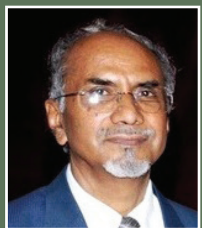
About the Editors

Debabrata Das (b.1969), Ph.D. in Botany (Ecology) from Vidyasagar University, W.B. is presently working as Associate Professor and Head, Department of Botany, Govt. G.D. College, Lalgarh, Jhargram, W.B. He has worked in various Medicinal Plants Conservation Areas (MPCAs) as expert along with his team at Eastern Himalayan part, Dooars and in South Bengal (Susunia Hills) of W.B with Forest department. He authored more than 130 scientific research papers and 4 books including 8 edited books. He is working in the field of Ornithology since 2016 and covered many aspects of IBAs for academic and scientific research and visited many parts of Indian Eco-habitats. Primary aim of his work is to knowledge dissemination and biodiversity conservation.



Prof. (Dr.) Mammen Daniel is an internationally acclaimed Phytochemist and Taxonomist. He received his Ph. D. in Botany from M. S.University, Baroda in 1976 and thereafter joined the same Department as Lecturer. He was promoted as a reader in 1987 and Professor in 1997. He served as The Head of Department of Botany and Dean, Faculty of Science of the same University. He retired from University services in 2012 and with his students, started his own pharmaceuticals named "Dr. Daniel's Laboratories" in Baroda which now manufactures more than 15 well-acclaimed herbal medicines.

Prof. Daniel has published more that 180 research papers in the fields of Chemotaxonomy, Phytochemisry, Phytoalexins, Allelopathy and Medicinal plants and authored 18 books of which 5 are international publications. He has guided 18 students for their Ph.D and more than 50 for M. Sc. projects. Known for his oratorical skills, he had travelled far and wide and gave more than 150 lectures and about 30 webinars during Covid times. He has conducted about 5 major research projects and five national/international seminars. He is serving as a Mentor for Life Sciences in Navrachana University of Baroda and Member, Board of Studies of a number of Universities.

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Dr. Debabrata Das
Prof. (Dr.) Mammen Daniel

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5 Carbon Sequestration of Mangrove Trees Enhancing the Climate Change Mitigation

Suresh A. Palve and Ajit B. Telave

INTRODUCTION

Carbon is an element commonly found on earth in various forms which is essential element of all life forms. The bodies of living organisms and non-living things like oil, natural gas, coal, rocks and air contains large amount of carbon. Globally carbon is found in a variety of different stocks as oceans, fossil fuel deposits, terrestrial system and the atmosphere (Kiran *et al.*, 2011). In the terrestrial system, carbon is stored in rocks, sediments, swamps, wetlands, forests, forest soils, grasslands and agriculture. About two-thirds of global terrestrial carbon is found in forests and forest soils (Alamgir, *et al.*, 2007). In addition, there are some non-natural human-created carbon stocks like wood products and waste dumps. Carbon dioxide (CO_2) concentration has grown by 31% from 280 ppmv in 1850 to 380 ppmv in 2005, and is now growing at 1.7 ppmv yr^{-1}, or 0.46% yr^{-1} (WMO 2006; IPCC 2007). Methane (CH4) and nitrous oxide (N2O) concentrations have also continuously risen during the same time period (IPCC 2001, 2007; Prather et al. 2001; WMO 2006). Increasing carbon concentration in the earth's atmosphere led to an imbalance in the carbon budget and raising serious issue in the human life. Hence the needs to improve understanding of carbon sequestration within global ecosystems and investigate solutions to mitigate the effects of resulting climate change in nowadays (Howard *et al.*, 2017).

Carbon sequestration is effective natural process of capturing, storing and removing atmospheric carbon dioxide (Sedjo, 2012).

* Post Graduate Research Centre, Department of Botany, Tuljaram Chaturchand College of Arts, Science and Commerce, Baramati, Pune, Maharashtra

The carbon sequestration mechanisms point of view, there are different systems of carbon sequestration like biological, geological, and chemical system. The physical and chemical system are based on reactions and engineering techniques without involvement of living organisms. The physical and chemical strategy of carbon sequestration in oceanic and geological structures has received large attention (Freund & Ormerod 1997), because theoretically physical and chemical sequestration has a larger sink capacity than biotic sequestration (Kerr, 2001). But biological systems are one of the natural and cost effective technologies which gives solutions to the most dreaded problems of all times and important for formulating energy policies for future economic growth and development at national and global scales. Carbon is transported in complex form ($CO_{2)}$ in an ecosystem, it sinks in the form of biomass by plant photosynthesis, which uses sunlight to combine CO_2 from the atmosphere and water to form glucose a simple sugar that is stored directly in the tissue of living plants; and indirectly, by the microbial decomposition of the biomass of plant and animal tissue. Into other compounds like carbohydrates, amino-acids/proteins, organic acids, wax, coal, oil, and natural gas etc., (Atkin *et al.*,2012). The photosynthetic fixation of atmospheric CO_2 in plants and trees could be of great value in maintaining a CO_2 balance in the atmosphere (Trumper *et al.* 2009). The atmospheric carbon removing and storing in green plants, that's called sink. These sinks are aboveground biomass of living organisms and belowground biomass in soil, root system and microorganisms (Jina*et al.*, 2008). Many reviews have been published various aspects of biotic carbon sequestration like forest, grasslands, microbes, wetlands and soil carbon sequestration (Bruce *et al.*, 1999; Lehmann 2007; Lal 2008).

Forests, soils and wetlands plays significant role in terrestrial carbon sequestration process in which wetlands play an important and complex role in the global carbon cycle. They contributing to the ecosystem service of greenhouse gas regulation through carbon sequestration (Mcleod*et al.*, 2011). Coastal wetlands are some of the most biologically and geochemically active regions within the biosphere (Gastusso*et al.*, 1998). Coastal wetlands in particular are gaining increasing recognition as efficient carbon sinks (Bouillon *et al.*, 2008). Wetlands have unique biogeochemical characteristics, accreted sediment and organic matter which increase their potential for carbon storage as compare to other terrestrial ecosystems (Bridgham*et al.*, 2006). Tidal and saline wetlands have continuously accreted and bury sediments that are rich in organic carbon while emitting negligible amounts of greenhouse gases such as CH_4 because of the saline and anaerobic environment (Pof-fenbarger*et al.* 2011). Mangroves, sea grasses and tidal salt marshes are highly productive ecosystems. They sequester carbon 10–50 times faster than terrestrial systems (McLeod *et al.*, 2011). A combination of high productivity, anaerobic conditions and high accumulation rates account for the high carbon storage capacity of particular mangrove ecosystems (Chmura *et al.*, 2003).

NEED OF CARBON SEQUESTRATION

The CO^2 concentration has rapidly increased in the past 50 years due to anthropogenic processes such as soil exploitation, land use change, deforestation, biomass burning, draining of wetlands and more use of fossil fuels (Lal, 2001). The atmosphere is being overloaded by fire, thermal power generation, logistics, transport, and many other humans made activities. The biggest environmental problem facing society in the twenty-first century is the need to stabilise atmospheric quantities of greenhouse gases (Smith, 2007). The average temperature of the earth is increasing as a result from increasing greenhouse gas concentrations, which is also disturbing the biological balance between animal and plant species. Climate change is one of the major risks on planets for survival of all living organisms. Sea levels are rising as oceans get warmer. Crops, biodiversity and freshwater resources are all at danger due to the ongoing, severe droughts. The diversity of life on our world is affected by the changing climate, from polar bears in the Arctic to marine turtles off the coast of Africa (Taj *et al.*, 2020). Human populations around the ocean, forest, and coral reefs are particularly vulnerable to climate change. The carbon dioxide is a main greenhouse gas. The main reason of carbon dioxide emission is industrial activities (O'Neill *et al.*, 2012). The majority of its emissions come from the burning of carbonaceous fuels. To reduce the effects of climate change or global warming to must be CO_2 emissions decreased. The requirement for electricity must be supplied by the production of energy from nuclear, hydro, fossil fuels, and coal in significant quantities, but CO_2 emissions must be decreased, clean coal technologies and efficient, clean coal combustion must be created. The different approach to helping in reducing the level of greenhouse gas. Capture and Storage Technologies are used to reduce the emission of Greenhouse gasses by capturing the CO_2 gas from the possible surface (Herzog, *et al.*, 2000). sequestration of atmospheric carbon dioxide as organic carbon in the biosphere attracts attention as an alternate way to help to reduce the rate of greenhouse gas and associated changes in our climate.

MANGROVE CARBON SEQUESTRATION

Mangroves are coastal forest ecosystems that may be found in the coastal intertidal zones of tropical, subtropical and warm temperate parts of the world. They grow on unconsolidated soil layers. Mangroves provide a multitude of benefits, such as the preservation of fisheries and biodiversity in coastal and estuarine water masses, as well as the defence of coastal regions against the force of wind and waves (Mazda *et al.*, 2006). Over the last 20 years, research has confirmed that mangrove forests assist additional environmental function by carbon sequestration (Alongi, 2014). Twilley *et al.*, (1992) reported that mangroves are the most productive ecosystems in world and also have one of the highest carbon storage capacities per unit area. Kathiresan *et al.*, (2008) reported that greatest potential for mangroves to capture and store atmospheric carbon and this helps to keep the ecosystem's balance. National Geographic magazine (Feb, 2007) statement on the mangrove ecosystem is also known as a "carbon factory" because it has the highest net carbon productivity of any natural ecosystem. Mitra *et al.*, (2011) Research has shown that coastal vegetation sequesters carbon more effectively and permanently than land forests. Donato *et al.*, (2011) reported that world's mangrove forests carbon sequestration five times more than any other tropical forest. Alongi. (2014) studied the characteristics of mangrove carbon cycling and reported that mangroves carbon sequestration about 6 times more than other subtropical and tropical coastal ecosystem. According to IUCN (2009) mangroves store approximately 25.5 million metric tonnes of carbon annually and per hectare carbon sequester approximately 1.5 tonnes. This is comparable to the amount of carbon dioxide that a vehicle releases into the environment per year, (assuming that each car uses approximately 2,500 litres of fuel annually) by Spalding (2010). Alongi (2012) reported that mangroves allocate proportionally more carbon belowground, and have higher below- to above-ground carbon mass ratios than terrestrial trees and the most mangrove carbon is stored as large pools in soil and dead roots. Alongi (2014) observe that the Mangrove forests carbon store more than other ecosystems per unit area, particularly in soils; among a mean whole-ecosystem carbon stock of 956 tha^{-1}, soil organic carbon (SOC) constitutes 75% of the carbon pool.

INDIA MANGROVES CARBON SEQUESTRATION

In India, mangrove spreads over an area of 4,975.00 km^2 occupying only 0.15% of the geographical area of the country and 3% of globe and 8% in Asian mangrove cover (FAO, 2019). India with a long coastline of about 4,975.00 km^2, including the island territories (Anon, 2001), In India Mangroves occupy 4740 km^2, about 3 % of the world's mangrove cover. (Shedage*et al.*, 2018). These mangrove habitats (69°E89.5°E longitude and 7°N-23°N latitude) comprise three distinct zones: East coast habitats having a coast line of about 2700 km, facing Bay of Bengal, West coast habitats with a coast line of about 3000 km, facing Arabian sea, and Island Territories with about 1816.6 km coastline. According to FSI (2011) West Bengal has been covering the largest area (42.45%) under mangrove formations that includes Sundarbans Biosphere Reserve, followed by Gujarat (23.6%) and Andaman & Nicobar Island (12.39%) complex. Other state by Andhra Pradesh, Maharashtra, Odisha, Tamil Nadu, Goa, Karnataka and Kerala cover by Area under mangroves (8.12%), (5.04%) (6.44%), (0.90%), (0.52%) and (0.20%), (0.18%) respectively. Sundarbans in India is the largest man-grove site in the world, colonized with many threatened animal species (Shedage*et al.*, 2018). The long coastlines and their mangrove vegetation have massive role to protecting coastal biodiversity. The carbon sequestration of mangrove in India work has been done by some scientists. Singh *et al.*, (2005) reported the mangrove wetlands of are the important sources of biological diversity and world's second largest source of primary productive ecosystems next to rainforests. They have capacity to trap significant quantities of phosphorus which play a key role in biogeochemical cycle. Kathiresan and Khan (2010) they have observed coastal mangrove flora has higher biomass and carbon sequestration potential than other aquatic flora. But due to its extensive use, anthropogenic activities, climate change, storms etc. has lead to decreased area of mangrove (Banerjee *et al.* 2015). Patil *et al.*, (2012) reported mangroves to be good sequesters of carbon. But mangrove carbon sequestration is depending on numbers of factors such as physical (waves, tides, erosion, accretion etc.), biological (vegetation types and density) and anthropogenic (urbanization, barrage, discharge, nature of livelihood etc.) Noordwijik*et al.*, (1997) reported carbon sequestration in the mangrove forest depends on geographical location, mangrove species and their biomass. Mukherjee (2007) reported carbon sequestration in the mangrove shows variation as per age of plantation. A similar observation was reported by Mitra (2011). Carbon sequestration is highest in young forest and will tend to reduce as forest reach maturity. Sahu*et al.* (2016) did a comparative study on physico–chemical parameters, diversity, biomass and carbon stock potential of natural and plantation mangrove forest of Mahanadi Delta, Odisha. They reported carbon stock in plantation 60.9±13.9 tha^{-1} and natural mangrove forest 54.3±7.4 tha^{-1}. Kathiresan *et al.*, (2013) reported mangroves biomass depends on physicochemical parameters like rate of carbon sequestration, height, DBH, growth, net canopy photosynthesis, growth efficiency, leaf longevity and sediment. This parameter depending on season, type and age of the species. Banerjee *et al.* (2012) studied anthropogenic and natural effect on characteristics of soil. They observed the SOC, pH and salinity of the Sundarbans ranges between 1.02%, 7.47±0.071, 9.75 psu and 0.64%, 7.57±0.067, 13.85 psu in anthropogenic and natural forest region respectively. They reported that SOC is influenced by physical, biological and anthropogenic factors of the mangrove forest. Banerjee *et al.* (2012) studied salinity based allometric equations for biomass estimation of Sunderban mangrove. They observed the Salinity affects the growth of biomass negatively in the mangrove species such as *Sonneratia apetala*. Shinde (2018) studied on carbon sequestration in mangrove habitats of Mumbai region they observed mangrove parts show a different potential level for carbon sequestration. Mangrove leaves show second largest carbon stock, because leaves are absorbing atmospheric carbon through photosynthesis & carbon becomes a part of their biomass. Mangrove root exchange or uptakes carbon from their adjacent regions. Here roots show least amount of carbon stock than other parts which are probably due to polluted sediment quality.

Roy Chowdhury (2014) examined Indian Sundarbans they estimated the AGB of *S. apetala, E. agallocha, A. marina, A. alba* and *A. officinalis* of even age group of ≈12 years and reported the AGB of the selected species ranged between 12.37±1.39 to 73.09±6.88 tha^{-1} with an average value of 49.37 tha^{-1} and 38.32tha^{-1} in western and central sector of Indian Sundarbans respectively. Mitra *et al.*, (2011) studied the AGB and AGC of the *S. apetala, E. agallocha* and *S. alba*. They found that AGB and AGC varied significantly with stations due to salinity difference. The stored carbon in the AGB exhibited the trends stem > branch > leaf. Vinod Kavungal*et al.*, (2018) assess the biomass of mangroves in the Kadalundi wetland, south-west coast of India and evaluated the potential of *A. officinalis R. mucronata B. cylindrica S. alba and E. agallocha* mangroves to sequester and store carbon. The C-stocks of above-ground and root biomass were 83.32±11.06 t C ha^{-1}

and 34.96±4.30 t C ha^{-1} respectively, while the C-stock in sediment was estimated to be 63.87±8.67 t C ha^{-1}. Sankar *et al.*, (2014) estimated the biomass carbon and total SOC of Muthupet mangrove, Southeast Coast of India. They reported biomass carbon of leaf and stem ranged between 35.16% (*Suaedamonoica*) to 54.06% (*A. corniculatum*), 51.61% (*A. ilicifolius*) to 54.06% (*A. corniculatum*). Joshi and Ghose (2014) studied the diversity and AGB along with physicochemical characteristics of sediment in Indian Sundarbans. They found that AGB was low ranged from 8.9 tha^{-1} to 50.9 tha^{-1} high range in different communities, depending on the structural characteristics and tidal flood significantly affected the biomass. Manna *et al.*, (2014) studied the AGB and carbon stock of 5yearold*A. marina* plantation in India Sundarbans of an area approximately 190 ha using high resolution satellite data. They reported 236 tha^{-1} of biomass and 54.9 tha^{-1} of carbon stock in above ground. Pandey and Pandey (2013) have examined the carbon sequestration by mangroves of Gujarat. A total 8.116-million-ton carbon has been sequestered by mangroves of Gujarat. Vinod Kavungal *et al.*, (2018) assess the biomass of mangroves in the Kadalundi wetland, south-west coast of India and evaluated the potential of *A. officinalis, R. mucronata, B. cylindrica, S. alba and E. agallocha* man-groves to sequester and store carbon.

WORLD MANGROVES CARBON SEQUESTRATION

The world's total mangrove covers 15 million hectares, equivalent to 1% of the world's tropical forests. Mangroves are found mostly in 123 tropical and subtropical countries and territories. Asia has the world's largest mangroves. About 40% of the world's mangrove forests are in Southeast and South Asia, followed by South America, North and Central America, and West and Central Africa. Among the remaining six regions (South Asia, Australia/New Zealand, East and South Africa, Pacific Ocean, East Asia and Middle East), South Asia has the highest share at 6.8% and contains 10,344 km^2 of mangrove forest. India has about 3% of the total mangrove cover in South Asia. (Forest Survey of India, 2019). The last 20 years increasing interest in studying storage and flux of carbon or organic matter in mangrove ecosystems. In particular, the "outwelling" hypothesis, first proposed for mangroves by Odum (1968) and Odum and Heald (1972) suggested that a large fraction of the organic matter produced by mangrove trees and exported to the coastal ocean, where it should form the basis of a detritus food chain and they supporting to coastal fisheries.

The number of reports available on mangrove biomass from different regions in world. AGB of 460 tha^{-1} was reported from a forest dominated by *R. apiculata* in Malaysia (Putz and Chan, 1986). AGB of more than 300 tha^{-1} was documented in mangrove forests in Indonesia (Komiyama *et al.* 1988) and French Guiana (Fromard*et al.*, 1998). The AGB was less than 100 tha^{-1} in most secondary forests or concession areas. In high latitude areas (>24° 23`N or S), primary forests mostly have AGB of around 100 tha^{-1}, however, even at 27° 24′ S, an AGB of 341 tha^{-1} was reported for an *Avicennia marina* forest (Mackey, 1993). The lowest AGB reported was 7.9 $tha-^{1}$ for a *Rhizophora mangle* forest in Florida, USA (Lugo and Snedaker, 1974). The canopy height of mangrove forests is generally lower at higher latitudes (Saenger and Snedaker, 1993) which is a justified reason for relatively lower AGB in higher latitudes. Alongi (2012) studied on Mangrove carbon stocks and they have been measured in 52 countries on world. It's reported that total ecosystem carbon stocks are, on average value, greatest on the Pacific Islands (987.4 Mg C ha^{-1}) of Kosrae, Yap and Palau, followed by mangroves in Southeast Asia (860.9 Mg C ha^{-1}), Central and North America and the Caribbean (777.7 Mg C ha^{-1}) and Africa (664.2 Mg C ha^{-1}). Total ecosystem carbon stocks were considerably lower in Australia and New Zealand (563.4 Mg C ha^{-1}), South America (424.0 Mg C ha^{-1}), South and East Asia (395.5 Mg C ha^{-1}) and the Middle East (248.4 Mg C ha^{-1}).

Mangroves carbon stock and sequestration in the aboveground biomass depend on mangrove forests age, dominant species, locality latitude, climatic parameters, physiographic types and age (Komiyama, 2008). According to Estrada*et al.*, (2017) It was shown in this study that at the global/ regional scale, carbon stock increases towards the Equator and its variability is dependent on climatic parameters like primarily temperature of coldest periods, isothermality, annual precipitation and water balance. The highest aboveground biomass (460 tha^{-1}) was found in a forest dominated by *R. apiculata* in Malaysia (Putz and Chan, 1986). The lowest aboveground biomass reported was 7.9 tha^{-1} for a *Rhizophora mangle* forest in Florida, USA (Lugo and Snedaker, 1974). The canopy height of mangrove forests is generally lower at higher latitudes (Saenger and Snedaker, 1993). Therefore, in low latitudes, primary or mature mangrove forests generally have high aboveground biomass. The aboveground biomass is always low in temperate areas and may be related to different climatic conditions, such as temperature, solar radiation, precipitation and frequency of storms. Fromard*et al.*, (1998) estimated the aboveground biomass to be 180.0 and 315.5 tha^{-1}, respectively for *Avicennia* and *Rhizophora* stands in French Guiana. According to this studies aboveground biomass tends to be relatively low in stands near the sea and increases inland. Mangrove forests usually show "zonation" patterns. In Southeast Asia, *Sonneratia* or *Avicennia* stands are often found on the sea front, and *Rhizophora* or *Bruguiera* stands are distributed more inland (Watson, 1929), although Ellison *et al.*, (2000) questioned the concept of "zonation". Fromard*et al.*, (1998) estimated the aboveground biomass to be 180.0 and 315.5 tha^{-1}, respectively for *Avicennia and Rhizophora* stands in French. The number of scientist studies on pattern of biomass allocation to the aboveground organs of *Rhizophora* stands is shown results in all stands, stems and branches comprise the largest proportion of aboveground biomass. A tendency exists for the stem and branch portion to become larger as total aboveground biomass increases. The biomass of prop roots accounted for 15–17% of the aboveground biomass in mature stands. Cairns *et al.* (1997) reviewed root biomass studies conducted worldwide in upland forests, finding that root biomass is normally below 150 tha^{-1}. The prop roots formed a part of the root system of *Rhizophora* trees that was nearly equal to the branch biomass. Leaf biomass comprised the smallest portion of aboveground biomass and varied from 0.4 to 29.8 tha^{-1}. In mature forests, the leaf/woody biomass ratio was quite low.

CONCLUSION

The information provided here supports the idea that mangrove habitats are some of the most carbon rich ecosystems in the tropics. It was show in this study that at the mangroves are beneficial and chief alternative way to reduce the rate of greenhouse gas and associated changes in our climate. Mangroves carbon stock and sequestration in the aboveground biomass dependence on mangrove forests age, dominant species, locality latitude, climatic parameters, physiographic types and age. In this study that at the global/ regional scale, carbon stock increases towards the Equator and its variability is dependent on climatic parameters, primarily temperature of coldest periods, isothermality, annual precipitation, and water balance.

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