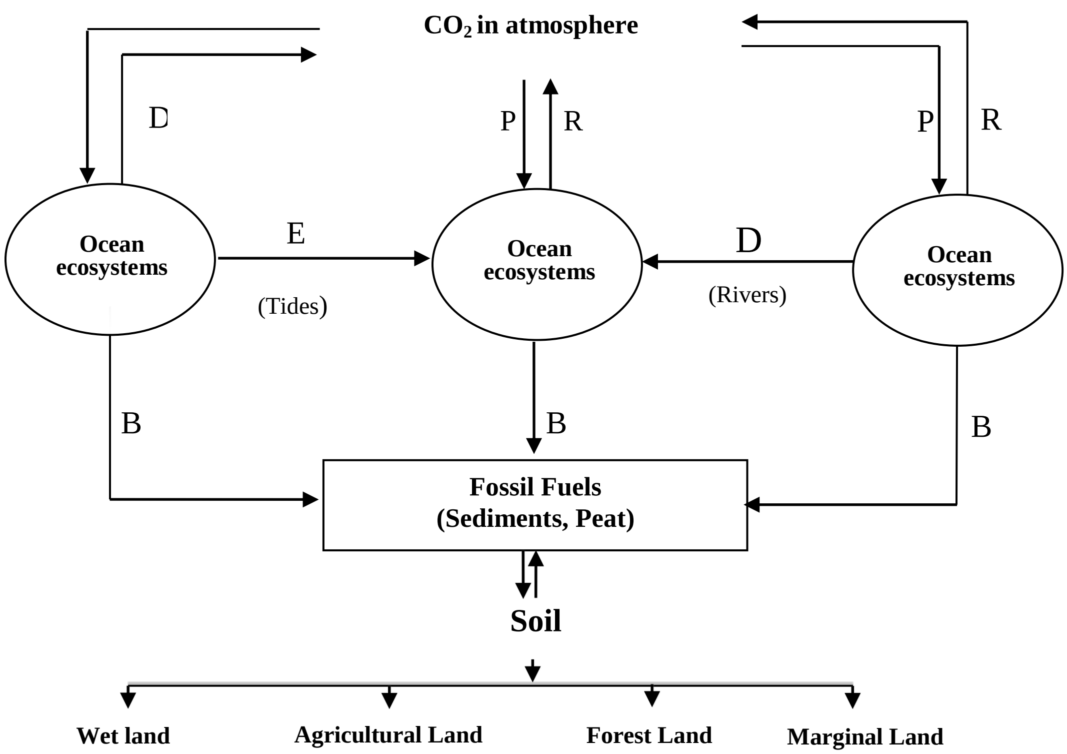

Fig. 2. A simple model for the carbon cycle in ocean, coastal and terrestrial ecosystems (D = diffusion, P = photosynthesis, R = respiration, E = exchange, B = burial).

The carbon stored depends on vegetation types and salinity zones. The Sundarban, a single uninterrupted largest mangrove forest in the world where the Sundri (*Heritiera fomes*) forest types stored 360.1 ± 22.71 Mg C ha^{-1}, which is the highest among the other vegetation types (Rahman et al., 2015). Coastal waters constitute only 7% of the total area of the ocean. Nonetheless the productivity of ecosystems such as coral reefs, and these blue carbon sinks mean that this small area creates the centre of the world's primary fishing grounds, providing an assessed 50% fishery of the world. They provide vital nutrition for close to 3 billion people, as well as 50% of animal protein and minerals to 400 million people of the least developed countries in the world. Some 93% of the earth's CO_2 (40 Tt) is stored and cycled through the oceans. Maintaining or improving the ability of forests and oceans to absorb and bury CO_2 is a crucial aspect of climate change mitigation. The contribution of forests in carbon sequestration is well recognized and is braced by relevant financial mechanisms as well as the land management system is the key factor for organic carbon stock (Rahman, 2017). However, the serious role of the coastal land management in carbon stock has been ignored all over the world.

7. MANGROVE FORESTS AND ACID SULFATE SOILS MANAGEMENT

Acid sulfate soils are of major concern throughout the world and particularly in Australian environment and economy. This problematic soil covered approximately 21.5 million ha all over Australia, of which around 27% is coastal acid sulfate soils and 73% is inland acid sulfate soils (Alongi, 2002). Acid sulphate soils in Bangladesh covering an area of about 0.23 million ha (FAO, 1988). Acid sulfate soils produce sulfuric acid when exposed to air. Consequently, this acid causes dissolution of other minerals in soil, and releases iron, aluminium, manganese and zinc, which are detrimental to the environment, deteriorate water quality, and harmful for the ecology. These soils are generally unproductive as well due to soil acidity, salinity, aluminium, iron and hydrogen sulfide toxicity, low content of phosphorus, and other mineral nutrients. However, mangrove forests being eco-coefficient agro-forest grow naturally in acid sulfate soils (a marginal land) with zero inputs. Acid sulfate soils management under mangrove forests are different from those of other soils and crops, and will have an important impact to enhance and/or maintain soil carbon stocks in Mediterranean climate compared with other regions. There is research potential for evaluating carbon storage in acid sulfate soils under mangrove forests which might be needed to participate in carbon trading schemes. Therefore research should be focused on whether acid sulfate soils are carbon source or sink under mangrove ecosystems. Investigating acid sulfate soil carbon stock requires (i) selection of proper sampling techniques (depth increment or genetic horizon) and strategies (maximum soil depth, position and spatial dimension of sampling) (ii) adopt the most appropriate method and what factors should be considered when selecting the method (iii) ability to understand the spatio-temporal distribution of soil organic carbon as well as inorganic carbon (iv) knowledge on microbial transformations of soil organic carbon and nitrogen (v) monitor vegetations and litter systems and analysis of their carbon content and (vi) establish surveillance site and baseline benchmarks. We have intention to test our thoughts and validate those recommendations on acid sulfate soils under mangrove ecosystems in the southern Australia and other regions in Australia. The work will also (i) demonstrate the impact of mangrove forests on the net carbon storage in acid sulfate soils (ii) managing acid sulfate soil and groundwater during development, and mitigating the impacts and (iii) disseminate the guidelines for economically and environmentally sustainable carbon storage in acid sulfate soils. Mangrove forests grown on the tidal flats of wide range of soils viz. mineral soils (sulfaquents), organic soils (sulfafemists), acid sulfate soils, and saline soils associated with bioclastic and coralline sands. Sediments along with mangrove forests are mostly saline with brown or reddish brown mottles when leached at the surface. Seaward mangrove forests are generally grown on acid sulfate soils which contain iron sulfides. Mangrove grown on soils under strong reducing conditions with redox potential indicating strong anaerobiosis due to oxygen depletion by bacterial oxidation of organic matter. As soil metabolism is dominated by sulfate reduction under strong reducing condition resulting in sulfide formation. The sulfide will precipitates as framboidal pyrite in mangrove soils which may responsible for the accumulation of huge amount of sulfide forming metals in mangrove ecosystems in Australian (Lacerda, 1998; Lacerda et al., 2002).

8. GREENHOUSE GAS EMISSIONS

Anthropogenic activities release significant amount of greenhouse gases viz. carbon dioxide, nitrous oxide and methane to the atmosphere. Methane (CH_4) is one of the important greenhouse gases that contribute to a rise in global mean surface temperature. Methane is produced during the fermentative (oxygen-deprived condition) breakdown of organic materials. Wetland plant ecosystems (like mangrove forests) emit significant quantities of methane. Methane emissions in agricultural systems can be controlled by improved water management and keeping soil dry. However, all those practices are impossible to apply on mangrove forests. It is therefore, very important to quantify the methane emissions in mangrove forests and take necessary action to reduce methane emission. Lindau et al. (1993) indicated that methane emissions from mangroves show large variability due to the complexity of environmental factors. Salinity and sulphate are the major inhibitors of methane production as they stimulate the activity of sulphate reducing bacteria (Bartlett et al., 1987). Soil texture is responsible for transferring and trapping methane and affects the net methane emission in reduced soil (Le Mer and Roger, 2001). Moreover, methane production and emission from the subsurface to the atmosphere is strongly influenced by soil temperature (Dunfield et al. (1993). Studies conducted in South India (Purvaja and Ramesh, 2001) and south-eastern coast of Puerto Rico (Sotomayor et al., 1994) mangrove forests indicated that methane emission rate ranged from 0.0473 to 0.3245 g m^{-2} day^{-1} and 0.0004-0.0082 g m^{-2} day^{-1}, respectively. Lekphet et al. (2005) stated theseasonal variation of emission rate with the highest in the rainy season, followed by summer and cold seasons, and their estimated values were 0.00052, 0.00027, and 0.00019 g m^{-2} day^{-1}, respectively, in Ranong Province, Thailand. They reported that these seasonal variations were as a result from water conductivity, soil temperature, and water level etc. Lyimo et al. (2002) observed that the methane emission rate was 0.0-0.0192 g m^{-2} day^{-1} in Mtoni mangrove sediments in Tanzania. Some studies found that methane emissions from mangrove were considered to be negligible (Alongi et al., 2001).

Above research data revealed that Indian (average of 0.1859 g m^{-2} day^{-1}) mangrove forests emitted highest methane followed by Tanzania (average of 0.0096 g m^{-2} day^{-1}) and Puerto Rico (average of 0.0043 g m^{-2} day^{-1}), and the lowest was in Thailand (average of 0.00033 g m^{-2} day^{-1}). It is clear from the research that greenhouse gas emissions from mangroves showed large variability. Additionally the greenhouse gas emission from mangrove forests might depends on (a) season and water conductivity, (b) soil/sediment texture and density, temperature and nutrient contents (c) redox potential of sediment and water (d) DO, BOD and COD of sediment and water (e) vegetation types: species and ecotypes, (f) physical structure and chemical characteristics of litters (g) type of microbial communities active in litter systems, and (h) growing seasons and ecological zones. Introducing appropriate plant species and microbes interaction can mitigate methane emissions in mangrove forests.

9. BIOCHEMICAL POTENTIALITY

Large number of mangrove plants have been using as folklore medicine. Numerous secondary metabolites are synthesised in mangrove plants which have proven activity against human, animal and plant pathogens. Aliphatic alcohols, amino acids and alkaloids, carbohydrates, carotenoids, hydrocarbons, polyunsaturated fatty acids, lipids, pheromones, phorbol esters, phenolics, steroids, triterpenes and tanins have been characterised from mangrove plant or plant parts (e.g. bark, leave, stem, root, flower, fruit, seed, and latex). All these secondary metabolites are commonly used by mangrove dwellers for medicines (Rollet, 1981). Numerous scientists disclosed the different medicinal properties of mangrove plants. Some of those that are important in this review include *Aegiceras* spp. which has traditionally been used for the treatments of asthma, diabetes, fish poisoning, haemataria, leprosy, heumatism and ulcers (Hsieh et al., 2000). *Avicennia* mangrove species are being used to treat different diseases viz. antifertility, skin disease, snake bite, blood purifier, small pox (Ito et al., 2000). *Derris uliginosa* has anti-haemorrages effects (Meow-Chang and Choo-Loh, 1987). The flowers and leaves of *rhizophora lamarckii* is used for the treatment of hepatitis (Rollet, 1981). *Rhizophora* mangle is being used to treatment of boils fungal infection, diarrhoea, dysentery, elephantiasis malaria tuberculosis and antiseptic (Williams, 1999).

10. NATURAL CAPITAL & SOCIO-ECONOMIC CONTRIBUTION

The indigenous and local people have been traditionally utilized mangrove forests for a variety of purposes in all over the world (World Resources Institute, 2000). They have been dependent on mangrove forests for their timber for construction, firewood, shelters, charcoal, poles, fishing gear, honey, pulp and tannin, and traditional medicines from many parts of the plants (Bandaranayake, 1998). Yaṅez-Arancibia et al. (1985) have showed a clear positive correlation between commercial finfish catches and the total area of mangrove forests in the Gulf of Mexico. The world's mangrove forests are economically very valuable and Costanza et al. (1998) estimated the economic value worth as US$ 180 895 923 000. Janssen and Padilla (1999) compared the costs and benefits of mangrove conservation with those generated by various alternative plans of aquaculture and forestry. A comparison of net annual benefits of goods and services provided by mangroves indicates that aquaculture generates the greatest value at US$ 6793 ha^{-1} yr^{-1}, followed by forestry of US$ 150 ha^{-1} yr^{-1}, and fisheries of US$ 60 ha^{-1} yr^{-1}.

11. REASON BEHIND DETORIATION OF MANGROVE FOREST

Mangrove forests have been losing gradually are well acknowledged by numerous scientists (Erftemeijer et al., l989; Fernandez, 1978; Hussain and Acharya, 1994; Mastaller, 1989; Mastaller, 1996; Ross, 1974). The natural as well as man-made activities are the main reasons to reduce mangrove forest. The main causes of mangrove forest degradation are as follows:

1. Natural-induced
    - i. Natural disasters (storms, tsunami, cyclone, surges etc.)
    - ii. Pests and diseases (*Hetiteira fomes* die-back, pathogenic gall cankers, caterpillars etc.)

iii. Climate change (increased soil salinity due to reduced water flow, rising temperature, reduction in periodic inundation, excessive flooding, sedimentation, nutrient imbalances etc.)

iv. Invasion of exotic species (e.g. Nipa palm: *Nypa fruticans*)

2. Man-made activities

   i. Urbanization

   ii. Agriculture

   iii. Constructing embankments

   iv. Aquaculture practices

   v. Cutting for timber, fuel and charcoal

   vi. Prevention of freshwater flow and tidal flow

   vii. Over grazing of buffaloes, sheep, goats and camels

   viii. Pollution

   ix. Mining operations

   x. Social activities

12. RESEARCH GAPS AND CONCLUSIONS

The important tropical and subtropical natural capitals, mangrove forests are declining worldwide due to anthropogenic activities which can change terrestrial and marine ecosystems into undesirable direction by altering temperature, evapotranspiration, light penetration, nutrient and organic matter cycling, and macro-and micro-faunal community structure and composition. There are no species-specific studies on (i) protective capacity of natural calamities (ii) biodiversity conservation and management (iii) carbon stock and sequestration (iv) carbon footprint and life cycle analysis (v) and socio-economic values of mangrove forests with special reference to ecological zones. Mangrove forests are economically very viable and most of them are highly productive which can assimilate more carbon from the atmosphere. It is therefore an asset in stabilizing ecosytems. Mangroves are used for a wide variety of items, such as timber, poles, food, medicines etc. Shoreline ecology and commercially viable coastal food chain are supported by mangroves. Mangroves and adjacent environments have a strong ecological tie, hence, require a sustainable management. Therefore mangrove forests could be considered as a global estimator for ecological stability and carbon sink. Cost-benefit analysis of forest management options (Ruitenbeek, 1994) indicated links among fishery production, mangrove use and clearance rates, erosion control and biodiversity, and mentioned that clear-felling of mangroves is a viable management option only when all the linkages are ignored, thus the mangrove forests is not a liability but an asset.

Mangroves are under increasing stress from anthropogenic pollutants (Tam and Wong, 1993). In-depth knowledge of nutrient cycling and factors influencing these pathways will help us to understand nutrients and heavy metals accumulation in coastal ecosystems. Future research needed to concentrate to leaf-scale processes and attributes, plant-scale processes and attributes, stand-scale processes and attributes, soil and environmental factors, plant-soil-microbial relations, species diversity, root production and respiration, and plant-soil carbon dynamics in mangrove ecosystems.

A large number of studies and research significantly enriched our knowledge about mangrove systems and related biogeochemical processes. However, there is still lack of information based on practical research and shortage of long-term data to find human and environmental impacts on mangroves in relation to abrupt climate change. A sound knowledge of biogeochemical processes and the factors influencing mangrove systems is very important for proper restoration success. Extensive research is required to identify the site-specific as well as species-specific mangrove forests management and conservation for better management of natural disasters in marine and terrestrial ecosystem. Moreover, it is vital for the people and governments to develop widespread agitation for mangroves as an “eco-efficient agro-forest”. Conversely fallacious conservation and management programme of mangrove forests based on total negligence could cause severe socio-economic and ecological consequences for decades.

References

Alongi, D. M. 2002. Present state and future of the world’s mangrove forests. Environmental Conservation. **29:**331-349.

Alongi, D. M. 2012.Carbon sequestration in mangrove forests. Carbon Management. **3:**313-322.

Alongi, D. M., G. Wattayakorn, J. Pfitzner, F. Tirendi, I. Zagorskis, G. J. Brunskill, A. Davidson, and B. F. Clough. 2001. Organic carbon accumulation and metabolic pathways in soil of mangrove forests in Southern Thailand. Marine Geology. **179:**85-103.

Bandaranayake, W. M. 1998. Traditional and medicinal uses of mangrove forests. Mangrove and Salt Marsh. **2:**133-148.

Bandaranayake, W. M. 2002. Bioactivities, bioactive compounds and chemical constituents of mangrove plants. Wetlands Ecology and Management. **10:**421-452.

Bartlett, K. B., D.S. Bartlett, R.G. Harris and D.I. Sebacher. 1987. Methane emissions along a salt marsh salinity gradient. Biogeochemistry. **4:**183-202.

Christensen, B.O. 1978. Biomass and primary production of *Rhizophora apiculata* BL. in a mangrove in southern Thailand. Aquatic Botany. **4:**43-52.

Cintrón, G. and Y. Schaeffer-Novelli. 1984. Caracteristcas y desarrollo structural de los manglares Norte y Sur America. Programa Regional de Desrrollo Cientificoy Technologico. **25:**4-15.

Cintrón, G., A.E. Lugo, D.J. Pool and G. Morris, 1978. Mangroves of arid environments in Puerto Rico and adjacent islands. Biotropia. **10:**110-121.

Costanza, R. R., R. d'Arge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton, and M. van den Belt. 1998. The value of the world's ecosystem services and natural capital. Ecological Economics. **25:**3-15.

Dittmar, T., N. Hertkorn, G. Kattner and R.J. Lara. 2006. Mangroves, a major source of dissolved organic carbon to the oceans. Global Biogeochemical Cycles. 20:1,GB101210, doi:10.1029/2005GB002570.

Duke, N. C., J.-O. Meynecke, S. Dittman, A.M. Ellison, K. Anger, U. Berger, S. Cannicci, K. Diele, K.C. Ewel, C.D. Field, N. Koeam, S. Y. Lee, C. Marchand, I. Nordhaus and F. Dahdouh-Guebas. 2007. A world without mangroves? Science. **317:**41-42.

Dunfield, P., R. Knowles, R. Dumont and T. R. Moore. 1993. Methane production and consumption in temperate and sub artic peat soils: Response to temperature and pH. Soil Biology and Biochemistry. **25:**321-326.

Ellison, A. 2002. Macroecology of mangroves: large-scale patterns and processes in tropical coastal forests. Tree Structure and Function. **16:**181-194.

Erftemeijer, P. G. Allen, and Zuwendra. l989. Preliminary resource inventory of Bintuni Bay and recommendations for conservation and management. In: Dir. Gen. Forest Protection and Nature Conservation and Asian Wetland Bureau, Bogor, Indonesia, 1-151.

FAO. 2007a. World's Mangrove 1980-2005. FAO Forestry Paper 153, FAO, Rome.

FAO. 1988b**.** Land Resources Appraisal of Bangladesh for Agricultural Development. Agroecological Regions of Bangladesh. Technical Report 2. FAO, Rome. p 530.

Fernandez, P. M. 1978. Regulations and their impact on mangrove areas for aquaculture – the Philippine experience. *Workshop Proceeding on the conversion of mangrove areas to aquaculture*, Iloilo, pp. 78-84.

Giri, C., E. Ochieng, L. L. Tieszen, Z. Zhu, A. Singh, T. Loveland, J. Masek and N. Duke. 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeograpy. **20:**154-159.

Gong, W. K. and J. E. Ong. 1990. Plant biomass and nutrient flux in a managed mangrove forest in Malaysia. Estuarine, Coastal Shelf Science. **31:**519-530.

Gopal, B. 2006. Wetlands and biodiversity. In: E. Maltby (ed.), The Wetlands Handbook. Blackwell Science, Oxford, U.K.

Granek, E. and B. I. Ruttenberg. 2008. Changes in biotic and abiotic processes following mangrove clearing. Estuarine, Coastal and Shelf Science. **80:**555-562.

Harada, K. and F. Imamura. 2005. Effects of coastal forest on tsunami hazards mitigation-a preliminary investigation. Advance in Natural and Technological Hazards Research. **23:**279-292.

Hiraishi, T. 2005. Greenbelt technique for tsunami disaster reduction. Proc. APEC-EqTAP Seminar on Earthquake and Tsunami Disaster Reduction, Jakarta, Indonesia. p. 1-6.

Hiraishi, T. and K. Harada. 2003. Greenbelt tsunami prevention in South Pacific region. Report of the Port and Airport Research Institute # 42, p. 1-23.

Hossain, M., S. Othman, J.S. Bujang and M. Kusnan. 2008. Net primary production of *Bruguiera parviflora* (Wight & Arn.) dominated mangrove forest at Kuala Selangor, Malaysia. Journal of Forest Ecology and Management. **255:**179-182.

Hsieh, M. T., W. H. Peng, C. R. Wu and W. H. Wang. 2000. The ameliorating effects or the cognitive-enhancing Chinese herbs on scopolamine induced amnesia in rats. Phytotherapy Research. **14:**375-377.

Hussain, Z. and G. Acharya. 1994. Mangroves of the Sundarbans, Volume **2**: Bangladesh". IUCN, Gland, Switzerland, 257 pp.

Ito, C., S. Katsuno, Y. Kondo, H.T. Tan, and H. Furukawa. 2000. Chemical constituents of Avicennia alba. Isolation and structural elucidation of new napthoquinones and their analogues. Chemical Pharmalogical Bulletin. **48:**339-343.

Janssen, R. and J.E. Padilla. 1999. Preservation or conversion? Valuation and evaluation of a mangrove forest in the Philippines. Environmental and Resource Economics. **14:**297-331.

Kathiresan, K. and N. Rajendra. 2005. Coastal mangrove forests mitigated tsunami. Estaurine, Coastal and Shelt Science. **65:**601-606.

Khan, M. N. I., R. Suwa and A. Hagihara. 2009. Biomass and aboveground net primary production in a subtropical mangrove stand of *Kandelia obovata* (S. L.) Young at Manko Wetland, Okinawa, Japan. Journal of Wetland Ecology Management. **17:**585-599.

Komiyama, A., S. Havanond, W. Srisawatt, Y. Mochida, K. Fujimoto, T. Ohnishi, S. Ishidara and T. Miyagi. 2000. Top/root biomass ratio of secondary mangrove (Ceriops tagal. Perr. C. B. Rob) forest. Forest Ecology Management. **139:**127-134.

Lacerda, I. D., 1998. Biogeochemistry of trace metals and diffuse pollution in mangrove ecosystem. International Society for Mangrove Ecosystems. Okinawa, Japan.

Lacerda, I. D., J. E. Conde, B. Kjerfve, R. Alvarez-Leon, C. Alarcon and J. Polania. 2002. American Mangrove. In: Mangrove Ecosystems: Function and Management. Lacerda, I. D. (ed.) Springer-Verlag Berlin, Germany. pp. 1-62.

Le Mer, J. and P.A. Roger. 2001. Production, oxidation, emission and consumption of methane by soils. A review. European Journal of Soil Biology. **37:**25-50.

Lekphet, S., S. Nitisoravut and S. Adsavakulchai. 2005. Estimating methane emissions from mangrove area in Ranong Province, Thailand. Songklanakarin Journal of Science and Technology. **27:**153-163.

Lindau, C. W., Bollich, P.K., DeLaune, R. D., Mosier, A. R. and Bronton, K.F. 1993. Methane mitigation in flooded Louisiana rice fields.Biology and Fertility of Soils. **15:**174-178.

Lyimo, T. J., A. Pol and H.J.M. Camp. 2002. Methane emission, sulphide concentration and redox potential profiles in Mtoni mangrove sediment, Tanzania. Western Indian Ocean Journal of Marine Science. **1:**71-80.

Macnae, W. 1968. A general account of the flora and fauna of mangrove swamps in the Indo-Western Pacific region. Advances in Marine Biology. **6:**73-270.

Mastaller, M. 1989. Rehabilitation der Lagune Ciengaga Grande de Santa Marta, Kolumbien. Projekt prufungsberichti. A. GIZ, Eschborn, pp. 1-152.

Mastaller, M. 1996. Destruction of mangrove wetlands-causes and consequences. Natural Resources and Development. **43:**37-57.

Mazda, Y., M. Magi, Y. Ikeda, T. Kurokawa and T. Asano. 2006. Wave reduction in a mangrove forest dominated by *Sonneratia* spp. Wetlands Ecology and Management. **14:**365-378.

Meow-Chan, V. and L. Choo-Loh. 1987. n-Alkanes of the leaves of some mangrove plants. UNESCO regional seminar on chemistr of mangrove plants. Bangkok, Thailand.

Nellemann, C., E. Corcoran, C. M. Duarte, L. Valdés, C. De Young, L. Fonseca and G. Grimsditch. 2009. Blue Carbon-The Role of Healthy Oceans in Binding Carbon. A

Rapid Response Assessment. United Nations Environment Programme, GRID-Arendal, Norway.

Norhayati, A. and A. Lafiff. 2001. Biomass and species composition of a mangrove forest in Pulau Langkawi, Malaysia. Malaysian Applied Biology. **30:**75-80.

Osti, R., S. Tanaka and T. Tokioka. 2009. The importance of mangrove forest in tsunami disaster mitigation. Disasters. **33:**203-213.

Purvaja, G. R. and R. Ramesh. 2001. Natural and anthropogenic methane emission from coastal wetlands of South India. Environment Management. 27:547-557.

Putz, F. E. and H. T. Chan. 1986. Tree growth, dynamics, and productivity in a mature mangrove forest in Malaysia. Forest Ecology and Management. **17:**211-230.

Quartel, S., A. Kroon, P. G. E. F. Augustinus, P. Van Santen and N.H. Tri. 2007. Wave attenuation in coastal mangroves in the Red River Delta, Vietnam. Journal of Asian Earth Sciences. **29:**576-584.

Rahman, M. M., M. N. I. Khan, K. F. Hoque and I. Ahmed. 2015. Carbon stock in the Sundarbans mangrove forest: spatial variations in vegetation types and salinity zones. Wetlands and Ecological Management. **23:**269-283.

Rahman, M. H. 2017. Distribution and stratification of carbon in irrigated calcareous soil under rice-based cropping pattern in Bangladesh. International Journal of Soil Science. **12:**120-127.

Robertson, A. I., D. M. Alongi and K. G. Boto. 1992. Food chains and carbon fluxes. In: Tropical Mangrove Ecosystems, ed. A. I. Robertson, D. M. Alongi. Washingtong DC, USA., American Geographic Unit pp. 293-321.

Rollet, B. 1981. Bibliography on mangrove research. 1600-1975. UNESCO Paris. Pub. Information Retrieval Ltd., London, 479 pp.

Ross, P. 1974. The mangrove of South Vietnam; the impact of military use of herbicides. In: Walsh, G. E., Snedaker, S. C. and Teas, H. J. (Eds.), *Proceeding of International Symposium on Biology and Management of Mangroves*, 8-11 Oct. 1974, Hawaii, Gainsville, Unit. of Florida, pp. 126-136.

Ruitenbeek, H. J. 1994. Modelling economy-ecology linkages in mangroves: economic evidence for promoting conservation in Bintuni Bay, Indonesia. Ecological Economics. **10:**233-247.

Selvam, V. 2005. Impact assessment for mangrove and shelterbelt plantation tsunami for Tamil Nadu Forest project. M. S. Swaminathan Research Foundation, New Delhi.

Smith, R. L. and T. M. Smith. 2003. Elements of Ecology, 6th Edition. Benjamin Cummings, Belmont, CA.

Sotomayor, D., J. E. Corredor and J. M. Morell. 1994. Methane and emission from mangrove soil along the south-eastern coast of Puerto Rico. Estuaries. **17:**140-147.

Tam, N. F. Y. and Y. S. Wong. 1993. Retention of nutrients and heavy-metals in mangrove sediments receiving waste-water of different strengths. Environmental Technology. **14:**719-729.

Tanaka, N., Y. Sasaki, M. I. M. Mowjood, K. B. S. N. Jinadasa and S. Homchuen. 2007. Coastal vegetation structures and their functions in tsunami protection: experience of the recent Indian Ocean tsunami. Landscape Ecology and Engineering. **3:**33-45.

Twilley, R. R. 1982. Litter dynamics and organic exchange in black mangrove (*Avicennia germinans*) basin forest in south western Florida estuary. Doctoral dissertation, University of Florida, Gainesville, FL, USA.

Wardle, D. A., K. I. Bonner and G. M. Barker. 2000. Stability of ecosystem properties in response Ato above-ground functional group richness and composition. Oikos. **89:**11-23.

Williams, L. A. 1999. Rhizophora mangle (*Rhizophoracea*) triterpenoids with insecticidal activity. Naturwissenschaften. **86:**450-452.

Woitchik, A. F., B. Ohawa, J. M. Kazungu, R. G. Rao, L. Goeyens and F. Dehairs. 1997. Nitrogen enrichment during decomposition of mangrove litter in an east African coastal lagoon (Kenya): Relative importance of biological nitrogen fixation. Biogeochemistry. **39:**15:35.

Woodroffe, C. D. 1985. Studies of a mangrove basin, tuff crater, New Zealand: I. mangrove biomass and production of detritus estuarine. Coastal and Shelf Science. **20:**265-280.

World Resources Institute. 2000. World Resources 2000-2001. People and Ecosystems: The Fraying Web of Life. Elsevier Science.

Yaṅez-Arancibia, A., G. Soberon-Chavez and P. Sanchez-Gil. 1985. Ecology of control mechanisms of natural fish production in the coastal zone. In: Fish Community Ecology in Estuaries and Coastal Lagoons, Towards an Ecosystem Integration, Yaṅez-Arancibia, A. (Ed.), pp. 571-595. UNAM Press, Mexico.