Response of mangroves to climate change: A case study from the World Heritage Site of Indian Sundarbans

Arpita Saha[1], Nabonita Pal[2], Sufia Zaman[3], Gahul Amin[4], Abhijit Mitra[5]
[1, 2, 3]Department of Oceanography, Techno India University, West Bengal, Salt Lake Campus, Kolkata, India
[4]Department of Physics, Netaji Subhas Open University (Kalyani Campus), Kalyani, India
[5]Department of Marine Science, University of Calcutta, 35 B.C. Road, Kolkata, India
Email - abhijit_mitra@hotmail.com

Abstract: *The mangrove dominated Indian Sundarbans located in the lower Gangetic delta region sustains about 34 true mangrove species and provide a multitude of important ecosystem services such as reservoir of various threatened species, breeding ground and nursery of commercially importance of finfish and shellfish, the provision of food, fuel and natural coast line protection from erosion due to tidal action etc. Apart from this, mangroves act as the store house of carbon and thus play a pivotal role in retarding the global warming phenomenon at local scale. Mangroves also maintain the water quality by absorbing nutrients and various pollutants. Such unique ecosystems are now threatened by climate change like increase of temperature,* CO_2*, sea level rise etc. This paper discusses the impacts of these climate change induced threats on mangroves of the present geographical locale.*

Key Words: *Mangroves, Indian Sundarbans, Climate Change.*

1. INTRODUCTION:

Historically, mangroves once covered over 200,000 km^2 of coastline globally (Duke et al., 2007). Climate change is expected to have a significant impact on mangroves *via* a number of processes, such as increased storminess, temperature and CO_2 as well as changes in rainfall (Ward et al., 2016). Sea level rise (SLR) is predicted to have the most significant physical, ecological and socio-economic impacts on mangrove ecosystems. In the last half-century, 30% to 50% of mangroves have disappeared. This rate of loss is steady and in certain locations, even increasing (Godoy and Lacerda, 2015). Richards and Friess (2016) estimate a loss of 2 percent or ~100,000 hectares of mangroves between 2000 and 2012 in the SE Asian region alone. Furthermore, Duke et al (2007) write, 'mangroves are already critically endangered or approaching extinction in 26 out of the 120 countries having mangroves. In Indian Sundarbans due to increase of salinity stunted growth of mangroves have been observed and in certain patches of central Indian Sundarbans, extinction of *Heritiera fomes* has been reported (Mitra, 2013; Mitra and Zaman, 2014; Mitra and Zaman, 2015; Mitra and Zaman, 2016). Because of rise in temperature, alteration of salinity, precipitation *etc*. adverse impacts on mangrove ecosystem have been observed. The present study is a qualitative analysis on the basis of secondary data retrieved from several sources.

2. MATERIALS AND METHODS

A data set of 30 years in this first order analysis as per the minimum standard norm of climate related researches is considered in this study. World Meteorological Organization and the Intergovernmental Panel on Climate change (IPCC) define "climate" as the average state of the weather over time with the period generally being 30 years (although for some marine climate parameters such as storminess, longer averages are required). More than two decades of data (1984 - 2013) were compiled from the archives of the Department of Marine Science, University of Calcutta for this study. A number of studies on different aspects of the Sundarban complex have been published over the years, which include description of the data (and methods) at different times for more than two decades (Mitra, 2013; Mitra and Zaman, 2014; Mitra and Zaman, 2015; Mitra and Zaman, 2016).

.

3. RESULTS AND DISCUSSION:

3.1. Effect of rise in temperature

The Earth has warmed by 0.6-0.8°C since 1880 and it is projected to warm 2-6°C by 2100 mostly due to human activity (Houghton et al., 2001). Mangroves are not expected to be adversely impacted by the projected increase in sea temperature (Field, 1995). Most mangroves produce maximal shoot density when mean air temperature rises to 25°C and stop producing leaves when the mean air temperature drops below 15°C (Hutchings and Saenger, 1987). At temperatures above 25°C, some species may show a declining leaf formation rate (Saenger and Moverly, 1985). Temperatures above 35°C have led to thermal stress affecting mangrove root structures and establishment of mangrove seedlings (UNESCO, 1992). At leaf temperatures of 38-40°C, almost no photosynthesis occurs (Clough et al., 1982; Andrews et al., 1984). Some scientists have suggested that mangroves will move pole-ward with increasing air temperatures (UNEP, 1994; Field 1995; Ellison, 2005). Although it is possible that some species of mangroves will migrate to higher latitudes where such range extension is limited by temperature, Woodroffe and Grindrod (1991) and Snedaker (1995) suggest that extreme cold events are more likely to limit mangrove expansion into higher latitudes.

The oscillation of temperature also affects the mangrove photosynthesis. An optimum temperature range exists for mangroves in which the glucose synthesis exhibits maximum value, but this range is not strictly uniform for all the mangrove species. Andrews and Muller (1985) have shown that the rate of photosynthesis is much reduced at higher leaf temperatures. In few mangrove species examined so far the rate of photosynthesis appears to be relatively unaffected by leaf temperature over the range 17^0C to 25^0C, but falls sharply at temperatures much above 35^0C and is close to zero at 40^0C. The temperature response of photosynthesis in mangroves is thus similar to other C_3 plants and unlike that of C_4 plants, which generally have a higher optimum temperature for photosynthesis. In Florida mangroves, little or no photosynthesis occurred at 40°C and the temperature optima for photosynthesis was below 35°C (Moore et al., 1972). There are some views regarding the influence of leaf temperatures on the process and rate of mangrove photosynthesis. According to Andrews et al (1984) high leaf temperatures may influence photosynthesis indirectly through its effect on the vapour pressure deficit between the leaf and its environment. Apart from this, high leaf temperature also has an adverse effect on carboxylation reactions, with the result that the CO_2 compensation point rises with increasing leaf temperatures.

Considering the community structure of mangrove flora, the effect of rising temperature is, however, different in some regions. Increases in temperature are predicted to benefit Pacific Islands, because warming is projected to increase the diversity of marginal mangroves at higher latitudes, currently home to only *Avicennia* species (Burns, 2001). In the Pacific Islands, warming is projected to facilitate mangrove expansion into salt-marsh communities (Burns, 2001).

Mangrove species in China have demonstrated varying thermal tolerances. Li and Lee (1997) divided the mangrove species in China into three classes based on thermal tolerance: 1) cold-resistant eurytopic species (*e.g.*, *Kandelia candel*, *Avicennia marina* and *Aegiceras corniculatum*); 2) cold-intolerant (thermophilic) stenotopic species (*e.g.*, *Rhizophora mucronata*, *R. apiculata*, *Lumnitzera littorea*, *Nypa fruticans* and *Pemphis acidula*); and 3) thermophilic eurytopic species, (*e.g.*, *R. stylosa*, *Bruguiera sexangula*, *B. gymnorrhiza*, *Excoecaria agallocha* and *Acrostichum aureum* (Zhang and Lin, 1984).

Despite the uncertainties of how temperature changes will affect the species composition or the seasonal patterns of reproduction and flowering of mangroves, an increase in sea-surface and air temperatures would likely benefit mangroves living near the pole-ward limits of current distributions; leading to increased species diversity, greater litter production, and larger trees in these mangrove systems (Edwards, 1995). Temperature increases may impact mangroves by changing the seasonal patterns of reproduction and the length of time between flowering and the fall of mature propagules (UNEP, 1994; Ellison, 2000).

3.2. Effect of alteration of precipitation pattern

Precipitation rates are predicted to increase by about 25 percent by 2050 in response to global warming. However, at regional scales, this increase will be unevenly distributed with either increases or decreases projected in different areas (Knutson and Tuleya, 1999; Walsh and Ryan, 2000; Houghton et al., 2001). Changes in precipitation patterns caused by climate change may have a profound effect on both the growth of mangroves and their aerial extent (Field, 1995; Snedaker, 1995). Regional climate models predict that precipitation will decrease in certain areas (*e.g.*, Central America during the months of winter, Australia in winter) (Houghton et al., 2001). Decreased precipitation may not only result in less freshwater input to mangroves, but it may also cause less freshwater input into the groundwater which has significant probability to increase salinity of the ambient media. Increase in soil salinity results in the rise of salt content in mangrove tissues. Increased salinity and lack of freshwater is likely to decrease mangrove productivity, growth, and seedling survival, and may change species composition favouring more salt tolerant species (Ellison, 2000). The examples of Australian mangroves can be cited in this context. These mangroves are stunted, of narrower margins, and interrupted by salt flats in areas of lower rainfall mainly due to salt stress (Ellison, 2000). Decreased rainfall, combined with the increase in evaporation in arid areas, is also likely to result in a decrease in mangrove area, decrease in diversity, and projected loss of the landward zone to un-vegetated hypersaline flats (Snedaker, 1995).

In regions where rainfall is projected to increase due to climate change (*e.g.*, northern mid-latitude regions in winter and in the Pacific Islands north of 17°S; Houghton et al., 2001), mangrove area, diversity and growth rates may increase (Ellison, 2000). Maximal growth of mangroves has been linked to low salinities (Burchett et al., 1984; Clough, 1984). Thus if precipitation increases and results in decreased soil salinity, mangrove growth rates may increase in some species (Field, 1995). In Australia, mangroves grow taller, more productive, and more diverse in areas of higher rainfall (Ellison, 2000). Harty (2004) suggests that increases in rainfall reduce salinity levels within salt-marshes which allows mangroves to migrate and outcompete salt-marsh vegetation. This trend of mangrove transgression into salt-marsh habitat has been observed in southeast Australia due to increases in precipitation.

In Indian Sundarbans region, mangrove species like *Heritiera fomes* and *Nypa fruticans* are gradually vanishing from the central region owing to complete cut-off of the freshwater supply due to Bidyadhari siltation. These species are, however, coming up luxuriantly in low saline pockets of Sundarbans particularly in the western part, which is gradually freshening due to more flow of freshwater through Ganga-Bhagirathi-Hugli channel (Mitra et al., 2009). Decrease in salinity in this important World Heritage site, by ways of Bidyadhari dredging and interlinking the Ganga-Hugli-Bhagirathi channel (in the western Indian Sundarbans) with the Rivers of the hypersaline central sectors (like Matla) may increase the mangrove species diversity in and around the Matla River in the central Indian Sundarbans.

3.3. Effect of rise in CO_2 concentration

Atmospheric CO_2 has increased from 280 parts per million by volume (ppmv) in the year 1880 to nearly 370 ppmv in the year 2000 (Houghton et al., 2001) and this trend will continue due to intense industrialization and urbanization through out the globe. Researchers, however, state that most atmospheric CO_2 resulting from burning of fossil fuels will be absorbed into the ocean affecting ocean chemistry. According to UNEP (1994), the efficiency of mangrove water use will be enhanced, and there will be specific species variation in response to elevated CO_2. Due to the increase in water use efficiency, mangroves in arid regions may benefit because decreased water loss *via* transpiration will accompany CO_2 uptake (Ball and Munns, 1992). Increased salinity may, however, pose hindrance to this benefit. If salinity increases in arid regions, then this advantage may be lost, because increases in CO_2 do not affect mangrove growth when salinity is too high for a species to maintain water uptake (UNEP, 1994). Increases in CO_2 are not likely to cause mangrove canopy photosynthesis to increase significantly (UNEP, 1994). Several scientists, however, documented the positive influence of rising CO_2 on mangrove vegetation. In an experiment aimed to test the effects of humidity, salinity, and increased CO_2 on two Australian mangrove species, *Rhizophora stylosa* and *Rhizophora apiculata*, the rate of photosynthesis showed significant increase with increased levels of CO_2. In this experiment, the mangroves were grown in glasshouses for 14 weeks with different combinations of atmospheric CO_2 (340 and 700 ppm), relative humidity (43 and 86 percent), and salinity (25 and 75 percent of seawater) to determine the effects of these variables on their development and growth. Although *Rhizophora stylosa* has a slower relative growth rate and greater salt tolerance than *Rhizophora apiculata*, the scientists concluded that elevated CO_2 significantly increased rates of net photosynthesis in both mangrove species, but only when grown at the lower salinity level. In addition, while increased CO_2 levels did not significantly affect the relative growth rate of either species, the average growth rates of both species increased with atmospheric CO_2 enrichment in the lower salt environment. These scientists postulated that increased levels of CO_2 might allow these two mangrove species to expand into areas of greater aridity, thus increasing species diversity in those regions. Snedaker and Araújo (1998) exposed four mangrove species *Rhizophora mangle*, *Avicennia germinans, Laguncularia racemosa*, and *Conocarpus erectus* to increased CO_2 (361-485 ppm). All four species demonstrated significant decreases in stomatal conductance and transpiration and an increase in instantaneous transpiration efficiency. Only *L. racemosa* demonstrated a significant decrease in net primary productivity when exposed to increased CO_2. Snedaker and Araújo (1998) suggested that increased levels of CO_2 on a global scale may result in a competitive disadvantage of *L. racemosa* in mixed mangrove communities relative to the other species whose rates of net primary productivity are not significantly affected by increases in CO_2. The results of this study indicate that global increases in CO_2 may result in a competitive advantage of mangroves in arid regions due to their ability to minimize water use during periods of water stress while maintaining relatively high rates of CO_2 uptake (Snedaker and Araújo, 1998). Farnsworth et al (1996) analyzed the effects of doubled levels of CO_2 on *Rhizophora mangle* seedlings. The seedlings demonstrated significant increases in biomass, total stem length, branching activity, and total leaf area compared to seedlings grown in normal levels of CO_2. In this study, reproduction of *Rhizophora mangle* was achieved after only one year of growth in a high CO_2 environment, whereas it typically takes a full two years before they are able to reproduce in the field; thus elevated CO_2 also appeared to accelerate maturation in addition to growth. However, Ellison et al (1996) predict that whether increased atmospheric CO_2 results in enhanced growth of mangroves, it will likely not be enough to compensate for the negative impacts of sea level rise. One indirect impact on mangroves of increased temperature and CO_2 is the degradation of coral reefs caused by mass bleaching and impaired growth (Hoegh-Guldberg, 1999). Damage to coral reefs may adversely impact mangrove systems (where mangrove-reef couple system exists) that depend on the reefs to provide shelter from wave action.

3.4. Effect of sea level rise

In the last century, eustatic sea level has risen 10 - 20 cm primarily due to thermal expansion of the oceans and melting of glacial ice caused by global warming (Church et al., 2001). Several climate models project an accelerated rate of sea level rise over coming decades (Church et al., 2001). Sea level changes have also been influenced by tectonic and isostatic adjustments (i.e., ocean basin deformation and land subsidence or emergence) (Kennish, 2002). Past sea level change has been measured by tide gauges at different locations around the world. Tide gauges are not evenly distributed around the globe which biases the data and does not provide an accurate picture of the global pattern of sea level change (Cabanes et al., 2001). However, despite the uncertainties in tide gauge data, scientists estimate that the global average sea level rose at a rate of 1.0 to 2.0 millimeters (mm)/year during the 20th century (Houghton et al., 2001). This increase is an order of magnitude larger than the average rate over the previous several thousand years (CSIRO, 2001). During the 21st century, mean sea level projections range from 0.09 to 0.88 m (Houghton et al., 2001). In addition to the uncertainties of global sea level rise, uncertainties also exist for how regions will experience different rates and magnitudes of sea level rise. Regional sea level rise is affected by tectonic movements that can cause land subsidence or uplift. Natural and human induced sediment compaction can also exacerbate the impacts of sea level rise. Humans contribute to land subsidence through coastal development that causes deficits in the sediment budget, shipping channels that cause bank erosion, groundwater or oil extraction that causes submergence, and dredging and mining that causes losses of land. The combination of global sea level rise and local impacts that cause land subsidence threaten the existence of mangroves worldwide. Mangrove systems cannot keep pace with the rate of sea level rise. Hence they tend to migrate in response to rising sea level.

3.5. Effect of alteration of aquatic salinity

The polar ice melting being a consequence of global warming, results in the intrusion of seawater in the upstream zone of estuaries and connecting bays. This can create alteration in the physiological conditions of flora and fauna inhabiting the estuarine stretch. It has been observed that increased salinity decreases mangrove net primary productivity, growth, and seedling survival, and may possibly change competition between mangrove species (Ellison, 2000). The alteration of salinity in the river mouths and estuaries is a function of several factors like sea level rise, volume of freshwater discharge from barrage (constructed in the upstream zone of rivers or estuaries), evaporation, precipitation, continental runoff etc. Changes in precipitation patterns are expected to affect mangrove growth and spatial distribution (Field, 1995; Ellison, 2000) by altering the salinity level of the ambient aquatic phase. Based primarily on links observed between mangrove habitat condition and rainfall trends (Field, 1995; Duke et al., 1998), decreased rainfall and increased evaporation will increase salinity, decreasing net primary productivity, growth and seedling survival, altering competition between mangrove species, decreasing the diversity of mangrove zones, causing a notable reduction in mangrove area due to the conversion of upper tidal zones to hypersaline flats. Areas with decreased precipitation will have a smaller water input to groundwater and less freshwater flow to mangroves, increasing salinity. As soil salinity increases, mangrove trees will have increased tissue salt levels and concomitant decreased water availability, which reduces productivity (Field, 1995).

Reports on the adverse impact of salinity on chlorophyll content of mangrove species are also available (Kotmire and Bhosale, 1980; Shinde and Bhosale, 1985).

The present paper thus leads us to conclude a dramatic change in mangrove spectrum of Indian Sundarbans not only in terms of migration and stunted growth of the floral species, but also in context to extinction of certain species (like *H. fomes*) due to increase of salinity. A proper policy needs to be formulated to mitigate and adapt with pace of climate change induced threats in Indian Sundarbans.

4. CONCLUSION:

Human societies derive multiple benefits from mangrove ecosystems and these ecosystem services can be categorized into four major groups namely (i) nursery services of mangrove in which the forests act as the breeding and nursery of a wide spectrum of finfishes and shellfishes, (ii) fuel, fodder and timber generation as sources of livelihood, (iii) shoreline stabilization and land building capacity and (iv) carbon storage and subsequent sequestration. These valuable ecosystem services are often hampered due to adverse impact of climate change on mangroves. The changes in biomass and distribution pattern of mangrove due to alteration of ambient environmental parameters greatly reduce the availability of timber, fuel, fodder and other benefits of mangroves which are economically important at the local scale. The mangrove litter production is also adversely affected due to which the adjacent aquatic environment becomes nutrient deficit resulting in the poor production in the sector of fishery.

5. RECOMMENDATIONS:

Recognizing the magnitude of adverse impact of climate change on mangroves, a sound management and policy strategy must be undertaken so that the potentially negative economic effects are minimized, or even averted, while the potentially positive effects are enhanced. The roadmaps include interlinking of rivers to create a balance between hyper-saline and hypo-saline estuaries, rain water harvesting, providing alternative livelihood to local inhabitants as adaptation to climate change and prevent deforestation at the cost of developmental activities.

REFERENCES:

1. Andrews, T.J. and Muller, G. J. 1985. Photosynthetic gas exchange of the mangrove, Rhizophora stylosa Griff., in its natural environment. Oecologia, 65: 449-55.

2. Andrews, T.J., Clough, B.F. and Muller, G.J. 1984. Photosynthetic gas exchange and carbon isotope ratios of some mangroves in North Queensland. In: Physiology and Management of Mangroves, Tasks for Vegetation Science. H.J. Teas. (ed.)., 15–23.
3. Ball, M.C. and Munns, R. 1992. Plant responses to salinity under elevated atmospheric concentrations of CO_2. Australian Journal of Botany, 40: 515-525.
4. Burchett, M,D., Field, C.D. and Pulkownik, A. 1984. Salinity, growth and root respiration in the grey mangrove *Avicennia marina*. Physiologia Plantarum, 60: 113-118.
5. Burns, W.C.G. 2001. The possible impacts of climate change on Pacific Island State ecosystems. International Journal of Global Environmental, 1 (1): 56 pp.
6. Cabanes, C., Cazenave, A. and Le Provost, C. 2001. Sea-level rise during the past 40 years determined from satellite and in situ observations. Science, 294: 840-842.
7. Church, J., Gregory, J., Huybrechts, P., Kuhn, M., Lambeck, K., Nhuan, M., Qin, D. and Woodworth, P. 2001. Chapter 11. Changes in Sea Level. Pp. 639-693 in Houghton, J., Y, Ding, D. Griggs, M. Noguer, P. van der Linden, X. Dai, K. Maskell, C. Johnson, Eds. Climate Change 2001: The Scientific Basis. Published for the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 881 pp.
8. Clough, B.F. 1984. Growth and salt balance of the mangroves *Avicennia mari*na (Forsk.) Vierh, and *Rhizoplhora slylosa* griff. in relation to salinity. Australian Journal of Plant Physiology, 11: 419-430.
9. Clough, B.F., Andrews, T.J. and Cowan, I.R. 1982. Primary productivity of mangroves. In: Clough, B.F. Ed. Mangrove Ecosystems in Australia- structure function and management. AIMS with ANU press, Canberra, Australia.
10. Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2001. Climate Change Impacts for Australia. CSIRO Impacts and Adaptation Working Group, CSIRO Sustainable Ecosystems, Aitkenvale, Queensland.
11. Duke, N.C., Ball, M.C. and Ellison, J.C. 1998. Factors influencing biodiversity and distributional gradients in mangroves. Global Ecological Biogeography, 7: 27–47.
12. Duke, N.C., Meynecke, J.O., Dittmann, S., Ellison, A.M., Anger, K., Berger, U. C.S., Diele, K., Ewel, K.C., Field, C.D. and Koedam, N. 2007. A world without mangroves? Science, 317 (5834): 41-42.
13. Edwards, A. 1995. Impact of climate change on coral reefs, mangroves, and tropical seagrass ecosystems. In Climate Change Impact on Coastal Habitation. Lewis Publishers. D. Eisma, Ed.
14. Ellison, A.M., Farnsworth, E.J. and Twilley, R.R. 1996. Facultative mutualism between red mangroves and root-fouling sponges in Belizean mangal. Ecology, 77: 2431-2444.
15. Ellison, J.C. 2000. How South Pacific mangroves may respond to predicted climate change and sealevel rise. Chapter 15, pages 289-301 In A. Gillespie and W. Burns, (eds.) Climate Change in the South Pacific: Impacts and Responses in Australia, New Zealand, and Small Islands States, Kluwer Academic Publishers, Dordrecht, pp. 289-301.
16. Ellison, J.C. 2005. Impacts on mangrove ecosystems. The Great Greenhouse Gamble: A conference on the Impacts of Climate Change on Biodiversity and Natural Resource Management: Conference Proceedings, Sydney, NSW, EJ.
17. Farnsworth, E.J., Ellison, A.M. and Gong, W.K. 1996. Elevated CO_2 alters anatomy, physiology, growth and reproduction of red mangrove (*Rhizophora mangle* L.). Oecologia, 108: 599–609.
18. Field, C.D. 1995. Impacts of expected climate change on mangroves. Hydrobiologia, 295 (1-3): 75-81.
19. Godoy, M.D. and Lacerda, L.D.D. 2015. Mangroves Response to Climate Change: A Review of Recent Findings on Mangrove Extension and Distribution. Anais da Academia Brasileira de Ciências, 87 (2): 651-667.
20. Harty, C. 2004. Planning strategies for mangrove and saltmarsh changes in Southeast Australia. Coastal Management, 32, 405-415.
21. Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world’s coral reefs. Marine Freshwater Research, 50: 839-866.
22. Houghton, J., Ding, Y., Griggs, D., Noguer, M., van der Linden, P., Dai, X., Maskell, K. and Johnson, C. (eds.). Climate Change 2001: The Scientific Basis. Published for the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 881 pp.
23. Hutchings, P. and Saenger, P. (1987). Ecology of mangroves. Queensland (Australia): University of Queensland Press.
24. Kennish, M.J. 2002. Environmental threats and environmental future of estuaries. Environmental Conservation, 29 (1): 78–107.
25. Knutson, T.R. and Tuleya, R.E. 1999. Increased hurricane intensities with CO2- induced warming as simulated using the GFDL hurricane prediction system. Climate Dynamics, 15: 503-519.

26. Kotimire, S.Y. and Bhosale, L.J. (1980). Chemical Composition of Leaves of *Avicennia officinalis* Linn. & *A. marina* var. acutissima Stapf & Moldenke. Indian Journal of Marine Science, 9: 299-301.
27. Li, M.S. and Lee, S.Y. 1997. Mangroves of China: a brief review. Forest Ecology and Management, 96: 241–259.
28. Mitra and S. Zaman. 2014. Carbon Sequestration by Coastal Floral Community; published by The Energy and Resources Institute (TERI) TERI Press, India, ISBN 978-81-7993-551-4.
29. Mitra, A. 2013. In: Sensitivity of Mangrove becosystem to changing Climate. Springer DOI: 10.1007/978-; 81-322-1509-7, 323.
30. Mitra, A. and Zaman, S. 2015. Blue carbon reservoir of the blue planet, published by Springer, ISBN 978-81-322-2106-7 (Springer DOI 10.1007/978-81-322-2107-4).
31. Mitra, A. and Zaman, S. 2016. Basics of Marine and Estuarine Ecology, 2016, Springer, ISBN 978-81-322-2705-2.
32. Mitra, A., Gangopadhyay, A., Dube, A., Schmidt. A.C.K. and Banerjee, K. 2009. Observed changes in water mass properties in the Indian Sundarbans (Northwestern Bay of Bengal) during 1980 - 2007. Current Science, 1445-1452.
33. Moore, R.T., Miller, P.C., Albright, D. and Tieszen, L.L. 1972. Comparative gas exchange characteristics of three mangrove species during the winter. Photosynthetica 6, 387–393.
34. Richards, D.R. and Friess, D.A. 2016. Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. PNAS, 113 (2): 364-349.
35. Saenger, P. and Moverly, J. 1985. Vegetative phenology of mangroves along the Queensland coastline. Proceeding of Ecological Society of Australia, 13: 257-65.
36. Shinde, L.S. and Bhosale, L.J. 1985. Studies on salt tolerance in Aegiceros corniculatum (L) Blanco and Sesuvium portulacastrum (L), In: The Mangroves: Proceedings of National Symposium on Biology, Utilization and Conservation of Mangroves, 300-304.
37. Snedaker, S.C. 1995. Mangroves and climate change in the Florida and Caribbean region: scenarios and hypotheses. Hydrobiologia, 295: 43-49.
38. Snedaker, S.C. and Araujo, R.J. 1998. Stomatal conductance and gas exchange in four species of Caribbean mangroves exposed to ambient and increased CO_2. Marine Freshwater Research, 49: 325-327.
39. UNESCO 1992. Coastal systems studies and sustainable development. Proceedings of the COMAR Interregional Scientific Conference, UNESCO, Paris, 21-25 May, 1991. UNESCO, Paris. 276 pp.
40. United Nations Environment Programme (UNEP). 1994. Assessment and monitoring of climatic change impacts on mangrove ecosystems. UNEP Regional Seas Reports and Studies. Report no. 154.
41. Walsh, K.J.E, and Ryan, B.F. 2000. Tropical cyclone intensity increase near Australia as a result of climate change. Journal of Climate, 13: 3029-3036.
42. Ward, R.D., Friess, D.A., Day, R.H. and MacKenzie, R.A. 2016, Impacts of climate change on mangrove ecosystems: a region by region overview. Ecosystem Health and Sustainability, 2 (4).
43. Woodroffe, C.D. and Grindrod, J. 1991. Mangrove biogeography: the role of quaternary environmental and sea-level change. Journal of Biogeography, 18: 479-492.
44. Zhang, R.T. and Lin, P. 1984. Studies on the flora of mangrove plants from the coast of China. J. Xiamen Univ. (Nat. Sci.) 23, 232-239, in Chinese, with English abstract.