International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

Blue Carbon Stock of Mangrove Ecosystems

Ahalya A[1], Jin Soon Park[2]

[1]Marine Bioscience and Environment, Korea Maritime and Ocean University

[2]Ocean Science and Technology School, Korea Maritime and Ocean University

Abstract: ***Blue carbon has received international attention recently for its capability to mitigate climate change due to CO_2 emissions. Researches have proven the efficient way of fostering carbon sequestration by the mangroves; a blue carbon ecosystem, which can be a prominent tool in reduction of anthropogenic-driven CO_2 emissions. Despite their significant function as eminent carbon sequesters, mangroves are being destroyed mainly via deforestation and urban development. Estimates of national and global carbon sequestration are hindered by lack of awareness and poor estimates of ecosystem extent. Research should be fortified in assessment of blue carbon fluxes and stocks of mangroves coupled with awareness promotion around coastal communities; so they can be conserved from further dwindle.***

Keywords: Blue carbon, CO_2 emission, Mangroves, Climate mitigation

1. Introduction

Coastal wetlands are the most productive ecosystems and they help maintain well-being of the coastal communities and biodiversity [6], [12], [16]. These ecosystems sequester and store great quantities of "blue carbon" [14], [21], which defined as the carbon stored or exchanged in the oceanic and coastal realm [9], [16] through this term often colloquially refers to vegetated habitats within the coastal or near coastal zone [9]. In other words, the carbon sequestered in coastal and marine vegetated ecosystems [14] known to be "coastal wetland blue carbon" [13]. Generally, salt marshes, seagrasses and mangroves referred to as blue carbon ecosystem [6], [7], [9], [10], [12], [13], [15], [21], [24], [26]. Global coverage of blue carbon ecosystems are 51 million ha, of which 15.6 million ha (31%) is mangroves [2]. On a per area basis, coastal wetlands are more efficient carbon sinks than more terrestrial forests [16]. Blue carbon ecosystems mainly occupy the intertidal and shallow water environments, where their distribution, productivity and rats of vertical accretion of coils are strongly influenced by sea level and the space available to accumulate sediment [14].

However, these ecosystems account only for only 0.2% of the ocean area, but the carbon deposits in sediments account for approximately 50% of the total carbon deposits in marine sediments. The blue carbon concept was introduced as a metaphor aimed at highlighting the coastal ecosystems, in addition to terrestrial forests, contribute significantly to organic carbon sequestration. Later on, it has been projected as a tool for climate change mitigation [14].

Parties ratifying the Paris Agreement [11], [16], [24] have pledged to 'achieve a balance between anthropogenic emissions by sources and removals by sinks by 2100'. Within the context of climate-change mitigation, enhancing the capacity and role of natural carbon sink has become an increasingly important scientific topic. As anthropogenic climate change presents an ever-growing problem to the international community, it is necessary to seek out for creative yet ecofriendly ways to reduce the human carbon footprint, addressing the land-use changes. Thus, the notion of blue carbon is attractive, indeed exciting, to many in the conservation and policy communities [26]. However, the science and policy for the coastal blue carbon has not been well established [25]. Therefore, this paper focus to briefly summarize the scientific concept of blue carbon and role of mangrove ecosystems in carbon sequestration.

2. The concept of Blue Carbon

It has been reported that the ocean represents the largest active carbon sink on Earth, absorbing 20-35% of anthropogenic CO_2 emissions [13]. Ocean blue carbon refers to the absorbed and fixed carbon in the ocean from atmospheric CO_2. It has been proved that the blue carbon ecosystems are the highest carbon sinks per lot.

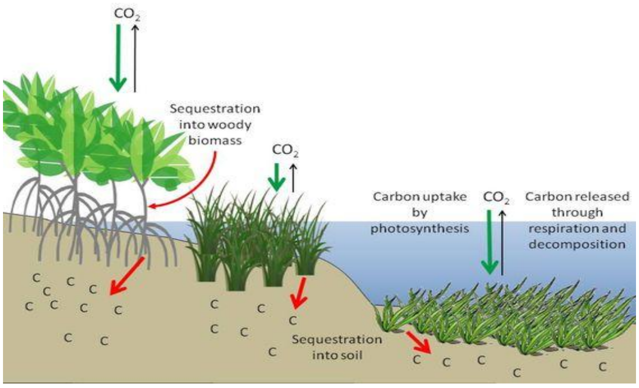

Figure 1: The fate of carbon dioxide in a blue carbon ecosystem (from left to right: mangroves, tidal marshes and seagrasses). In intact coastal wetlands, carbon is captured via photosynthesis (green arrows) and sequestered into woody biomass and soils (red arrows) while a part of it is lost again to the atmosphere via respiration (black arrows).

Studies have shown that these ecosystems are ten time both more effective at sequestering carbon dioxide on a per area basis than boreal, temperate or tropical forests. Carbon emissions together with other greenhouse gases (CH_4, N_2O) are likely to have a dominant influence on climate change. The global average atmospheric carbon dioxide concentration rose to 387 parts per million (ppm) in December 2009 [15]. According to IPCC, 2013 the cumulative anthropogenic carbon dioxide emission is about 555 (470 to 640) GtC. Human emissions of CO2 from fossil energy and industrial production release approximately 7.8 PgC yr^{-1} [25]. The scientific community believes that this rapid increase has been driven by anthropogenic influence and substantially contributed to the increase in atmospheric CO2 from 320 ppm to approximately 400ppm over the past 70 years. Actions like burning of fossil fuels [7], [15] ,[21] anthropogenic degradation and deforestation [21], [27] of coastal wetlands [3], [7], [13] can convert the blue carbon ecosystems from net sinks to sources of carbon [13], [15], [27].

The blue carbon ecosystems absorb the CO2 and store in them for millennia, aiding in climate change mitigation. Mangroves, tidal marshes and seagrasses sequester and store large amounts of carbon through natural capture during photosynthesis or by trapping sediments and natural debris in their complex root systems. Within these ecosystems, CO2 from the atmosphere is taken up via photosynthesis, most of which is returned almost immediately plant and microbe reparation or temporarily stored in the plant foliage, whereas the remainder is sequestered for a long period in woody biomass and soils [13].

Research on natural carbon sinks has focused predominantly on either ocean ecosystems. The ocean has absorbed one third of anthropogenic CO2 emissions through physical, chemical and biological processes. Efforts should be taken to reduce anthropogenic emissions while conserving the coastal wetlands. The value of blue carbon ecosystems in sequestering organic carbon has intensified conservation interests as measure to mitigate climate change and offset CO_2 emissions [10].

3. Mangroves: Unique blue carbon ecosystem

Blue carbon ecosystems cover a vast area worldwide. Of them mangroves account only about 0.5% of the global coastal area [19] and 0.7% of the global tropical forest cover [18]. However, they are the most productive ecosystems along the estuaries, sea coasts and river mouths in the tropical and sub-tropical intertidal zones[7], that store enormous amount of carbon [1], [2] [6] as a significant fraction of their soil carbon is plant-derived. Mangroves play a significant role as blue carbon sinks. It has been estimated that globally they can capture approximately 24Tg C/year [20], store approximately 6.5 petagrams of carbon (PgC), which is nearly 26.8 petagrams of carbon dioxide equivalent [6]. Literatures show that mangroves can store up to five times the carbon present in tropical forests per area [2], [20], sequestering over 2 tons of carbon on average per ha/year [20].

A recent estimation proves based on a spatial data generated by Chandra Giri in 2011, mangroves has a global coverage of 13.8-15.2 million ha [2], [13], [14], [21], [25]. It has been demonstrated that these coastal forests can store up to five times the carbon present in tropical forests per area, sequestering over 2 tons of carbon on average per ha/year [20]. Mangroves are architecturally simple compared with the terrestrial forests [6]. Nevertheless, the standing biomass of some mangrove forests in equatorial regions can be immense, rivaling the height and weight of many tropical rainforests [4].

Mangrove forests occur along the ocean coastlines [4], [9] regularly flooded by tidal water [8], [13] and support numerous ecosystem services, including fisheries production nutrient cycling [8], nursery grounds for fish, mammals and other semi-terrestrial [18] and aquatic fauna including crabs, mollusks, oysters, and shrimps [2], depocenters for sediment, carbon and other elements, shoreline protection against coastal erosions, tsunami and tropical storms, waves and coastal erosion [19], [23]. Moreover, they maintain the water cycle and water quality [19].

Mangroves are the woody halophytes [22] that live along the world's subtropical and tropical coastlines [2], [4], [22]. Overall mangroves have a significant role in coastal economics and ecology.

Table 1: Carbon sequestration potential of mangroves

Geographic extent	Annual carbon sequestered	Mean global estimate of carbon stock	Anthropogenic conversion rate	Estimated emission due to conversion#
Million ha	Million Mg C yr^{-1}	Million Mg C	% yr^{-1}	Million Mg CO_2
13.8-15.2	31.2-34.4	5617-6186	0.7-3.0	144.3-681.1

#Estimated value assuming that all carbon is converted to CO_2

Carbon stock estimation of mangroves has become an increasingly trend during the past years, since they play a key role in climate mitigation [4] strategies. Mangrove blue carbon stocks are the sum of carbon stored in tree shoots, roots, downed wood and soils, stratified into depth layers [18]. Kauffman and Donato showed that prominent portion of the carbon stock is stored in soil [1] because they have a tendency to accumulate carbon relatively quickly [4]. Mangrove soils consist of a variable thick, tidally submerged suboxic layer [20] (variously called 'peat' or 'muck') supporting anaerobic decomposition pathways and having moderate to high carbon concentration [8]. This has been proved in studies because authors have found out that an estimate of 78% of the carbon is stored in soils whereas 20% in living trees and roots (or biomass) and the remaining 2% in dead or downed wood [2], [4], [19]. Carbon in the plant biomass is stored for years to decades while carbon in soils can remain sequestered for millennia [13]. Other carbon studies present that both above and below ground biomass increases, and that the ratio of below to above ground biomass decreases with increasing stand age.

Formation of mangrove soils is a result of cumulative ecological processes like weathering, transportation, sedimentation, and burial of organic matter [22]. It is evident that the carbon storage is thus dependent on such biophysical dynamics. A major reason for the overestimation or underestimation of mangrove carbon pools is that they are complex and non-linear with considerable dynamism allied with constantly changing shorelines and varied sea levels [26]. The amount of carbon stored in mangrove soils varies widely, from <0.1% by soil dry weight to >40% with a grand median of 2.2% [4], [22].

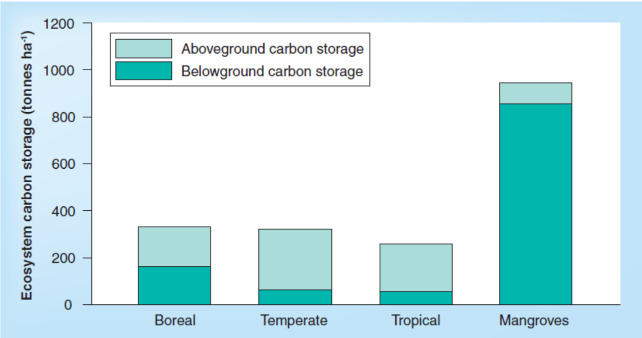

Figure 2: Difference in whole-ecosystem carbon stocks among boreal, temperate and tropical forests and subtropical and tropical mangrove forests [4].

Carbon burial rates within a mangrove forest may be affected by variability in hydro period, salinity, nutrient status and suspended sediment supply. Variations in carbon burial capacity are linked to the extensiveness of plant parts, decomposition, primary productivity that are driven by physical (temperature, precipitation, sea level, nutrients, sediment type), biological (species composition, bioturbation, trophic cascades) [5], [15], [20], [22] and biogeochemical variables [14]. With respect to biological factors, it remains unclear how primary producer diversity and traits (biochemical composition, productivity, size and biomass allocation) influence blue carbon burial rate [14]. Studies also notify pH, soil texture, temperature, rainfall pattern, hydrology and management practices as factors responsible for retaining the carbon sequestered in the mangrove soils [22]. Alongi further relates mangrove soils carbon burial rate to number of other factors including location of the forest in relation to the open coast, distance to the adjacent aquatic habitats, tidal amplitude, forest position in the tidal seascape and productivity of primary producers [4].

4. Mangrove blue carbon sinks to source

According to studies, globally, among the carbon captured through photosynthesis, 45% is stored in terrestrial ecosystems as green carbon and the remaining 55% is stored in the ocean by phytoplankton and coastal blue carbon ecosystem [25]. Despite the substantial role played by blue carbon sinks, destruction of these ecosystems would convert them from sinks to sources of carbon dioxide emission. [27]. Threats to blue carbon ecosystems are complicated and multi-faceted [12]. Such alarming threats are at its highest concern by the scientific community.

When coastal habitats are degraded or converted to other land uses, the sediment carbon is destabilized or exposed to oxygen, and subsequent increased microbial activity releases large amounts of greenhouse gas (GHG) to the atmosphere or water column [21]. Coastal wetland destruction and drainage is estimated to be 0.7-3% annually (0.7-7% [15], [27]) (depending on vegetation type and location), resulting in 0.23-2.25 billion Mg of CO_2 release [13]. The estimated annual CO_2 emission from the disturbance of blue carbon ecosystems were estimated at 0.45 Petagrams CO_2 globally [14]. Studies suggest that blue carbon ecosystems are mostly threatened by coastal development and land use changes [6], which mangroves and tidal marshes are often prone to [13]. It have been reported that human activities have greatly modified the exchange of carbon and nutrients between terrestrial and coastal zones, prominently affecting the coastal ecosystem carbon cycling [9], [27].

Mangrove deforestation causes carbon emission and reduces carbon sequestration. Blue carbon emissions are being critically augmented due to devastating effects on mangroves [2]. Mangroves are naturally disturbed by tsunamis, floods, cyclones, lightning, pests and disease, and become stressors that are more susceptible when human such as pollutants are introduced [4]. Almost one-third of the of world's mangroves have been lost in the past 50 years mainly due to conversion to aquaculture [9] and agricultural fields [4], [7], engineering [15] and urban development, mining and overexploitation of timber, fish, crustaceans and shell fish [4], land clearing [8], coastline disturbance and upstream soil loss [12], [13], dredging, diking, drainage, trophic cascades, and invasive species [15]. Such losses reduce their capacity for carbon storage and have serious implications for human populations that depend of these ecosystems for food, livelihoods, and coastal protection [15]. Mangrove habitat loss carries with it the loss of critical functions including; carbon sequestration, biodiversity conservation through the provision of structure, nutrients and primary productivity; filtration of pollutants; nurseries for commercially important fish and shrimp; buffering against tsunamis and hurricane [17].

A 30-50% areal decline over the past-century has prompted estimates that mangroves may functionally disappear in as little as 100 years [8]. Globally, deforestation and conversion of mangroves has been shown to contribute to 0.08-0.48 Pg $CO_2e\ yr^{-1}$, or 10% of the total global emissions from the tropical deforestation [18].

5. Mangrove blue carbon conservation

Understanding their prominent role in carbon cycle, actions should be taken to conserve the pristine mangrove ecosystem for the sustainability of blue carbon flux and to ensure the reduction of impacts by anthropogenic-driven CO_2 emissions. Mangroves can be used increasingly in carbon sequestration and global climate mitigation strategies [1]. Mangrove restoration is considered part of adaptation to climate change since it is potentially a low-cost aid to address the amplified risks from climate change [2]. Various studies have shown the potential for significant GHG emissions if the high per-hectare carbon stocks of mangroves are disturbed (Table 1) [4].

With regard to the threats against blue carbon ecosystems, it can be argued that the common concern principle is applicable for various reasons. Most important of all, is global acknowledgement that blue carbon ecosystems face a number of pressures, including specific recognition of threats to mangrove swamps chiefly rising due to rising sea levels and coastal developments and attempts to include blue carbon ecosystems in climate change mitigation strategies have recently emerged [6]. However, the synergies between mitigation and adaptation using nature-based solutions have become increasingly clear. Mangrove conservation and restoration are already incorporated in UNFCCC forest mechanisms such as Reducing Emissions form Deforestation and Forest Degradation (REDD+) and as part of Land Use, Land-Use Change and Forestry (LULUCF) activities if a country defines mangroves as a forest [11], [13].

To achieve emissions reduction targets and inform climate mitigation policies, we argue that a comprehensive strategy is necessary, one that recognizes the role of science-driven management practices in natural ecosystems, including coastal wetlands. However, there is an insufficiency or a gap prevailing regarding the availability of scientific data about the geographical extent and the carbon sequestration potential of mangroves. Despite the limitations, it should be clearly understood that they drive the marine carbon dynamics and associated biogeochemical processes, apart from the other functions like costal protection, habitat provision and tourism promotion. The scientific evidence addressing the vital role of mangroves as long-term carbon sinks should be well established. Specific studies are required to improve the understanding on the value of mangrove blue carbon sinks. In doing so, we can conserve the existing mangrove patches and protect them from further rapid degradations.

References

[1] Adame, M. F., Cherian, S., Reef, R., & Stewart-Koster, B. (2017). Mangrove root biomass and the uncertainty of belowground carbon estimations. *Forest Ecology and Management*, *403*(August), 52–60. https://doi.org/10.1016/j.foreco.2017.08.016

[2] Ahmed, N., & Glaser, M. (2016). Coastal aquaculture, mangrove deforestation and blue carbon emissions: Is REDD+ a solution? *Marine Policy*, *66*, 58–66. https://doi.org/10.1016/j.marpol.2016.01.011

[3] Alongi, D. M., Murdiyarso, D., Fourqurean, J. W., Kauffman, J. B., Hutahaean, A., Crooks, S., … Wagey, T. (2016). Indonesia's blue carbon: a globally significant and vulnerable sink for seagrass and mangrove carbon. *Wetlands Ecology and Management*, *24*(1), 3–13. https://doi.org/10.1007/s11273-015-9446-y

[4] Alongi, Daniel M. (2012). Carbon sequestration in mangrove forests. *Carbon Management*, *3*(3), 313–322. https://doi.org/10.4155/cmt.12.20

[5] Bouillon, S., Borges, A. V., Castañeda-Moya, E., Diele, K., Dittmar, T., Duke, N. C., … Twilley, R. R. (2008). Mangrove production and carbon sinks: A revision of global budget estimates. *Global Biogeochemical Cycles*, *22*(2). https://doi.org/10.1029/2007GB003052

[6] Buditama, A. (2016). Blue carbon for reducing the impacts of climate change: An Indonesian case study. *Environmental and Planning Law Journal*, *33*(1), 68–88.

[7] Chanda, A., Mukhopadhyay, A., Ghosh, T., Akhand, A., Mondal, P., Ghosh, S., … Hazra, S. (2016). Blue Carbon Stock of the Bangladesh Sundarban Mangroves: What could Be the Scenario after a Century? *Wetlands*, *36*(6), 1033–1045. https://doi.org/10.1007/s13157-016-0819-7

[8] Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience*, *4*(5), 293–297. https://doi.org/10.1038/ngeo1123

[9] Gao, Y., Yu, G., Yang, T., Jia, Y., He, N., & Zhuang, J. (2016). New insight into global blue carbon estimation under human activity in land-sea interaction area: A case study of China. *Earth-Science Reviews*, *159*, 36–46. https://doi.org/10.1016/j.earscirev.2016.05.003

[10] Geraldi, N. R., Ortega, A., Serrano, O., Macreadie, P. I., Lovelock, C. E., Krause-Jensen, D., … Duarte, C. M. (2019). Fingerprinting Blue Carbon: Rationale and Tools to Determine the Source of Organic Carbon in Marine Depositional Environments. *Frontiers in Marine Science*, *6*(May), 1–9. https://doi.org/10.3389/fmars.2019.00263

[11] Herr, D., & Landis, E. (2014). Coastal blue carbon ecosystems. *National Wetlands Newsletter*, *36*(1), 5–7. https://doi.org/http://dx.doi.org/10.2305/IUCN.CH.2015.10.en

[12] Himes-Cornell, A., Pendleton, L., & Atiyah, P. (2018). Valuing ecosystem services from blue forests: A systematic review of the valuation of salt marshes, sea grass beds and mangrove forests. *Ecosystem Services*, *30*, 36–48. https://doi.org/10.1016/j.ecoser.2018.01.006

[13] Howard, J., Sutton-Grier, A., Herr, D., Kleypas, J., Landis, E., Mcleod, E., … Simpson, S. (2017). Clarifying the role of coastal and marine systems in climate mitigation. *Frontiers in Ecology and the Environment*, *15*(1), 42–50. https://doi.org/10.1002/fee.1451

[14] Macreadie, P. I., Anton, A., Raven, J. A., Beaumont, N., Connolly, R. M., Friess, D. A., … Duarte, C. M. (2019). The future of Blue Carbon science. *Nature Communications*, *10*(1), 3998. https://doi.org/10.1038/s41467-019-11693-w

[15] McLeod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., … Silliman, B. R. (2011). A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Frontiers in Ecology and the Environment*, *9*(10), 552–560. https://doi.org/10.1890/110004

[16] Meng, W., Feagin, R. A., Hu, B., He, M., & Li, H. (2019). The spatial distribution of blue carbon in the coastal wetlands of China. *Estuarine, Coastal and Shelf Science*, *222*(February), 13–20. https://doi.org/10.1016/j.ecss.2019.03.010

[17] Miteva, D. A., Murray, B. C., & Pattanayak, S. K. (2015). Do protected areas reduce blue carbon emissions? A quasi-experimental evaluation of mangroves in Indonesia. *Ecological Economics*, *119*, 127–135. https://doi.org/10.1016/j.ecolecon.2015.08.005

[18] Murdiyarso, D., Purbopuspito, J., Kauffman, J. B., Warren, M. W., Sasmito, S. D., Donato, D. C., … Kurnianto, S. (2015). The potential of Indonesian mangrove forests for global climate change mitigation. *Nature Climate Change*, *5*(12), 1089–1092. https://doi.org/10.1038/nclimate2734
[19] Nehren, U., & Wicaksono, P. (2018). Mapping soil carbon stocks in an oceanic mangrove ecosystem in Karimunjawa Islands, Indonesia. *Estuarine, Coastal and Shelf Science*, *214*(September), 185–193. https://doi.org/10.1016/j.ecss.2018.09.022
[20] Palacios Peñaranda, M. L., Cantera Kintz, J. R., & Peña Salamanca, E. J. (2019). Carbon stocks in mangrove forests of the Colombian Pacific. *Estuarine, Coastal and Shelf Science*, *227*(May), 106299. https://doi.org/10.1016/j.ecss.2019.106299
[21] Pendleton, L., Donato, D. C., Murray, B. C., Crooks, S., Jenkins, W. A., Sifleet, S., … Baldera, A. (2012). Estimating Global "Blue Carbon" Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems. *PLoS ONE*, *7*(9). https://doi.org/10.1371/journal.pone.0043542
[22] Perera, K. A. R. S., & Amarasinghe, M. D. (2019). Carbon sequestration capacity of mangrove soils in micro tidal estuaries and lagoons: A case study from Sri Lanka. *Geoderma*, *347*(February), 80–89. https://doi.org/10.1016/j.geoderma.2019.03.041
[23] Ramos, S., & Hesp, P. A. (2018). Threats to Mangrove Forests. *Threats to Mangrove Forests*, *25*(April), 419–427. https://doi.org/10.1007/978-3-319-73016-5
[24] Taillardat, P., Friess, D. A., & Lupascu, M. (2018). Mangrove blue carbon strategies for climate change mitigation are most effective at the national scale. *Biology Letters*, *14*(10). https://doi.org/10.1098/rsbl.2018.0251
[25] Tang, J., Ye, S., Chen, X., Yang, H., Sun, X., Wang, F., … Chen, S. (2018). Coastal blue carbon: Concept, study method, and the application to ecological restoration. *Science China Earth Sciences*, *61*(6), 637–646. https://doi.org/10.1007/s11430-017-9181-x
[26] Thomas, S. (2014). Blue carbon: Knowledge gaps, critical issues, and novel approaches. *Ecological Economics*, *107*, 22–38. https://doi.org/10.1016/j.ecolecon.2014.07.028
[27] Wylie, L., Sutton-Grier, A. E., & Moore, A. (2016). Keys to successful blue carbon projects: Lessons learned from global case studies. *Marine Policy*, *65*, 76–84. https://doi.org/10.1016/j.marpol.2015.12.020

Author Profile

Ahalya Arulnayagam attached to the Department of Coastal and Marine Resources Management of Ocean University of Sri Lanka**;** received B. Sc (Special) degree from University of Jaffna, Sri Lanka, M. Sc from University of Peradeniya, Sri Lanka and currently reading for Master's Degree in Marine Bioscience and Environment at Korea Maritime and Ocean University, Busan, South Korea. Presently she is conducting a research titled, "Assessment of Mangrove Blue Carbon Stock of Sri Lanka" in the Marine Ecology Lab of KMOU.