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Biomass and carbon stock assessment in two savannahs of Western Ghats, India

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ABSTRACT: Carbon inventory was done on two savannah ecosystems (sites I & II) of Kanyakumari Wildlife Sanctuary, Western Ghats, India. Ten plots of 20 m × 20 m each were laid in each site to study woody vegetation and a total of forty quadrats (4 in each plot) of 1 m × 1 m were laid in each site for the understorey. Both sites showed remarkable variations in biomass and carbon accumulation patterns. Site I (213 Mg C/ha) had higher woody biomass carbon than site II (185.9 Mg C/ha). However, the latter had greater understorey biomass carbon (site I – 3.2 Mg C/ha; site II –20.7 Mg C/ha). Overall, the total vegetation carbon accounted to 216.2 Mg C/ha in site I and 206.6 Mg C/ha in site II. On the other hand, soil carbon was higher in site II (183.5 Mg C/ha) than site I (172.3 Mg C/ha). Soil bulk density increased with increase in soil depth in both sites. Cumulatively, even though both sites had almost equal carbon stocks, they show considerable variation in the amount of carbon stocked in their carbon pools. Woody biomass was the largest carbon pool, followed by soil and understorey biomass. The observed variations could be due to differences in terrain characteristics, edaphic factors, incidence of fires, etc. The study emphasizes the important role of savannahs in stocking considerable amounts of carbon in their different carbon pools.

KEY WORDS: Carbon mitigation, Climate change, Hotspot, Soil carbon, Tropical forest, Wildlife Sanctuary, Woody biomass.

INTRODUCTION

In this crucial era of global warming and climate change, partially triggered due to increase in atmospheric carbon dioxide (CO_2), assessment of carbon (C) stocks is necessary to prioritize different ecosystems for conservation, carbon mitigation and adaptation programmes. The amount of biomass in a forest directly quantifies the potential amount of C that would be added to the atmosphere or sequestered on the land (Brown *et al.*, 1999; Borah *et al.*, 2013), depending on whether the forests act as sources or sinks. Forests comprise 80% of the total plant biomass (Kindermann *et al.*, 2008) and stock more C in biomass and soils than present in the atmosphere (Pan *et al.*, 2011). Estimation of biomass, C and its allocation patterns, even in local forest ecosystems plays a crucial role in global C budget (Brown *et al.*, 1993; Majumdar *et al.*, 2016). Tropical forests serve as hotspots for both carbon and biodiversity as they span only 7–10% of Earth's surface (Poorter *et al.*, 2015), but they act as sinks for around 40% of the terrestrial C (Lewis *et al.*, 2004; Clerici *et al.*, 2016) and are widely recognized to be highly productive ecosystems (Das and Singh, 2016). Intact tropical forests seem to be increasing in their biomass and absorbing C from the atmosphere at a rate of 1.1 ± 0.3 Pg C per year, thereby decelerating the rate of global warming by about 15% (Malhi, 2010, 2012; Sundarapandian *et al.*, 2013).

The understorey vegetation of tropical forests is markedly different from that of overstorey which could be due to differences in light intensity, nutrient availability and temperature (Bhat and Murali, 2001; Siebert, 2002; Ramadhanil *et al.*, 2008; Gandhi and Sundarapandian, 2014). The understorey vegetation is known to play a crucial role in maintaining ecosystem dynamics. As stated by Perala and Alban (1982) and Augusto *et al.* (2003), the understorey vegetation stocks considerable levels of nutrients in the forest, especially during early stages of stand development (Switzer *et al.*, 1968). Augusto *et al.* (2003) further reinstates that the understorey could alter the nutrient fluxes of an ecosystem during throughfalls (Hornung *et al.*, 1990), nitrification (Wedraogo *et al.*, 1993), mineralization and aftermath of clear-felling (Dahlgren and Driscoll, 1994). According to Burton *et al.* (2013), most of the forest's diversity occurs in the understorey and only a few researchers had studied the relationship between understorey communities and forest carbon. Carbon stocks in overstorey partly control the resource availability and productivity of the understorey (Gray *et al.*, 2002; Burton *et al.*, 2013; Reich *et al.*, 2012). Understorey vegetation influences carbon allocation patterns to a certain extent as stated by Yin *et al.* (2016). Woziwoda *et al.* (2014) indicated that the total annual production of the understorey may level up to 20% of the total aboveground biomass, provided the seasonal changes in its composition are also taken into account.

According to Fidelis *et al.* (2013), grasslands are often neglected as potential C stocks, partly because there aren't many studies conducted on the aspects of biomass and C dynamics. Grasslands span across around 50 million km^2 and stock around 39% of the terrestrial soil C (White *et al.*, 2000; Chang *et al.*, 2015).

Grassland C indicates the carrying capacity of the earth (Piao *et al.,* 2004; Hasituya *et al.,* 2013). Grassland soils have the potential of storing large amounts of soil organic carbon that is mainly due to high belowground C input by roots and their exudates (Bolinder *et al.,* 2012; Poeplau *et al.,* 2016). Savannahs have the potential of retaining large amounts of C (Buis *et al.,* 2009). Tropical savannahs have a high net primary productivity (1–12 t C ha^{-1} $year^{-1}$) and biomass accumulation, which is driven mostly by seasonality (Grace *et al.,* 2006). According to Gandiwa *et al.* (2016), herbivore dynamics (Doughty *et al.,* 2016) and plant invasions (Rouget *et al.,* 2015) influence the vegetation dynamics of savannahs. Grasslands in India are formed from deforested forest lands and abandoned agricultural fields and these are maintained in different stages of succession by different management practices such as burning, grazing and harvesting (Thokchom and Yadava, 2016a).

According to Alencar *et al.* (2006) and Balch et al. (2010), understorey fires, although they destroy more than twice the annually deforested forest land are often excluded in most of the assessments of C emissions from deforestation. Fire alters the vegetation dynamics and therefore subsequently influences biomass and C dynamics as well (Fidelis *et al.,* 2013). The impacts of fire help in maintaining vast areas of the seasonal tropics as savannahs (Silva *et al.,* 2013). Pathak *et al.* (2015) emphasized the importance of understanding the role of fire practice in the carbon budget of grasslands in the current scenario of climate change. With this backdrop, an attempt has been made to assess the biomass and carbon stocks of two savannah ecosystems in the Western Ghats, a biodiversity hottest hotspot (UNESCO, World Heritage Convention: http://whc.unesco.org/en/list/1342).

MATERIALS AND METHODS

Study area

Kanyakumari Wildlife Sanctuary, Western Ghats, India is located between 77°10′– 77°35′E and 8°5′– 8°35′ N. The area receives an average annual rainfall of 1369.5 mm and the average monthly maximum and minimum temperatures are 30°C and 24°C. Forests of Kanyakumari Wildlife Sanctuary are rich in biodiversity with several microhabitats, due to its exposure to wide range of climatic conditions and its geographic location at the southernmost tip of the subcontinent. There are 14 forest types in this sanctuary, based on Champion and Seth's classification (1968). The rainfall varies from 50 to 310 cm and elevation up to 1829 m asl across different forest types (Tamil Nadu Forest Department, http://forests.tn.nic.in/WildBiodiversity/ws_kws.html).

Two savannah ecosystems (I and II) were selected from Kanyakumari Wildlife Sanctuary that differ in their location and other characteristics (Table 1; Fig. 1). Site I had a slopy terrain facing the east, while site II had a flat terrain. Site I is located at a higher elevation (530-630 m asl) than site II (317-360 m asl). Based on enquiry with locals, it was known that both sites were left unperturbed in the last few years, although site I is more undisturbed as it is located quite far from human settlements and has restricted entry, while site II had a previous history of annual fires before the declaration of the site as a part of wildlife sanctuary in 2002. Since

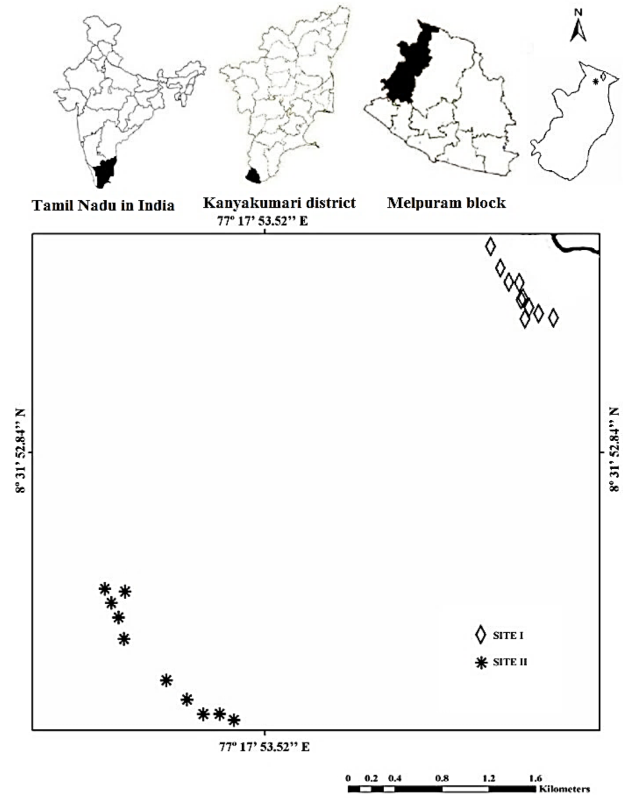

Fig 1. Map showing study area and two savannah ecosystems in Kanyakumari Wildlife Sanctuary, Western Ghats, India.

Table 1. Site characteristics of two savannah ecosystems in Kanyakumari Wildlife Sanctuary, Western Ghats, India.

Parameter	Site-I	Site-II
Site features		
Elevation (m asl)	530-630	317-360
Terrain	East-facing slope	Flat
No. of species (No./4000 m^2)		
Juveniles	40	23
Adults (≥ 10 cm DBH)	26	12
Understorey	19	6
Total no. of species	62	31
Abundance (No./ha)		
Juveniles	2330	1201
Adults	527	448
Total no. of woody individuals	2857	1649
Understorey	280208	401000
Basal area (m^2/ha)		
Juveniles	2.76	0.98
Adults	35.33	30.83
Understorey	6.95	4.20

then, both sites are in different stages of succession and therefore have differences in the vegetation composition.

Methods

Carbon inventory was done on the two selected savannah ecosystems (sites I & II). Ten plots of 20 m × 20 m each were laid at each site and all the individuals of woody species ≥ 10 cm DBH (diameter at breast height) were enumerated as adults and those < 10 cm DBH were considered as juveniles. A total of forty quadrats (4 in each plot) of 1 m × 1 m were laid in each site to study the understorey. Aboveground biomass of adults was estimated using the allometric equation of Brown (1997).

$$\text{Aboveground biomass of adults} = \exp(-2.289 + 2.649 \times \ln(\text{DBH}) - 0.021 \times \ln(\text{DBH}^2))$$

To estimate the aboveground biomass of juveniles, the allometric equation of Chaturvedi *et al.* (2012) was used.

$$\text{Aboveground biomass of juveniles} = 3.344 + 0.443 \times \ln(\text{DBH}^2)$$

Belowground biomass was computed from the aboveground biomass using a root-shoot ratio of 0.26 (Ravindranath and Ostwald, 2008). Carbon is considered to be a fraction of 44.53% of biomass and therefore 0.4453 is used as the conversion factor (Júnior *et al.*, 2016).

$$\text{Carbon} = (\text{aboveground biomass} + \text{belowground biomass}) \times 0.4453$$

A total of thirty soil samples were collected from each site using a soil core sampler (cylindrical corer of diameter 4.2 cm) for quantifying the soil fractions of carbon and nitrogen during May 2015. A total of six samples were taken from both the depths separately (0-10 cm and 10-30 cm) from each plot and three sets of composite soil samples were prepared for each plot by mixing two samples of the same depth. The composite soil samples were air-dried, sieved using a 2 mm mesh and ground using a mortar and pestle to get fine particles. Soil carbon (C%) and nitrogen (N%) were then quantified for the aforesaid soil samples using vario EL cube CHNOS Elemental Analyzer, Elementar.

Another set of thirty soil samples were collected from each site for the measurement of bulk density. In total, three sets of undisturbed soil samples were taken from both the depths (0-10 cm and 10-30 cm) in each plot. Proper care was taken while removing these cores to prevent the loss of any soil from the samples. The samples were oven-dried at 105 ± 5°C for 72 hours and then weighed. The coarse fragments were separated by sieving and the samples were then re-weighed. Soil bulk density and soil carbon stocks were then calculated using the formulae of Pearson *et al.* (2005) as follows:

$$\text{Bulk density (g/m}^3\text{)} = \frac{\text{Oven dry mass (g/m}^3\text{)}}{\text{Core volume (m}^3\text{)} - (\text{Mass of coarse fragments (g)} / 2.65\ (\text{g/cm}^3)}$$

where, 2.65 was taken as a constant for the density of rock fragments (g/cm^3)

$$\text{Soil carbon (Mg/ha)} = [(\text{soil bulk density (g/m}^3) \times \text{soil depth (cm)} \times \text{C (\%)}] \times 100$$

Statistical analysis

t-test was applied using MS-Excel to examine the differences in biomass, vegetation carbon, soil bulk density, soil carbon, soil nitrogen, carbon-to-nitrogen ratio between the study sites and also depths.

RESULTS

(a) Overstorey biomass and carbon stocks

The two sites showed significant variation in terms of biomass and carbon stocks (Table 2). The total woody biomass was considerably higher at site I (478.3 Mg/ha) than at site II (417.4 Mg/ha). As a result, the woody biomass carbon was also higher at site I (213 Mg C/ha) than site II (185.9 Mg C/ha). The biomass and carbon stocks of top ten woody contributor species are presented in Table 3. *Pterocarpus marsupium* and *Ficus beddomei* at site I and *Terminalia elliptica* and *Terminalia paniculata* at site II were the largest contributors in the accumulation of woody biomass and carbon.

(b) Understorey biomass and carbon stocks

The understorey biomass and carbon stocks also showed considerable variation among both sites. The understorey of site II was dominated by a grass species, that is, *Themeda cymbaria* while site I had a mixed undertorey with grasses, herbs, seedlings, saplings, etc. The abundance of top ten species in understorey in both sites is presented in Fig. 2. The total understorey biomass of site II (46.5 Mg/ha) is significantly ($t=17.95$; $P>0.000$) higher than site I (7.2 Mg/ha). Consequently, the understorey biomass carbon is also significantly ($t=17.95$; $P>0.000$) higher at site II (20.7 Mg C/ha) than site I (3.2 Mg C/ha).

(c) Soil carbon stocks

Carbon percentage in the surface layer (0–10 cm) is significantly ($t=7.56$; $P>0.000$) higher at site I than site II, while a reverse trend was observed in the bottom layer ($t=5.12$; $P>0.000$). However, soil carbon stock (Mg C/ha) was comparatively higher at site II (183.5 Mg C/ha) than site I (172.3 Mg C/ha). The soil carbon stocks of both sites were presented in Fig. 3 and 4 for the depths 0–10 cm and 10–30 cm respectively. Soil carbon percentage decreased significantly with increase in soil depth at both sites ($t=11.51$, $P>0.000$ at site I; $t=4.07$, $P>0.000$ at site

Table 2. Biomass and carbon stocks of two savannah ecosystems in Kanyakumari Wildlife Sanctuary, Western Ghats, India.

Parameter	Site I	Site II	t-value	Level of significance
Woody aboveground biomass (Mg/ha)	379.6±46.8	331.3±36	0.81	Not significant
Woody belowground biomass (Mg/ha)	98.7±12.2	86.1±9.4	0.81	Not significant
Woody biomass carbon (Mg C/ha)	213±26.3	185.9±20.2	0.81	Not significant
Aboveground biomass of understorey (Mg/ha)	5.7±0.6	36.9±1.6	17.9	<0.0001
Belowground biomass of understorey (Mg/ha)	1.5±0.2	9.6±0.4	17.9	<0.0001
Understorey biomass carbon (Mg C/ha)	3.2±0.3	20.7±0.9	17.9	<0.0001
Total vegetation carbon (Mg C/ha)	216.2±26.4	206.6±19.9	0.29	Not significant
Soil bulk density (g/m^3)				
0-10 cm	1.25±0.02	1.33±0.01	3.85	0.001
10-30 cm	2.93±0.03	3.12±0.04	3.43	0.003
Total soil C%				
0-10 cm	6.88±0.46	3.2±0.16	4.03	0.001
10-30 cm	1.47±0.06	2.28±0.15	3.35	0.006
Total soil N%				
0-10 cm	0.20±0.01	0.24±0.07	0.61	Not significant
10-30 cm	0.12±0.06	0.13±0.01	0.86	
Soil carbon (Mg C/ha) (0-30 cm)	172.3±10.8	183.5±14.6	0.62	Not significant
C:N				
0-10 cm	34.8±2.46	17.5±0.58	6.86	<0.0001
10-30 cm	13.3±0.54	20.1±0.95	6.20	<0.0001
Cumulative carbon (Mg C/ha)	388.5	390.1	-	-

Table 3. Total biomass (TB) and total carbon stocks (TC) (Mg C/ha) of top ten species in each of the two savannah ecosystems in Kanyakumari Wildlife Sanctuary, Western Ghats, India.

Name of the species	Site I		Site II	
	TB	TC	TB	TC
Aporosa cardiosperma	13.2	5.9	2.1	1.0
Buchanania lanzan			15.2	6.8
Calophyllum inophyllum	8.5	3.8		
Careya arborea	6.8	3.0	21.4	9.5
Dillenia pentagyna			37.1	16.5
Ficus beddomei	127.7	56.8		
Ficus benghalensis	6.2	2.7		
Hopea parviflora	21.6	9.6		
Isonandra perrottetiana	20.2	9.0		
Monoon fragrans			1.1	0.5
Phyllanthus emblica	13.4	6.0	9.8	4.4
Pterocarpus marsupium	179.2	79.8	65.5	29.2
Terminalia chebula			9.8	4.4
Terminalia elliptica			126.4	56.3
Terminalia paniculata	51.3	22.8	125.9	56.1

II). Similarly, nitrogen percentage also decreased significantly (t=9.74;P>0.000) with increase in depth in site I. However, the nitrogen percentage is comparatively more at site II in both the depths than site I. The carbon-to-nitrogen ratio in surface layer was significantly (t=6.86; P>0.000) higher at site I than site II, while in the bottom layer, a reverse trend was observed. Soil bulk density was significantly (t=3.85; P>0.001 in 0–10 cm, t=3.43; P>0.003 in 10–30 cm) higher at site II than site I in both the depths. Soil bulk density increased with increase in soil depth in both sites.

(d) Cumulative carbon stocks

Cumulatively, both sites had almost equal carbon stocks, with site II (390.1 Mg C/ha) having slightly higher values than site I (388.5 Mg C/ha). The total vegetation carbon was more at site I (216 Mg C/ha) than site II (207 Mg C/ha). There was a notable difference in the carbon allocation among the different carbon pools in both sites, although the trend remained almost the same. At site I, woody biomass (54.8%) was the highest carbon sink, which was followed by soil (44.4%) and understorey (0.82%). On the other hand, at site II, woody biomass (47.7%) and soil (47%) had almost equal carbon stocks, while the understorey contributed to 5.3%.

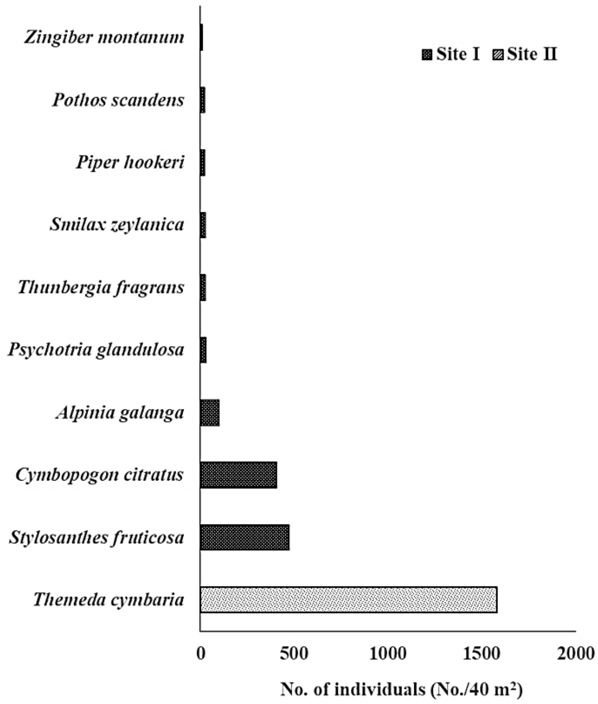

Fig. 2. Abundance of understorey species in two savannah ecosystems of Kanyakumari Wildlife Sanctuary, Western Ghats, India.

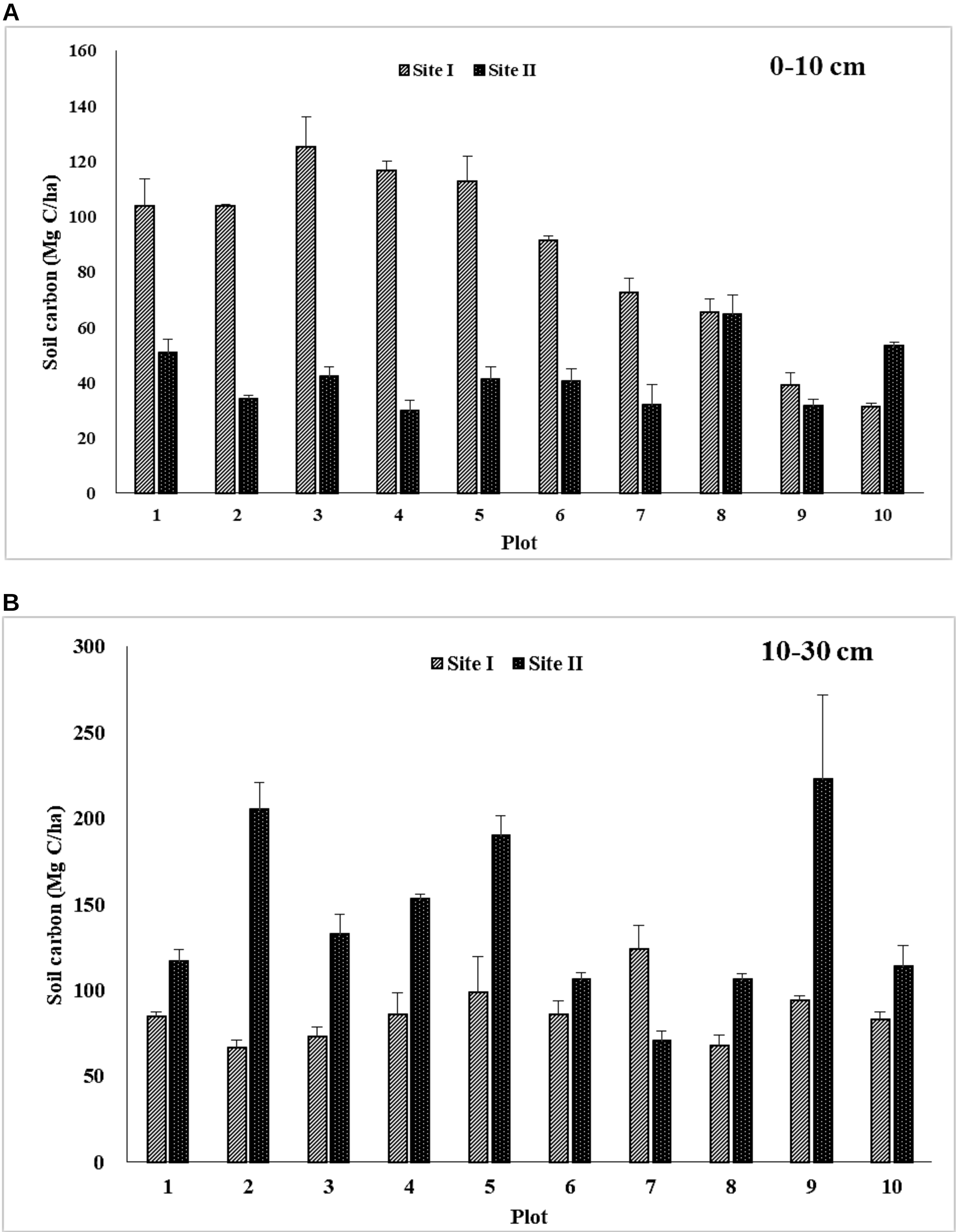

Fig. 3. Soil carbon stocks at a depth of 0-10 cm (**A**) and 10-30 cm (**B**) in two savannah ecosystems of Kanyakumari Wildlife Sanctuary, Western Ghats, India.

DISCUSSION

The aboveground standing crop biomass of woody vegetation is often considered to be one of the largest carbon pools (Sheikh *et al.,* 2011). The aboveground biomass values of woody vegetation observed in the present study were 379.6 (site I) and 331.3 (site II) Mg/ha. These values are closer to the African average (395.7 Mg/ha; Lewis *et al.*, 2013), higher than the Amazonian average (288.6 Mg/ha; Malhi *et al.*, 2006), but lower than the Bornean average (457.1 Mg/ha; Slik *et al.,* 2010). The values observed in the present study were within the range of biomass values reported by Mohanraj *et al.* (2011), Becknell *et al.* (2012), Becknell and Powers (2014) and Sahu *et al.* (2016) and comparable with several reports from the world tropical forests (Bhat and Ravindranath, 2011; Shahid and Joshi, 2015; Berta *et al.*, 2015; Gandhi and Sundarapandian, 2017; Mensah *et al.*, 2016). The values are higher than those reported by Khun *et al.* (2012), Anup *et al.* (2013), Borah *et al.* (2013), Sundarapandian *et al.* (2013), Pawar *et al.* (2014), Nagler *et al.* (2015), Devisscher *et al.* (2016), Majumdar *et al.* (2016) and Zaragoza *et al.* (2016), but lower than Yam and Tripathi (2015). The variation in woody biomass in tropical forests could be influenced by slope, geography, climate, rainfall pattern, species composition, level of human interference, etc as stated by Slik *et al.* (2010), Lewis *et al.* (2013) and Berenguer *et al.* (2014). The woody biomass was higher at site I than at site II which could be due to high density of woody species. In addition, large diameter class trees such as *Pterocarpus marsupium* and *Ficus beddomei* contributed for the increase in biomass at site I. Several researchers have also confirmed that large diameter class trees contribute to more aboveground biomass in forests (Brown and Lugo, 1992; Brown, 1996; Clark and Clark, 1996).

Carbon allocation in above- and belowground plant parts is a major process of carbon cycling (Chen *et al.,* 2015). The carbon stock of woody biomass was higher at site I (213 Mg C/ha) than site II (186 Mg C/ha). The carbon stock values obtained in the present study are comparable with the global tropical forest carbon stock density of 242 Mg/ha as reported by Pan *et al.* (2011). The woody biomass carbon is comparable with the world tropical forest values (Table 4; Mohanraj *et al.*, 2011; Pan *et al.*, 2013, Berenguer *et al.*, 2014, Pawar *et al.*, 2014, Shahid and Joshi, 2015). The values obtained here were higher than those reported by Ryan *et al.* (2011), Ullah and Al-Amin (2012), Borah *et al.* (2013), Sundarapandian *et al.* (2013), Nagler *et al.* (2015), Majumdar *et al.* (2016), Zaragoza *et al.* (2016), but lower than Ngo *et al.* (2013), Berta *et al*. (2015) and Murthy *et al.* (2016). The greater woody carbon stock at site I could be attributed to greater tree density, basal area and presence of many large diameter class trees. In addition, the study site is located far away from the human settlements and hence the disturbance is almost nil. This could also be one of the reasons for greater biomass and carbon stocks here.

In contrast to woody vegetation, the understorey biomass was significantly higher at site II (46.5 Mg/ha) than site I (7.2 Mg/ha), which could be due to the domination of the dense and tall grass, *Themeda cymbaria*. Site characteristics and subsequently soil characteristics are the main influential factors that determine ground flora composition (Augusto *et al.*, 2003) and productivity, that invariably affect the biomass of understorey. Site II more or less looks like a plain while site I is sloped. This variation could also be one of the reasons for differences in understorey biomass. Tropical tall grasses were prevalent in both study sites. However, the abundance of tall grasses was significantly more at site II than site I, while dicots' contribution was greater at site I. These variations in species composition and their abundance may also influence the understorey biomass. Understorey plants have a great potential to sequester carbon (Chastain *et al.*, 2006; Chen *et al.*, 2015). The understorey biomass carbon was significantly higher at site II (20.7 Mg C/ha) than site I (3.2 Mg C/ha). Larger contribution of understorey to carbon sequestration is often related to greater resource availability, especially light (Chen *et al.*, 2015). This is true in the case of site II, where the trees are sparsely distributed, leading to less canopy cover and more light penetration favouring luxuriant mondominant grassland, that is in contrast to site I, where the trees are dense with large canopies. Moreover, the tree species present are also known to affect the understorey, thereby influencing their carbon stocks (Augusto *et al.*, 2003). Overall, the total vegetation carbon differed only slightly between the two sites (site I – 216.2 Mg C/ha; site II – 206.6 Mg C/ha). These values were higher than those reported by Thokchom and Yadava (2016b) from a grassland in Manipur, India. Although the contribution by understorey carbon pool is relatively negligible (0.01-5.3%) with other pools like woody biomass and soil in the present study, it alters the carbon accumulation on an ecosystem level.

Soil C is diverse in its chemistry and interactions with soil particles (Trumbore, 2000; Schmidt *et al.*, 2011; Manning *et al.*, 2015). Site II (183.5 Mg C/ha) had higher soil carbon stocks than site I (172.3 Mg C/ha) at the depth of 0–30 cm. This could be due to the adventitious root binding and leaching of surface carbon by grasses. Soils in grasslands are rich in organic carbon and hold an extensive fibrous root system that forms a favourable environment for soil microbial activity leading to accumulation of more soil carbon (Conant *et al.*, 2004; Thokchom and Yadava, 2016a). Soil bulk density increased with increase in soil

Table 4. Comparison of biomass and carbon stocks of present and previous studies.

Vegetation type	Location	Area studied	Biomass (Mg/ha)	Carbon (Mg C/ha)	Reference
Savannah	Kanyakumari Wildlife Sanctuary, Tamil Nadu, India	0.8 ha	379.6. 331.3	213, 185.9	Present study
Intact closed-canopy tropical forests	Africa	1.2 ha	395.7	-	Lewis *et al.* (2013)
Intact rainforests	Amazonia	5.76 × 10^6 sq. km	288.6	-	Malhi *et al.* (2006)
Tropical forests	Borneo	83 locations	457.1	-	Slik *et al.* (2010)
Different forest types	Kolli hills, Eastern Ghats, India	503 sq. km	15.61-597.13	7.8-298.56	Mohanraj *et al.* (2011)
Secondary tropical dry forests	Costa Rica	8.4 ha	1.7-409	-	Becknell and Powers (2014)
Tropical dry forests	Eastern Ghats of Odisha, India	5.12 ha	13.96-514.5	6.98-257.25	Sahu *et al.* (2016)
Tropical rain forests	Western Ghats of Karnataka, India	6 ha	181.6-331.93	90.58-165.96	Bhat and Ravindranath (2011)
Moist deciduous forests	Doon Valley, Western Himalaya, India	1.5 ha	338.4-438.17	169.2-219.08	Shahid and Joshi (2015)
Riverine and terrestrial forest	Gambella National Park, Ethiopia	1.52 ha	384.36	192.18	Berta *et al.* (2015)
Tropical dry deciduous forest	Sathanur reserve forest, Eastern Ghats, India	30 ha	255.74	131.38	Gandhi and Sundarapandian (2017)
Mistbelt forests	Limpopo Province, South Africa	707 ha	358.1	179	Mensah *et al.* (2016)
Deciduous forest	Seima Protection Forest, Cambodia	0.75 ha	17.9-91	9-45.5	Khun *et al.* (2012)
Community forest	Ghwangkhola Sapaude Babiyabhir Community Forest, Nepal	1 ha	126.3	59.36	Anup *et al.* (2013)
Tropical moist evergreen and semi-evergreen forests	Cachar district. Assam, India	4 ha	32.47-261.64	16.24-130.82	Borah *et al.* (2013)
Tropical dry forests	Sivagangai, Tamil Nadu, India	4 ha	58.43-102.76	33.9-58.99	Sundarapandian *et al.* (2013)
Tropical dry forest	Katghora forest division, Chhattisgarh, India	0.3 ha	111.2-199.42	55.13-98.55	Pawar *et al.* (2014)
Larch grasslands	Eastern Alps, Italy	5.21 ha (166 plots)	-	184-265	Nagler *et al.* (2015)
Seasonally dry tropical forests	Chiquitania, Bolivia	0.8 ha	128.53-204.85	-	Devisscher *et al.* (2016)
Different forest types	Trishna Wildlife Sanctuary, Tripura, India	10 ha	37.85-85.59	18.93-42.8	Majumdar *et al.* (2016)
Mahogany plantation, secondary forest, grassland	Municipality of Kapatagan, Lanao del Norte, Philippines	-	0.11-295.02	0-132.75	Zaragoza *et al.* (2016)
Subtropical forests	Ziro Valley, Arunachal Pradesh, India	0.3 ha	575.05	287.53	Yam and Tripathi (2015)
Tropical forests	Worldwide	-	-	242	Pan *et al.* (2011)
Seasonally dry tropical forests	Worldwide	229 estimates	39-334	-	Becknell *et al.* (2012)
Tropical forests	Worldwide	-	-	163.9	Pan *et al.* (2013)
Tropical rain forests	Amazon	56.25 ha	-	49.69-204.82	Berenguer *et al.* (2014)
Miombo woodland	Nhambita, Mozambique	27.2 ha	-	29.7	Ryan *et al.* (2011)
Natural forest	Tankawati natural hill forest, Bangladesh	3.2 ha	209.85	110.94	Ullah and Al-Amin (2012)
Primary and secondary forests	Bukit Timah Nature Reserve, Singapore	47.2 ha	334.98, 209.04	167.5, 104.5	Ngo *et al.* (2013)
Evergreen and deciduous forests	Western Ghats of Karnataka, India	12 ha	308-417	-	Murthy *et al.* (2016)

depth. Bulk density in natural ecosystems could be altered due to fine root mat formation with microbial and arthropod activities that subsequently lead to aeration of the soil (Jobbagy and Jackson, 2000). Apart from pedo-climatic factors, the soil carbon storage depends on the tree species, as well as their litter quality and quantity (Lugo and Brown, 1993; Ullah and Al-Amin, 2012). Soil type is a major determinant of woody vegetation structure and composition (Gandiwa *et al.*, 2016). Therefore, vegetation and soil mutually influence the carbon dynamics of each other. Chang *et al.* (2015) stated that soil organic carbon stocks are partly related to grass biomass. Native savanna soils are known to store at least as much carbon as that stored in above- and below-ground biomass (Anderson, 1991; Eswaran *et al.*, 1993; Scholes and Hall, 1996; Grace *et al.*, 2006). The greater soil carbon stock in site II may be due to bulk density, vegetation characteristics, particularly dominance of grasses in the understorey, terrain features, etc.

Pan *et al.* (2011) have stated that tropical forests store 56% of carbon in their biomass and 32% in soil. In the present study, around 47-55% of carbon is stored in biomass and the rest in soil. Overall, both sites had almost equal carbon stocks (site I – 388.5 Mg C/ha; site II – 390.1 Mg C/ha), but they show considerable variation in the amount of biomass and carbon stored in different carbon pools. Site II dominated site I in terms of understorey biomass carbon and soil carbon stocks, although the latter had a greater woody biomass carbon. The observed variations could be explained due to the difference in terrain characteristics, where site I is sloped, while site II is plain. Edaphic factors, precipitation and incidence of fires also play a prominent role. Site I was observed to be a savannah in 1993, which has since been left undisturbed and is therefore now in a transitional stage of succession from savannah to moist deciduous forest. This follows the reports of Hughes *et al.* (2002) and Nagler *et al.* (2015), which say that the abandonment of grasslands and their conversion to forest results in increased aboveground carbon stocks. In contrast, site II has a known history of annual fires, which although occasional in recent years, helps maintain its savannah structure. This could also be one of the reasons for more allocation of carbon stocks in understorey and soil. Fidelis *et al.* (2013) and Hasituya *et al.* (2013) also reported that fire frequency, seasonality and precipitation influence understorey composition and therefore biomass and carbon dynamics as well.

CONCLUSION

The study emphasizes the crucial role of savannahs in stocking considerable amounts of carbon in this critical period of rise in atmospheric CO_2. It is also evident that savannahs can sequester substantial amounts of biomass carbon that is comparable with global averages, when left unperturbed for decades, by its conversion into a natural forest. Conserving them would enhance carbon sequestration in the future that would significantly contribute to stabilizing atmospheric CO_2 levels.

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