

# **CARBON RICH MANGROVE FORESTS: AN OVERVIEW FOR STRATEGIC MANAGEMENT AND CLIMATE CHANGE MITIGATION**

## **ABSTRACT**

Carbon dioxide (CO<sub>2</sub>) once emitted to the atmosphere, takes centuries for natural removal. Every 4 giga tones of carbon (GtC) emitted to the atmosphere results in a rise of one ppm of CO<sub>2</sub> in the atmosphere. Mangroves growing near the coast play an important role in carbon sequestration by acting as sink for carbon, thereby receiving considerable international attention. In India Mangroves occupy 4740 sqkm, about 3 % of the world's mangrove cover. Sundarbans in India is the largest mangrove site in the world, colonized with many threatened animal species. About 58 % of the mangroves occur on the east coast along the Bay of Bengal, 29 % on the west coast bordering the Arabian Sea, and 13 % on Andaman and Nicobar Islands (Dasgupta and Shaw 2013). The State forest report of 2015, states that out of total cover of mangrove, Sundarbans contributes about 44 %, followed by Gujarat 23 % and Andaman and Nicobar Islands 13%. On the basis of density of mangrove cover about 40 % area covered by the open mangrove, 29% by the moderately dense mangrove and 31% by the very dense mangrove. The paper attempts to highlight the Carbon storage in Mangrove living biomass and sediments and their help in climate sustainability. Reviews suggest that C storage in mangroves at different climatic regions, sites, stands and different depths of soils store more carbon per unit area. All the reviews suggest that mangroves are a globally significant contributor to the carbon cycle.

Key words: Carbon dioxide, carbon stock, GHGs, mangrove, soil carbon

## **INTRODUCTION**

Mangroves are taxonomically diverse assemblages of wood plant communities belonging to several unrelated angiosperm families with special adaptations to saline conditions (Tomlinson, 1986). Mangrove ecosystems occur in tropical as well as subtropical regions and the floristically richest mangroves are occurring in the tropical Southeast Asia. Mangrove forests are considered to be a unique and complex major component of coastal

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reference

33 zones in the tropical and sub-tropical regions. They represent transitional ecosystems where  
34 the sea, land and freshwater meet. The main vegetation consists of generally evergreen trees  
35 or shrubs that grow along coastlines, brackish estuaries or delta habitats. Mangrove habitats  
36 are easily recognized as they are located at tideland mud or sand flats inundated daily with  
37 sea water. They not only play critical roles in ensuring sustainability of coastal ecosystems,  
38 but also in fulfilling important socio-economic benefits to coastal communities. [references](#)

39 Recently, the role of mangrove forest as an important atmospheric CO<sub>2</sub> sink has been  
40 highlighted. CO<sub>2</sub> is a major contributor to global warming. Thus increasing CO<sub>2</sub> emission is  
41 one of the major environmental concerns and it has been well addressed in 'Kyoto protocol'.  
42 The living vegetation, sea water and soils play a key role in absorbing atmospheric CO<sub>2</sub> (Rao,  
43 *et al.* 2017). In is context, the trees act as a major sink of CO<sub>2</sub> as they have high potential of  
44 tapping atmospheric carbon through photosynthesis. The sequestered carbon is stored in the  
45 plant tissues which results in the growth (Gawali and Sheikh 2016). [Check how references are written](#)

46 Mangroves have long been known as extremely productive ecosystems that cycle  
47 carbon quickly, but until now there had been no estimation of how much carbon resides in  
48 these systems (Daniel Donato *et al* 2011). This essential information should be generated  
49 because when land-use change occurs, much of that standing carbon stock can be released to  
50 the atmosphere. The mangrove forest's ability to store such large amounts of carbon can be  
51 attributed to the deep organic rich soils in which it thrives (Daniel *et al* 2011). Mangrove  
52 sediment carbon stores were on average five times larger than those typically observed in  
53 temperate, boreal and tropical terrestrial forests, on a per unit area basis (Kibria G, 2013).  
54 The mangrove forest's complex root systems, which anchor the plants into underwater  
55 sediment, slow down incoming tidal waters, allowing organic and inorganic material to settle  
56 into the sediment surface. Low available oxygen conditions with slow decay rates, resulting  
57 in much of the carbon accumulating in the soil. In fact, mangroves have more carbon in their  
58 soil alone than most tropical forests have in all their biomass and soil combined (Mitra and  
59 Zaman 2014).

60 This high carbon storage suggests mangroves may play an important role in climate  
61 change management. Loss of mangrove through human interventions has been documented  
62 from many parts of the world as a result of land reclamation, grazing of live stock, cutting of  
63 timber (Walsh, 1974; Hussein, 1995; Semesi, 1998) salt pond construction (Terchunian *et al.*,  
64 1986), oil spills (Ellison and Farnsworth, 1992) mining (Lewis, 1990; Wolanski, 1992) and  
65 dumping of rubbish (Saenger *et al.*, 1983). Reduction in the abundance of mangroves has  
66 usually been interpreted in terms of loss of biodiversity or fisheries resources. Since

67 mangroves become increasingly threatened by various human impacts (ITTO, 1993, Pernetta,  
 68 1993; Farnsworth and Jackes, 1987), there is a need to investigate the mangrove vegetation  
 69 with the purpose of predicting changes in the future. The present paper summarizes and  
 70 discusses about the role of mangroves in the context of carbon sequestration as well as  
 71 climate change mitigation, published over the years. Paraphrase this sentence

## 72 Extent of Mangroves

73 Giri *et al.* (2011) estimated that largest extent of mangroves found in Asia (42%)  
 74 followed by Africa (20%), North and Central America (15%), Oceania (12%) and South  
 75 America (11%). Approximately 75% of mangroves are concentrated in just 15 countries. The  
 76 mangroves grow in river deltas, lagoons and estuarine complexes; also occur on colonized  
 77 shorelines and islands in sheltered coastal areas with locally variable topography and  
 78 hydrology.

79 Table 1. Previous estimates of global extent of mangroves.

Reference	Reference year	No. of countries included	Estimated total area (ha)
FAO, UNEP, 1981	1980	51	15 642 673
FAO, 1994	1980-1985	56	16 500 000
Spalding <i>et al.</i> , 1997	1997	112	18 100 077
Aizpuru <i>et al.</i> , 2000	2000	112	17 075 600

80

81 Table 2: Current and Past Mangrove Extent by Region (1980-2005)

Region	Most recent reliable estimates		1980	1990	2000	2005
	X 1000 ha	Ref year	1000 ha	1000 ha	1000 ha	1000 ha
Africa	3,243	1997	3,670	3,428	3,218	3,160
Asia	6,048	2002	7,769	6,741	6,163	5,858
North and Central America	2,358	2000	2,951	2,592	2,352	2,263
Oceania	2,019	2003	3,181	2,090	2,012	1,972
South America	2,038	1992	2,222	2,073	1,996	1,978
<b>World</b>	<b>15,705</b>	<b>2000</b>	<b>19,794</b>	<b>16,925</b>	<b>15,740</b>	<b>15,231</b>

82 Source: (Lang'at, 2013).

83 As can be seen from Table 2, the most extensive area of mangroves is found in Asia,  
 84 followed by Africa and South America. Four countries (Indonesia, Brazil, Nigeria and  
 85 Australia) account for about 41 percent of all mangroves and 60 percent of the total  
 86 mangrove area is found in just ten countries.

87 These forests provide important ecosystem goods and services to the region's dense  
 88 coastal population and support important functions of the biosphere. Mangroves are under

89 threat from both natural and anthropogenic stressors. They mapped the current extent of  
 90 mangrove forests in South Asia and identified mangrove forest cover change (gain and loss)  
 91 from 2000 to 2012 using Landsat satellite data. **Giri *et al* (2015)** stated that mangrove forests  
 92 in South Asia occur along the tidal sea edge of Bangladesh, India, Pakistan and Sri Lanka.

93 They also conducted three case studies in Indus Delta (Pakistan), Goa (India) and  
 94 Sundarbans (Bangladesh and India) to identify rates, patterns, and causes of change in greater  
 95 spatial and thematic details compared to regional assessment of mangrove forests.

96 Table 3. Areal extent of mangrove forests and forest gain and loss in each country

Country	Mangrove area in ha	Loss	Gain
Bangladesh	411,487.0	16179.4	6575.4
India	3,065.2	8020.7	29654.7
Pakistan	411,487.0	7691.6	44230.7
Sri Lanka	21,437.1	243.5	0.0

97

98 Table 4. Mangrove rich countries and their percentage (**Giri *et al* 2011**).

Country	Area	Percentage of global total	Cumulative percentage
Indonesia	3,112,989	22.6	22.6
Australia	977,975	7.1	29.7
Brazil	962,683	7.0	36.7
Mexico	741,917	5.4	42.1
Nigeria	653,669	4.7	46.8
Malaysia	505,386	3.7	50.5
Burma (Myanmar)	494,584	3.6	54.1
Papua new Guinea	48,121	3.5	57.6
Bangladesh	436,570	3.2	60.8
Cuba	421,538	3.1	63.9
India	368,276	2.7	66.6
Guinea Bissau	338,652	2.5	69.1
Mozambique	318,652	2.3	71.4
Madagascar	278,078	2.0	73.4
Philippines	263,137	1.9	75.3

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### 100 **Status of Above Ground Carbon Stock by Mangroves**

101 Mangroves function like other forests in exchanging gases with the atmosphere and like other  
 102 tidal ecosystems, exchange gases, solutes and particles with the coastal ocean and or sea as  
 103 they inhabit the margin between land and sea (Alongi, 2009). Mangroves are tightly linked to  
 104 land, ocean and atmosphere, yet still manage to store carbon and other elements in their  
 105 biomass and soils (Feller *et al.*, 2010). Mangroves are, on average, highly productive tidal  
 106 forests utilizing an advantageous strategy of maximizing carbon gain and minimizing water  
 107 loss with high water use and nutrient use efficiencies and low transpiration rates. These

108 physiological mechanisms result in rapid rates of CO<sub>2</sub> uptake and respiratory release despite  
109 living in waterlogged saline soils (Ball, 1988). Despite mangrove accounting for only 0.7% of  
110 tropical forest, it generates emissions up to 10% from total global deforestation (Pan *et al.*,  
111 2011). Hence, mangroves are considered as an important component in climate change  
112 mitigation and reducing emissions from deforestation and degradation. Mangroves have  
113 experienced rapid deforestation worldwide with 30-50 per cent decline in the past 50 years.  
114 Mangrove deforestation generates green house gas emissions of 0.02-0.12 **pentagrams** of  
115 carbon per year, which is equivalent up to 10 per cent of carbon emissions from global  
116 deforestation, according to the report of Daniel (2011). The global storage of carbon in  
117 mangrove biomass is estimated to be 4.03 **pg (petagram)** C, 70% of which occurs in coastal  
118 margins from 0<sup>0</sup> to 10<sup>0</sup> latitude (Twilley *et al.*, 1992).

119 Alongi and Mukhopadhyay (2015) studied the characteristics of mangrove carbon  
120 cycling, such as the allocation of fixed carbon into biomass and patterns of respiratory CO<sub>2</sub>  
121 release, are strikingly similar to tropical humid forests. They store more about 6 times more  
122 carbon (26 Tg C yr<sup>-1</sup>) than is buried in sediments (≈4Tg C yr<sup>-1</sup>) of subtropical and tropical  
123 coastal margins. The export of mangrove derived Particulate organic carbon, dissolved  
124 organic carbon and dissolved inorganic carbon (POC, DOC and DIC) accounts for 18%, 10%  
125 and nearly one-third (29%) of tropical river discharge of these compounds globally. The  
126 mangrove contribution to the tropical coastal carbon cycle is modest due to their small global  
127 area. However, their contribution to coastal sequestration is much larger (30% of total C  
128 burial). Kauffman *et al.* (2011) quantified ecosystem C storage at the Palau site ranged from  
129 479 Mg/ha in the seaward zone to 1,068 Mg/ha in the landward zone; in the Yap site C  
130 storage ranged from 853 to 1,385 Mg/ha along this gradient. The living biomass of estuarine  
131 mangroves sequester 237 -563 tonnes CO<sub>2</sub> ha<sup>-1</sup> compared to only 12- 60 tonnes CO<sub>2</sub> ha<sup>-1</sup> for  
132 marshes (**Murray *et al.* 2011**). This is also consistent with earlier work of (Day *et al.*, 1989)  
133 that showed the typical standing crop of biomass for marshes and mangroves are 500 to 200 g  
134 dry wt m<sup>2</sup> and 10,000 to 40,000 g dry wt m<sup>2</sup> according to **Twilley *et al.*, 1992**.

135 In the paper of Lee (2016) data from the regional sources of South China Sea (SCS) countries  
136 suggests average C contents of mangrove litter at 41%. Total estimated influxes of C from  
137 mangrove litter production from the SCS countries in 2010 are  $2.04 \times 10^6$  tC y<sup>-1</sup>. The value  
138 was  $2.86 \times 10^6$  tC y<sup>-1</sup> in 1997. The influx from mangroves therefore has decreased by 28.6%  
139 between 1997 and 2010. Siteo *et al.* (2014) found that C more concentrated in live trees, with  
140 28.0 Mg ha<sup>-1</sup> (47.8% of plant carbon). The average carbon stock in the mangrove forest was  
141 218.5 Mg ha<sup>-1</sup>, around 73% of which was stored in the soil, supporting the findings of other

142 studies that the soil of mangrove forests contains about 72–99% of the total carbon of these  
 143 types of forests. Similar result was found by Fatoyinbo *et al.* (2008). Stringer *et al.* (2015)  
 144 quantified the ecosystem C stock of the Zambezi River Delta mangroves utilizing a rigorous,  
 145 yet operationally feasible approach. The average biomass C density for the height classes  
 146 ranged from 99.2 Mg C ha<sup>-1</sup> to 341.3 Mg C ha<sup>-1</sup>. Ecosystem C stocks of sampled mangrove  
 147 forests ranged from 437 Mg C ha<sup>-1</sup> to 2186 Mg C ha<sup>-1</sup> (Murdiyarso *et al.*, 2009). This C  
 148 storage is exceptionally high compared with upland tropical forests, which typically store  
 149 between 150 and 500 Mg C ha<sup>-1</sup> (Murdiyarso *et al.*, 2002) and is perhaps second only to the  
 150 renowned C stocks of peat swamp forests (Page *et al.*, 2002).

151 Table-5 Biomass and carbon stock of plantation and natural stands in Mahanadi Mangrove  
 152 Wetland MMW (Sahu *et al.* 2016).

Stand	Above ground		Below ground	
	Biomass (tonne ha <sup>-1</sup> )	Carbon (tonne ha <sup>-1</sup> )	Biomass (tonne ha <sup>-1</sup> )	Carbon (tonne ha <sup>-1</sup> )
Plantation	125.55	62.77	55.72	27.86
Natural Forest	124.91	62.45	53.3	26.69

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154 The study reveals that MMW stores substantial amount of atmospheric carbon and  
 155 therefore needs to be conserved and sustainably managed to maintain as well as increase  
 156 carbon storage. Kishwan (2009) has estimated carbon sequestration per unit area by littoral  
 157 and swam forests of India as 106.9 t ha<sup>-1</sup>. Mitra *et al.* (2011) evaluated carbon stocks in the  
 158 above ground biomass (AGB) of three dominant mangrove species (*Sonneratia apetala*,  
 159 *Avicennia alba* and *Excoecaria agallocha*) in the Indian Sundarbans. Examined whether  
 160 these carbon stocks vary with spatial locations (western region *vs.* central region) and with  
 161 seasons (pre-monsoon, monsoon and post-monsoon). Among the three studied species, *S.*  
 162 *apetala* showed the maximum above ground carbon storage (t ha<sup>-1</sup>) followed by *A. alba* (t  
 163 ha<sup>-1</sup>) and *E. agallocha* (t ha<sup>-1</sup>). The AGB varied significantly with spatial locations but not  
 164 with seasons

165 Gujarat has the second largest mangrove cover (1058 sq km) of India. Mangrove  
 166 being the major woody habitats forms the important carbon sinks in the coastal regions.  
 167 Pandey and Pandey (2013) have examined the carbon sequestration by mangroves of Gujarat.  
 168 A total of 8.116 million ton carbon has been sequestered by mangroves of Gujarat.

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171 **Soil Carbon Stock**

172 Mangrove forests play an important role in the terrestrial and oceanic carbon cycling (Liu *et al.*, 2014), where they contribute to 10% of the total net primary production and 25% of the  
173 carbon burial in the global coastal zone although they colonize only 0.7% of the global  
174 coastal zone (Alongi, 2007).

176 In 1998, German Advisory Council on Global Change (WBGU), estimated areas and carbon  
177 storage (Gt) for various biomes. Deserts/semi deserts are biomes with the largest area  
178 ( $45.5 \times 10^6$  km<sup>2</sup>), but store only a relatively small amount of organic carbon. Boreal forests  
179 store the highest total amount of carbon (559 Gt), which is mainly attributed to the carbon  
180 pool in the soil (471 Gt). Tropical forests have the largest vegetation carbon pool (212 Gt),  
181 which makes this biome the second largest carbon pool in total. In comparison to other  
182 biomes, wetlands cover a smaller area but with relatively high carbon storage in it.

183 Table 6- soil carbon stock (for top 1-100 cm soil) of estimated areas of mangrove sites

Reference	Global carbon (Gt C)
Sjors <i>et al.</i> (1980)	300
Adams <i>et al.</i> (1990)	202-377
Eswaran <i>et al.</i> (1993)	357
Batjes, (1996)	330
WBGU (1998)	225

184

185 According to Chmura *et al.* 2003 carbon sequestration rates by ecosystem type (mangrove  
186 swamp or salt marsh) overall average rate of carbon sequestration per unit area is about 210 g  
187 CO<sub>2</sub> m<sup>2</sup> yr<sup>-1</sup>

188 Plants remove CO<sub>2</sub> from the atmosphere to prepare carbohydrates, some of which are  
189 incorporated into plant tissues. As plants and plant parts die, some of these tissues are added  
190 to the soil as soil organic matter (Lal, 1998). Given the proper conditions, some soils can  
191 become net C sinks (Mosier, 1998), because CO<sub>2</sub> can be removed from the atmosphere by the  
192 soil plant system, interest in soil C sequestration is increasing. Coastal wetlands are areas  
193 with high NPP their soils and sediments sequester C at high rates. Grossman *et al.* (1998)  
194 shown that, where sedimentation rates are high, organic C may be sequestered at depths  
195 greater than those typically sampled during soil studies. Soil C density was the largest  
196 measured C pool, containing 274.6 Mg C ha<sup>-1</sup> to 314.1 Mg C ha<sup>-1</sup> and accounting for 45-73%  
197 of the height class ecosystem C densities (Stringer *et al.* 2015) at Zambezi River Delta.

198 Mangrove sediments are characterized by intense carbon processes with a potentially high  
199 impact on the global carbon budget (Alongi, 2007). Ceron-Breton *et al.* (2011) determined



200 carbon sequestration rate in mangrove forest soil located within the natural protected area.  
201 The organic matter content and organic carbon decreased at greater depths of soil. The  
202 sampling areas with sandy soils where the buttonwood mangrove is the dominant species  
203 showed a reduced ability to capture carbon ( $1.2 \text{ kg C m}^{-2}$ ) and black mangrove-red  
204 mangrove-white mangrove, showed the highest rates of carbon sequestration ( $22.2 \text{ kg C m}^{-2}$ ).  
205 The accumulation of organic matter and organic carbon content were higher during the dry  
206 season. It was expected, since in this climatic period the evapotranspiration process increases,  
207 which concentrates salts and dissolve organic carbon. Carbon storage was lower in the days  
208 of "rain" when the dilution effect was greater, resulting in lower concentrations of dissolved  
209 organic carbon, salinity and density. Bianchi *et al.* (2013) conducted a study and determined  
210 Carbon sequestration rates were in the Mud Island Mangrove and the Marsh sites ranged  
211 from 253 to 270 and 101-125  $\text{g C m}^{-2} \text{ yr}^{-1}$ , respectively in wetland soils of the north western  
212 Gulf of Mexico. Significantly higher carbon sequestration in mangrove compared to marsh  
213 sites on Mud Island, are consistent with the recent reports on blue carbon sinks, which show  
214 that mangroves store more carbon than marshes on a global scale (Cai, 2011; Donato *et al.*,  
215 2011).

216 Yang *et al.* (2014) stated that mangroves are an important affecter of atmospheric  $\text{CO}_2$  level  
217 via sequestering carbon and trapping sediments. In order to detect the determinants of  
218 organic carbon sequestration, study investigated four mangrove fringing locations along the  
219 Surface and core sediment samples were collected from these sites and analyzed sedimentary  
220 organic carbon content (SOCC). It was found that a significantly higher concentration and  
221 density of organic carbon were preserved in the interior surface sediments regardless of  
222 location or surface grain size distribution of coast of the Leizhou Peninsula. The belowground  
223 C pools of the mangrove forest transects were greater at 315, 428, and 818  $\text{Mg/ha}$  for the  
224 seaward, interior, and landward zones, respectively (Kauffman *et al.* 2011).

225 SOC content in the study of Eid and Shaltout (2016) is greatest in the surface soil  
226 where most carbon inputs occur and decreases with depth, this lies in agreement with some  
227 previous studies such as Eid and Shaltout (2013), Khan *et al.* (2007), Lunstrum and Chen  
228 (2014). Variation in SOC content distribution with depth are the result of interaction of  
229 complex processes such as decomposition, biological cycling, leaching, illuviation, soil  
230 erosion, weathering of minerals and atmospheric deposition (Girmay and Singh, 2012) total  
231 mean of SOC content in the 0-10 cm soil depth accounts for 35.5% indicating the importance  
232 of top soil layers as good sources of carbon sink, but also as a potential for large amount of  
233  $\text{CO}_2$  emission upon conversion and mismanagement. Similar results were reported by Eid and



234 Shaltout (2013) in Lake Burullus (a Mediterranean wetland in north Egypt) who indicated  
235 that 40.7% of the SOC content was located in the top 10 cm of the soil profile.

236 Sahu *et al.* (2016) revealed that the soil carbon stock in natural stands was  $54.3 \pm 3.0$   
237  $\text{Mg C ha}^{-1}$  and in plantation it was  $60.9 \pm 5.6 \text{ Mg C ha}^{-1}$ . The mean overall C-stock of natural  
238 stands and plantations was  $57.6 \pm 3.2 \text{ Mg C ha}^{-1}$ . A positive correlation was found between  
239 vegetation biomass and soil organic carbon in the surface soil (0–30 cm), indicating the role  
240 of vegetation in building surface soil organic carbon.

241 The carbon content in the soil of mangroves generally changes much more slowly  
242 with depth than in the upland forest Siteo *et al.* (2014). In the miombo woodlands of Malawi  
243 for instance, Walker and Desanker (2004) found an exponential decrease of carbon  
244 concentration up to a depth of 150 cm, indicating a sharp decrease in carbon concentration  
245 with the increase of soil. According to Wendling (2005), the reduction of carbon  
246 concentration with depth is more common in terrestrial forests due to high concentrations of  
247 biological activity, particularly litter deposition and decomposition near the soil surface,  
248 while deposition of sediments from the river stream constitute an important source of organic  
249 matter in mangrove soils depth. Panday and Panday (2013) was also examined carbon  
250 sequestered in the soil (up to 30 cm depth) by mangroves of Gujarat and revealed that  
251 mangrove soils contribute more than mangrove plants in the overall carbon sequestration.

252 The amount and dynamics of SOC in soil differ greatly in different mangroves, which  
253 are mainly influenced by the tidal gradient, mangrove forest age, biomass and productivity, as  
254 well as species composition and sedimentation of suspended matter. Proportions of soil  
255 carbon to the total ecosystem carbon suggest that mangrove soils are the most carbon rich  
256 when compared to upland ecosystem in the same region.

## 257 **Conclusion**

258 Recent studies have shown that coastal wetlands such as mangroves, salt marshes and  
259 sea grass beds are among the most efficient carbon (C) sinks on the planet. The data  
260 presented show that mangroves hold C-pools that are among the largest in the tropics.  
261 Plantation can store as much carbon as natural mangrove forests. This highlights the need for  
262 expanding mangrove plantations. Some study demonstrates that the biomass and carbon  
263 storage capacity of mangrove species vary with spatial locations due to varying salinity,  
264 perhaps moderated by soil and water management. Mangroves store more carbon than  
265 marshes on a global scale. As mangroves become recognized as important carbon storages,  
266 the need for quantifying and reducing the uncertainty of carbon inventories, such as those  
267 arising from specific carbon contents, becomes increasingly emphasized. Many aspects of

268 mangroves make them unique ecosystems. Improving their management, including wise use  
269 of resources, would enhance collateral benefits for both global and local communities.

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