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RESEARCH ARTICLE

Above – Ground Standing Biomass and Carbon Stock Dynamics under a Varied Degree of Anthropogenic Pressure in Tropical Rain Forests of Uttara Kannada District, Western Ghats, India

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ABSTRACT: Above-ground standing biomass and carbon-stock dynamics were monitored for 25 years (from 1984 to 2009) in six 1-ha permanent forest sites subjected to different levels of anthropogenic pressure in tropical rain forests of Uttara Kannada district,Western Ghats, south India. Over the years, total loss of trees ranged from 97 to 761 (23.95- 60 .7%) trees/ha, removal of trees by people ranged from 42 to 559 (5.5-55.17%) trees/ha and number of trees dead ranged from 55-370 (5.52-38.38%) trees/ha, leading to reduction in basal area in two sites (-1.81 m^2/ha, and -1.73 m^2/ha). In four sites, basal area increased from 0.98 to 22.19 m^2/ha, because of compensatory growth of surviving trees and added above-ground standing biomass ranging from 6.40 to 144.67 t/ha. Tree recruitment ranged from 214 to 1,840 trees/ha and it was more than the number of trees lost in four sites, indicating faster recovery of tree density. In the 25^{th} year, recruits formed 28.34 - 85.06% of the stand tree density and shared 1.20-18.47% of the stand basal area and accounted for 1.0-14.67% of the above-ground standing biomass and carbon stock, making all six sites as C-sinks. In general, the rate of carbon accumulation in forests of Uttara Kannada district was 1.13 t C /ha /yr , of which, 0.58 ± 1.18 t C /ha/year was contributed by surviving trees and 0.55 ± 0.33 t C/ha/year was added by recruits. With proper management strategies, the C-sequestration potential in the forests can be elevated and by reforesting degraded area, the carbon sink can be enhanced in the Western Ghats region. Role of recruits in forest dynamics must be considered while planning and management of forests to enhance carbon stocks.

KEY WORDS: Above-ground standing biomass, carbon stock dynamics, India, tropical rain forests, Uttara Kannada, Western Ghats.

INTRODUCTION

Anthropogenic emission of carbon dioxide (CO_2) reported lead to global warming and climate change affecting the biodiversity and destabilizing food and livelihood security. Rise in atmospheric CO_2 is because of large scale burning of oil, coal and natural gas, which are the energy sources for modern industrial economies and due to deforestation (Malhi and Grace, 2000). Forests are one of the major pools of carbon since plants fix atmospheric carbon in the tissues; thereby transform carbon from atmosphere to the biological systems. Carbon accumulation potential in forests is large and the period of carbon retention is long, so, they offer the possibility of sequestering significant amounts of additional carbon in relatively short period and keep it for many years. Therefore, forestry sector has been considered as one of the major mitigation sectors.

Tropical deforestation and forest degradation has attracted global interest in mitigating climate change. Tropical forests are important C-pools comprising approximately 40 % of terrestrial carbon storage (Dixon et al., 1994) and they support a large stock of carbon in the form of biomass, but release more CO_2 when disturbed (Palm et al., 1986). The net flux of carbon between forest and atmosphere determines whether forests are sources or sinks of carbon. While estimates of standing biomass in forests help to understand the carbon stocks, the knowledge of dynamics is useful to assess C-fixation potential of the stand and categorize them as C-source, C-sink or in C-steady state. Assessment of growth rate of the stand is useful to evaluate its potential to offset the emission of GHGs (green house gases) and to plan appropriate management strategies to reduce, stabilize and halt CO_2 emissions or to enhance C-sinks.

Long-term inventory of permanent forest plots provides data to evaluate above-ground standing biomass stock and C-dynamics and assesses the response of the forest to the environmental drivers such as elevated temperature, increase in incoming solar radiation, CO_2 fertilization and nitrogen enrichment. Long-term studies have reported increase in biomass, faster rate of C-accumulation, higher mortality and recruitment in biologically rich tropical rain forests in America, Africa and south-east Asia (Phillips, 1996; Condit et al., 2000; Baker et al., 2004; Lewis et al., 2004; Chave et al., 2008 a, b; Lewis et al., 2009). However, such studies are scanty from tropical rain forests of

India existing in Western Ghats, northeast India and in Andaman and Nicobar islands. The forests of the Western Ghats, rich in species diversity, recognized as one of the 18 hot spots of the world (Myers, 1988, 1990), are subjected to greater anthropogenic pressure in recent years leading to deforestation and degradation. Role and response of these forests in the changing ecological and environmental scenarios are less understood. This study focuses on the above-ground standing biomass and C-stock dynamics in six 1-ha tropical rain forest sites subjected to different levels of human pressures over a period of 25 years in Uttara Kannada district,Western Ghats, south India.

STUDY SITE AND METHODOLOGY

Study area

This study was conducted in Uttara Kannada district (lat., 13° 55′ to15° 31′; long., 74° 9′ to 75° 10′ E, Fig. 1) which is a hilly forested terrain situated all most in the middle of the Western Ghats in south India. It is the northernmost coastal district of the Karnataka state bordered by the Arabian Sea in the west. Geologically this is a transitional zone between the younger rocks of Archean shield of Indian peninsula. Considering the climate, rainfall and topography, the district can be divided in to three distinct zones. Coastal zone is a narrow strip, thickly populated, receiving more than 3,500 mm annual rainfall. Rice (*Oryza sativa* L), coconut (*Cocos nucifera* L) and ground nut (*Arachis hypogea* L) are the important crops in this zone. The crest line zone is forested, hilly tract, with low human population and receives 2,500 mm rainfall annually. Horticulture and agriculture is restricted to broad wet valleys and hill-pockets. Betel nut = Areca nut (*Areca catechu* L) and paddy are the important crops of this zone. Eastern flat maidan zone receives less rainfall (1,200 mm/ year) and the population density is high. Paddy, cotton (*Gossypium arboretum* L), ground nut, sugar cane (*Saccharum officinerum* L), Jowar = Sorghum (*Andropogon sorghum* L) and pulses are the important crops of this zone, mostly rainfed and to a little extent irrigated.

Comprising a total land area of 10,200 km^2, 80% of the total land area in the district is under the control of forest department. The forest cover in the district is 76.20 % (Forest Survey of India, 2005). Forests of the district are legally categorized into reserved forests forming > 60%, minor forests forming about 15%, leaf manure forests (locally known as 'Soppina bettas') form about 5%. Reserved forests (RF) are for the exclusive use of the state, minor forests (MF) are open access for community use and leaf manure forests are assigned to spice garden owners under certain privileges.

The vegetation of the district is broadly divided into two zones: the wet evergreen/semi evergreen zone comprises the areas facing western side from crest line up to the sea and the secondary/ moist deciduous zone includes area from crest line to the eastern flatter area. Puri (1960) has classified the forests facing the western side as topical wet evergreen type and included the eastern part in the tropical moist deciduous type. Champion and Seth (1968) have classified the forests on the western slope as tropical evergreen type and included the forests of the eastern zone in the category of south Indian moist deciduous type. According to Arora (1961), following three forest types are present in the district: evergreen forests, deciduous forests and scrub forests.

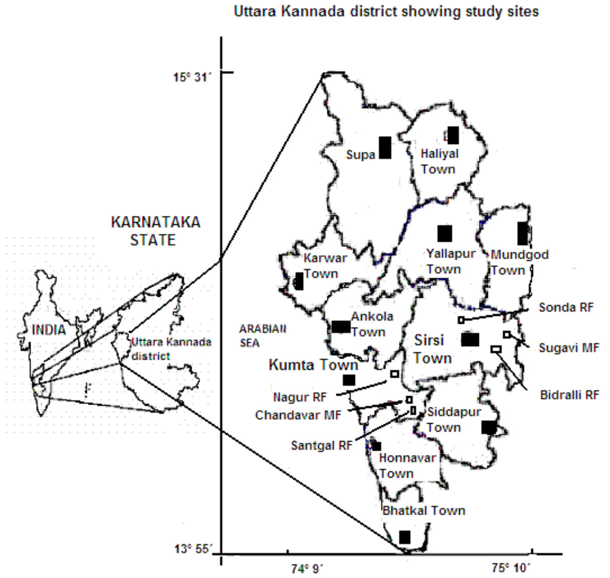

Fig. 1. Location map of study sites.

Methods

Data on basal area were obtained from six 1- ha forest plots located in evergreen/semi evergreen and secondary /moist deciduous zone in Uttara Kannada district. Brief descriptions of forest sites, land use category, floristic composition, accessibility and levels of disturbances etc., are given in Table 1. All individuals ≥ 10 cm GBH (girth at breast height i.e., at 132 cm from ground) were marked in 1984, numbered with embossed metal tags and enumerated as trees. Trees were identified to the species level following Cooke (1967). In case of uncertainty in identification, species were called as Unidentified I, II, III. Red colour strip of non-erasable oil paint was painted at the breast height to every marked tree. Girth measurements of surviving trees at the marked breast height continued annually up to 2009. During each measurement, cut and dead trees were recorded. Individuals not marked as trees during the benchmark enumeration i.e., in 1984 but measuring ≥10 cm GBH in 2009 are considered as recruits and their GBH were recorded. GBH values are converted to DBH

Table 1. Some important characteristics of the study plots located in two vegetation zones of Uttara Kannada district.

Forest sites	Chandavar	Bidralli	Nagur	Sonda	Sugavi	Santgal
Land use category	Minor forest	Reserve forest	Reserve forest	Reserve forest	Minor forest	Reserve forest
Level of biotic disturbance a) Removal of biomass by local people. b) Live-stock grazing c) Incidence of fire	 Very High -do- Occasional	 Very High -do- Occasional	 Moderate -do- -nil-	 Moderate -do- -nil-	 Minimum Moderate Occasional	 Negligible -nil- -nil-
Approximate distance (in Kilometers = km) from nearest human settlements	<0. 25 km	< 0. 25 km	<1 km	<1 km	<2 km	>3 km
Accessibility	Easily accessible	Easily accessible	Easily accessible	Easily accessible	Easily accessible	Difficult
Dominant species in the tree layer	*Hopea wightiana* *Lagerstroemia microcarpa* *Alseodphne semicarpifolia* *Aporosa lindleyana* *Flacourtia montana* *Ixora brachiata*	*Xylia xylocarpa* *Lagerstroemia microcarpa* *Adina cordifolia* *Schleichera oleosa* *Teminalia paniculata* *Randia spinosa*	*Hopea wightiana* *Holigarna arnottina* *Pterospermum* sp. *Aporosa lindleyana* *Myrstica attenuata*	*Terminala paniculata* *Terminalia tometosa* *Xylia xylocarpa* *Xantolis tomentosa* *Flacourtia montana* *Ervatamia heyneyana* *Aporosa. lindleyana*	*Terminalia bellerica* *Terminalia paniculata* *Terminalia tomentosa* *Lagerstroemia microcarpa* *Adina cordifolia* *Randia spinosa* *Phyllanthus emblica*	*Bishcofia javanica* *Dysoxylum binectariferum* *Nephelium longana* *Nothopodytes foetida* *Nothopegia colebrookiana*
Dominant species in the under growth (i.e., vegetation below the tree layer)	*Grewia microcos* *Psychotria flavida* *Strobilanthus* sp. *Uvaria* sp.	*Allophylus cobbe* *Murraya koengii* *Breynia* sp. *Clerodendrum infortunatum* *Eupatorium odoratum*	*Draecena ternifolia* *Glycosmis pentaphylla* *Psychotria flavida* *Uvaria* sp. *Neolitsea* sp.	*Grewia microcos* *Psychotria flavida*	*Acacia caesia* *Allophyllus cobbe* *Clerodendrum infortunatum* *Murraya koengii* *Pavetta* sp. *Wagatea spicata*	*Eugenia macrocephala* *Leea* sp. *Calamus* sp. *Ancestrocladus henyanus* *Glycosmis pentaphylla* *Gymnosporia rothiana* *Tarenna zeylanicum*

(= diameter at breast height) and these values are used in the present communication.

Above-ground standing biomass (AGSB) was estimated from basal area data following Ravindranath et al. (2000). This equation was specifically developed to estimate the AGSB from basal area data of the forests in the Western Ghats, India:

Biomass (in ton /hectare) = a + b (Basal Area in m^2)

where: a = 50.66, intercept constant and b = 6.52, regression coefficient.

Carbon stock was estimated assuming that it forms 50% of the biomass (Brown and Lugo 1982; Dixon et al 1994).

Mortality rate (M) was calculated following Sheil et al. (1995):

$M = [1-\{N_0-m)/N_0\}^{1/\Delta t}]$

where, N_0 = Tree density in initial year, m =number of dead trees among the initial tree density, $\Delta t =(t_2 - t_1)$ = period of observation, t_1 = initial year, t_2 =final year.

Recruitment rate (R) was calculated following Sheil and May (1996):

$R = [(N_0+r)/N_0]^{1/\Delta t} -1$

where, N_0 = Tree density in initial year, r = number of trees recruited in the period of observation.

Annual above-ground standing biomass change (Δ AGSB t/yr) was calculated as follows:

$\Delta AGSB = (AGSB_{t2} - AGSB_{t1})/ (t_2 - t_1)$

where, $AGSB_{t2}$ = Above-ground standing biomass in final year, $AGSB_{t1}$= Above-ground standing biomass in initial year, t_2 and t_1 are final and initial year respectively.

Annual carbon stock change (ΔC t/yr) was calculated following stock difference method (IPCC 2003):

$\Delta C = (C_{t2} - C_{t1})/ (t_2 - t_1)$

where , C_{t2} =carbon stock in final year, C_{t1} = Carbon stock in initial year, t_2 and t_1 are final and initial year respectively.

RESULTS

Tree density and dynamics

Over a period of 25 years all sites lost trees ranging from 23.95 % in Sugavi MF to 60.7 % in Chandavar MF

Table 2. Change in tree density over a period of 25 years in study sites in Uttara Kannada district.

Forest site	No. of trees		Loss of trees (No./ha) in 25 years due to			Mortality rate (% /yr)	No. of trees recruited over 25 years	Recruit-ment rate (% /yr)	Total No. of trees in 2009 including recruits	Net change in tree density from 1984 to 2009 due to recruits & (% change)	% Contribution in tree density in 2009 by	
	In 1984	In 2009	Removal by people & (%)	Death& (%)	Total loss of trees over 25 years & (% loss)						Survived trees	Recruits
Chandavar MF	580	228	320 (55.17)	32 (5.52)	-352 (-60.7)	0.23	602	2.89	830	250 (43.1)	27.47	72.53
Bidralli RF	306	164	93 (30.39)	49 (16.01)	-142 (-46.4)	0.70	453	3.70	617	311 (101.6)	26.58	73.42
Nagur RF	1,619	858	559 (34.53)	202 (12.48)	-761 (-47.0)	0.53	706	1.46	1,564	-55 (-3.4)	54.86	45.14
Sonda RF	692	385	190 (27.46)	117 (16.91)	-307 (-44.4)	0.74	799	3.12	1,184	492 (71.1)	32.52	67.48
Sugavi MF	405	308	42 (10.37)	55 (13.09)	-97 (-23.4)	0.58	1,840	7.09	2,148	1,743 (430.4)	14.34	85.66
Santgal RF	964	541	53 (5.50)	370 (38.38)	-423 -(43.9)	1.92	214	0.81	755	-209 (-21.68)	71.66	28.34
Mean ± SD	761 ± 479. 30	414 ± 253. 94	209.50 ± 200.43	137.16 ± 130. 18	-347 ± 238. 04		769 ± 563. 50		1,183 ± 583. 87	422 ± 695. 35	37.90 ± 21.21	62.09 ± 21.21

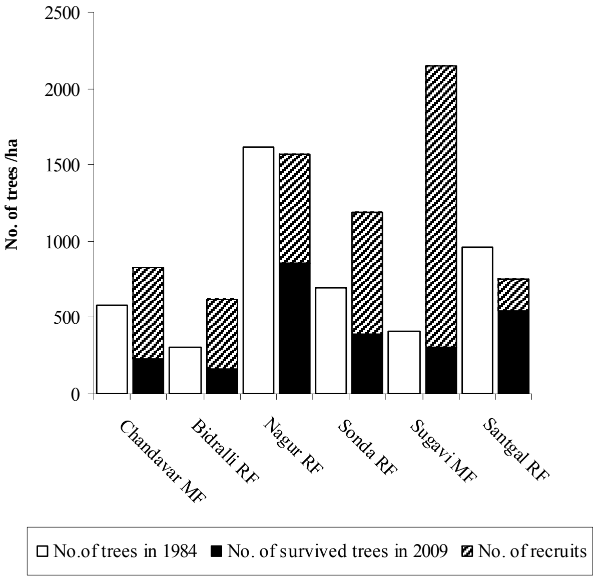

Fig. 2. Tree density change over a period of 25 years in study sites in Uttara Kannada district.

(Table 2, Fig. 2). Tree mortality ranged from 0.23-1.92 % /year. Loss of trees in 25 years due to removal by people was minimum in Santgal RF (5.50 %) and maximum in Chandavar MF (55.17 %) and natural death of trees ranged from 5.52% (in Chandavar MF) to 38.38 % (in Santgal RF, Fig 3). Number of trees removed exceeded the number of trees dead in Bidralli, Sonda, Nagur RFs and Chandavar MF, but in Sugavi MF and Santgal RF dead trees were more than the removal of trees by people. More number of trees were felled/ removed and dead in lower DBH classes in all sites, showing progressive declining trend in total loss of trees in higher diameter classes (Fig. 4).

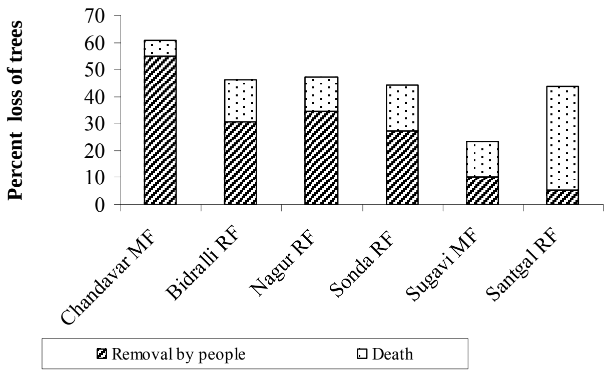

Fig. 3. Loss of trees due to felling/removal and death in different study sites over a period of 25 years in Uttara Kannada district.

Though all sites lost trees over a period of 25 years there was addition to stand tree density through recruits ranging from 214 in Santgal RF to 1,840 trees/ha in Sugavi MF (Table 2). Recruits have added over and above the lost trees and they out numbered the benchmark tree density in Sugavi and Chandavar MFs and in Bidralli and Sonda RFs (Fig. 2). In 2009 contribution of recruits to the stand tree density was 85.66% in Sugavi M.F, 73.42% in Bidralli RF, 67.48 % in Sonda RF and 72.53 % in Chandavar MF. However, in Nagur and Santgal RFs restocking of initial tree density was partial, so they continued to loose trees even after 25 years (Table 2).

Basal area and dynamics

Basal area values varied from 20.95 m^2/ha in Nagur RF to 32.62 m^2/ha in Sonda RF during 1984 (Table 3). Over a period of 25 years i.e., in 2009, lowest basal area was observed in Chandavar MF (20.02 m^2/ha) and

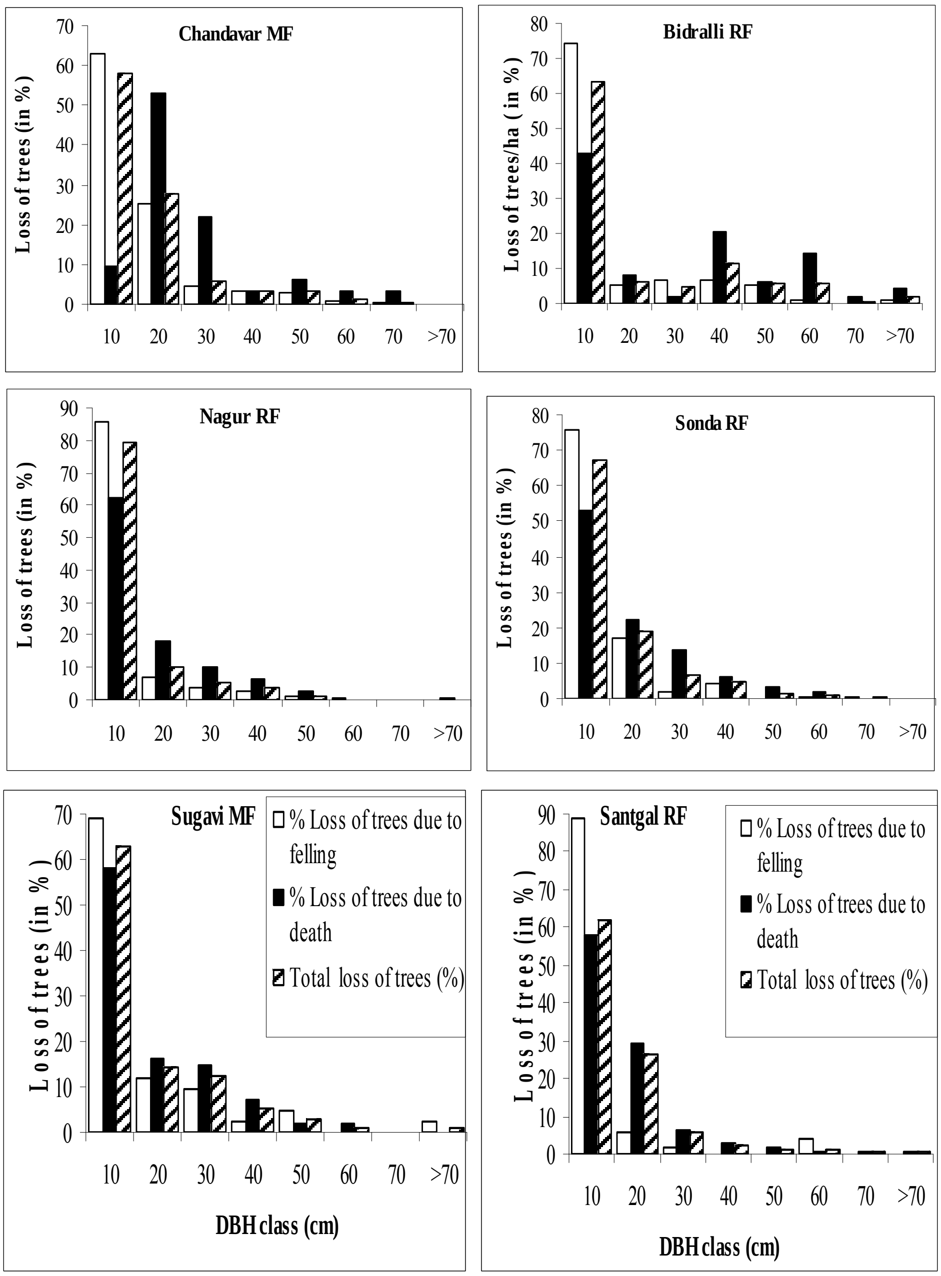

Fig. 4. Trends in loss of trees in different DBH classes due to felling/removal, death and total loss of trees (in %) in study sites in Uttara Kannada district.

maximum in Nagur RF (43.14 m^2/ha, Fig 5a). Increase in basal area was observed in Sugavi MF (8.58%), Sonda RF (3.01%), Nagur RF (105.91%) and Santgal RF (16.15%), while there was reduction in basal area in Bidralli RF (6.84%) and Chandavar MF (7.97 %). Addition of basal area in 25 years by recruits ranged from 0.45 m^2/ha in Santgal RF to 5.54 m^2/ha in Sugavi MF (Table 3). Because of recruits, basal area increased in all sites ranging from 4.11% in Bidralli RF to 113.39% in Nagur RF (Table 3, Fig. 5).

Estimated above-ground standing biomass (AGSB) and their change

Estimated values of above-ground standing biomass (= AGSB) in different forest sites during the benchmark year i.e., 1984 and their change after 25 years are given in Table 4. During the benchmark year lowest AGSB was observed in Nagur RF (187.25 t/ha) and maximum in Sonda RF (263.34 t/ha, Fig. 6). After 25 years, i.e., in 2009, highest AGSB was noticed in Nagur RF (331.93 t/ha) and lowest was in Chandavar MF (181.16 t/ha).

Table 4. Change in above- ground standing biomass (=AGSB t/ha) and Carbon stock (= C-stock t/ha) over 25 years in study sites of Uttara Kannada district.

Study site	AGSB & C		Change in AGSB & C over 25 years	% Change in AGSB & C over 25 years	Annual % change	Rate of change in AGSB & C (t/ha/yr)	Addition of AGSB & C by recruits	Rate of addition of AGSB & C by recruits (t/ha/yr)	Total AGSB & C in 2009 including recruits	Net change in AGSB & C due to recruits in 2009	% Change in AGSB & C due to recruits in 2009	% contribution of AGSB & C in 2009 by	
	In 1984	In 2009										Survived trees	Recruits
Chandavar MF	AGSB = 192.47 C = 96.24	181.16 90.58	-11.31 -5.65	-5.87	-0.23	-0.45 -0.23	36.43 18.21	1.46 0.73	217.59 108.79	25.12 12.56	13.05	87.81	12.19
Bidralli RF	AGSB = 222.92 C = 111.46	211.14 105.57	-11.78 -5.89	-5.28	-0.21	-0.47 -0.23	27.29 13.65	1.09 0.55	238.43 119.22	15.52 7.76	6.96	91.81	8.19
Nagur RF	AGSB = 187.25 C = 93.63	331.93 165.96	144.67 72.34	77.26	3.09	5.79 2.89	14.80 7.40	0.59 0.30	346.72 173.36	159.47 79.73	85.16	97.01	2.99
Sonda RF	AGSB = 263.34 C = 131.67	269.74 134.87	6.40 3.20	2.43	0.10	0.26 0.13	28.64 14.32	1.15 0.57	298.38 149.19	35.04 17.52	13.30	93.17	6.83
Sugavi MF	AGSB = 197.49 C = 98.75	210.09 105.04	12.60 6.30	6.38	0.26	0.50 0.25	52.28 26.14	2.09 1.05	262.37 131.19	64.88 32.44	32.85	85.33	14.67
Santgal RF	AGSB = 260.15 C = 130.07	293.97 146.98	33.82 16.91	13.00	0.52	1.35 0.68	4.29 2.15	0.17 0.09	298.26 149.13	38.11 19.06	14.65	99.00	1.00
Mean ± SD	AGSB = 220.60 ± 34.16 C = 110.30 ± 17.08	249.67 ± 58.10 124.84 ± 29.05	29.07 14.53	13.18	0.53	1.16 ± 2.36 0.58 ± 1.18	27.29 ± 16.70 13.64± 8.35	1.09 ± 0.67 0.55± 0.33	276.96 ± 46.90 138.48 ± 23.45	56.36 ± 53.17	27.66 ± 29.49	92.35 ± 5.23	7.64 ± 5.23

Maximum percentage loss of AGSB over 25 years was in Chandavar MF (5.87%) and maximum percentage gain was 77.26% in Nagur RF. Recruits have added AGSB in all sites (Fig. 6) ranging from 4.29 t/ha in Santgal RF to 52.28 t/ha in Sugavi MF (Table 4).

Carbon stock and dynamics

In benchmark year carbon stock was minimum in Nagur RF (93.63 t/ha) and it was maximum in Sonda RF (131.67 t/ha, Table 4, Fig. 7). After 25 years, substantial increase in C-stock was observed in Nagur RF, (77.26%) followed by Santgal RF (13%), Sugavi MF (6.38%) and Sonda RF (2.43%), but it decreased in Chandavar MF (5.87%) and Bidralli RF (5.28%, Fig. 7). Addition of carbon by recruits ranged from 2.15 t/ha in Santgal RF to 26.14 t/ha in Sugavi MF, resulting in increase in carbon stock in all forest sites (Fig 7).

DISCUSSION

Continuous annual observation of six 1- hectare forest sites over a period of 25 years in Uttara Kannada district in Western Ghats evidenced that removal of trees by people and tree mortality were the prime reasons responsible for the decrease in the tree density in all sites. Studies have reported dependency of rural population on forests for meeting their biomass requirements such as fuelwood, fodder, fencing poles and small timber for agriculture implements etc., leading to forest degradation (Silori and Mishra, 2001; Singhal et al., 2003; Arjunan et al., 2005; Chandrashekara et al., 2005; Davidar et al., 2007). Removal of more number of small sized trees suggests that people need them in bulk quantity to use frequently. Therefore, greater demand for trees of small size led to extraction of more number of live trees than they die in Bidralli RF, Sonda RF, Chandavar MF and Nagur RF. Occurrence of more number of dead trees in Sugavi MF and Santgal RF indicates less anthropogenic disturbance in these sites. Decrease in stem density has been attributed to disturbance intensity (Ramirez-Marcial et al., 2001), tree cutting for domestic use (Smiet, 1992), and because of selective and commercial extraction of timber (Elouard et al., 1997; Pomeroy et al., 2003). Several studies have reported invariably more intensive exploitation of forests close to human settlements than remote forests (Acharya, 1999; Sagar et al., 2003; Ramacharitra, 2006). In the present study, it was observed that removal of trees by people was more in Chandavar MF, Bidralli RF, Nagur RF, Sonda RF and it was marginal in Sugavi MF and minimum in Santgal RF. Former four sites are very close to human settlements and easily accessible (Table 1). Therefore, they are subjected to greater human pressure and over exploited, leading to decrease in tree density. However, in Sugavi MF, though easily accessible, removal of trees by people is marginal because there are only a few

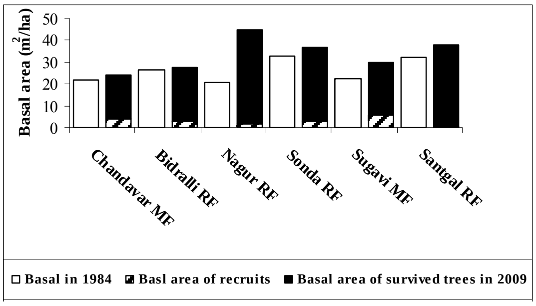

Fig. 5. Basal area (m^2/ha) change over a period of 25 years in study sites in Uttara Kannada district.

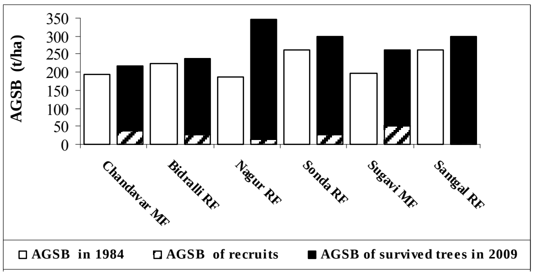

Fig. 6. Above-ground standing biomass (=AGSB, t/ha) change over 25 years in study sites of Uttara Kannada district.

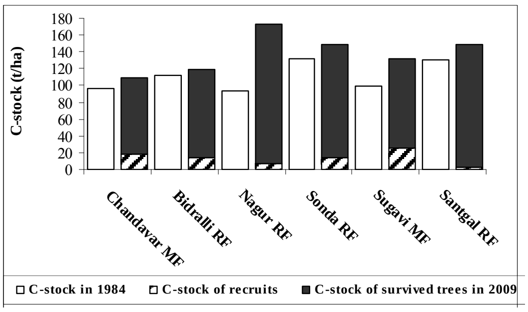

Fig. 7. Carbon stock (=C-stock, t/ha) change over 25 years in study sites of Uttara Kannada district.

houses scattered in the nearby settlements. In case of Santgal RF though it is away from human settlement and not easily accessible, a few trees were removed by people and tree mortality was very high. People do not visit this site frequently to cut trees for meeting their large scale demands, but go there to collect non-timber forest products (NTFPs) and other usufructs for own use or for marketing. During their visit, small trees are cut to use as support for walking on sloppy hills, harvest forests products, build temporary platforms to hunt animals, relaxing and store the collection. According to Karanth et al. (2006), village size class and proximity to other villages were significant predictors of disturbance index. Inaccessible hilly terrain and distant location as in case of Santgal RF and a few scattered houses around Sugavi MF may be leading to least removal of trees by humans in these forests.

Tree mortality ranged from 0.23 to 1.92 % / year, which is within the range of 1-2% as reported by Swaine et al. (1987). High mortality rate was related to global changes such as increase of CO_2 in atmosphere and metabolic imbalances (Phillips, 1996; Laurance et al., 1998), effect of habitat fragmentation and microclimatic alterations (Nascimento et al., 1999). In the present study, over 25 years, more number of trees in small diameter classes were dead in all sites leading to decrease in stand tree density as well as in lower DBH classes. According to Wolf et al. (2004), competition for light, water or nutrients among trees of smaller size classes is the major factor determining the death or survival. Turner (2001) reported higher rate of tree mortality in lower diameter classes, but Swaine et al. (1987), and Lieberman and Lieberman (1987), have argued that tree mortality is independent of size classes. Martinez-Ramos and Alvarez–Buylla (1998) assumed that mortality rate in older individuals could be higher because they lose vigour and become more liable to predation by natural enemies and physical damage. According to Lutz and Harplen (2006), end of life span, stress conditions such as - over crowding, competitive inability of trees in lower class with tall trees for light, moisture and nutrients due to their shallow roots and shady location below the canopy curtail availability of light- leads to higher mortality of small sized trees. According to Felfili (1995), greater mortality of trees among smallest diameter class should result from the lower competition capacity in relation to the larger trees, which occupy upper strata. In Santgal RF majority of the dead trees were from lower diameter classes, because they are under the shade of tall trees and the canopy is very much closed, so the availability of light is curtailed. Such a situation is not conducive for seed germination, establishment and growth of seedlings of many species. So tree recruitment is less than the mortality, therefore, tree density continued to decline even after 25 years. In Nagur RF, 47% of trees were lost in 25 years and recruitment of trees was 43.61%, so there was no restocking of initial tree density. This indicates opening of canopy increased availability of light partly and favoured the growth of suppressed advance regeneration and seedlings. However, continued decrease in tree density even after 25 years suggests removal of more number of trees than that are added. In more exploited sites such as Bidralli RF and Chandavar MF decrease in tree density resulted in sparse distribution of trees leading to more area available for each tree, thus easing competition for moisture and nutrients, increased canopy opening and availability of light. All these conditions are favourable for silvigenesis and faster growth of plants below the tree layer, therefore, there were more recruits. Apart from the favourable situations as in Bidralli RF and Chandavar MF, less anthropogenic disturbance favoured more tree recruitment in Sugavi MF.

Basal area of the study sites ranged from 20.95-32.62 $m^{2/}$/ha and these values are less than those reported for evergreen forest sites of Western Ghats in India, which ranged from 33.7-48.7 $m^{2/}$/ha (Pascal, 1992), 33.7-48.7 $m^{2/}$/ha (Rai and Proctor, 1986), 29.02-41.78 $m^{2/}$/ha (Swamy et al., 2010). Other studies have reported the basal area values ranging from 28-57 $m^{2/}$/ha in tropical rain forests of Sarawak (Proctor et al., 1983), 23-37 $m^{2/}$/ha in lowland rainforests of Africa (Dawkins, 1959). Rai (1983) reported basal area ranging from 19.66 to 40.37 $m^{2/}$/ha in tropical rain forests of Western Ghats in India and Murphy and Lugo (1986) reported a range of 20-75 $m^{2/}$/ha in Puerto Rican wet evergreen forests. The basal area values of the present study are within the range of latter two studies. Lower basal area results from indiscriminate logging, lower amount of precipitation, species composition, age of the trees, disturbance, succession stage of the stand and sample size (Sundarapandian and Swamy, 2000; Swamy et al., 2010). Mishra et al. (2004) reported basal area of 7.1, 18.6 and 26.19 $m^{2/}$/ha in highly disturbed, moderately disturbed and in undisturbed sacred groves respectively in semi evergreen subtropical wet hill forests of Meghalaya, northeast India. Rai (1983) attributed lowest basal area in one of the study sites to severe anthropogenic disturbances. Though Nagur RF had highest tree density in 1984 (1,619/ha) it showed least basal area, probably due to overcrowding, compelling trees to allocate more photosynthate to gain height to avail more light rather than investing in girth increment. According to Rice et al. (2004), higher tree density indicates regenerating condition of the site from the previous disturbance. So, higher tree density but with lowest basal area in Nagur RF, indicates fast recovery from the past disturbance.

Though all forest sites lost trees, basal area increased in Sugavi MF, Sonda, Nagur and Santgal RFs, suggesting compensatory growth of surviving trees in these sites. Such growth behaviour was reported from deciduous forest of south India (Sukumar et al., 1998). Canopy opening enhances light penetration, reduces competition for moisture and nutrients, and facilitates growth of existing trees (Swaine et al., 1987). Decline in tree density and reduction in competition favour fast growth of surviving trees (Pascal, 1988). Elouard et al. (1997) reported stimulation of individual diameter increment due to logging in a dense moist evergreen forest in Western Ghats, India. Primack et al. (1985) reported more growth in trees of Moraceae growing in logged forest area than trees in primary forests in Sarawak, Malaysia. According to Sundaram and Parthasarathy (2002), significant increase in the basal area in a highly disturbed forest site was due to growth induction by disturbance regimes such as tree felling, cattle grazing and addition of organic matter and nutrients through dung and pellets. Therefore, observed remarkable increase in basal area of 105.91% (with annual increase of 4.24 %, Table 3) in Nagur RF could be a combined effect of thinning and stimulatory growth of existing trees.

Decrease in basal area over 25 years in Bidralli RF and Chandavar MF, indicates greater anthropogenic pressure on these sites. Addition of basal area is possible by tree recruitment either sapling becoming trees or coppicing stems growing to tree dimensions. In the present study, it was observed that recruits contributed over and above the lost basal area leading to net gain in the basal in all sites.

In the present study the above-ground standing biomass values ranged from 187.25 to 263.34 t/ha. These are less as compared to the reported values of 225-446 t/ha in the tropical rain forests in Malaysia, 238-341 t/ha in tropical rain forests of Cameroon (Brown and Lugo, 1982), 332-353 t/ha in evergreen forests of Andaman and Nicobar islands in India (Rajkumar and Parthasarathy, 2008). However, above-ground standing biomass values of the present study are within the reported values of 153 -221 t/ha in Sri Lankan tropical rain forests (Brown and Lugo, 1992), 170-330 t/ha in lowland rainforest of Colombia (Fölster et al., 1976), 96.28-275.46 t/ha in tropical rain forests in Thailand (Terakunpisut et al., 2007). The carbon stocks in the present study ranged from 93.63-131.67 t/ha. These values are greater than the values of undisturbed tropical rain forest of Sri Lanka (77 t/ha), but lower than the relatively undisturbed matured tropical rain forest of Malaysia (223 t/ha, Brown and Lugo, 1982). The observed range of carbon stocks in this study is within the range of 60-179 t/ha as reported by Ogawa et al. (1965) for different tropical forest types in Thailand. Tropical forest structure and biomass storage is known to vary with soil types (Tuomisto et al., 1995), soil nutrients (Laurance et al., 1999), climate (Holdridge, 1979 ; Gentry, 1982), disturbance regime (Lugo and Scatena, 1996), successional status (Saldarriaga et al., 1988) and human impacts (Brown et al., 1994; Laurance et al., 1997; Gaston et al., 1998). The storage of carbon in a forest is related to climate, soils structure, nutrient availability and disturbance (Brünig, 1983; Chave et al., 2001; Wright, 2005). According to Lugo and Brown (1992) higher values of biomass / C-stocks are associated with less human or natural disturbances or better site qualities. According to Clarke (1908), vegetation / forests continue to accumulate biomass and act as C-sinks unless they are altered or disturbed. Wang et al. (2001), after studying the impacts of human disturbance on vegetation in China, reported negative correlation between carbon densities and human population density. In the present study in two forest sites, Bidralli RF and Chandavar MF, which are close to human habitation, there was decrease in above-ground standing biomass and they turn out to be C-sources to atmosphere, where as in other sites there was increase in above-ground standing biomass and are acting as C-sinks. According to Brown and Lugo (1990), recovering forests after previous disturbance accumulate more biomass and carbon. This is evident from the drastic increase in the above-ground standing biomass and carbon stock in Nagur RF.

Apart from addition of biomass and carbon by the growth of surviving trees, recruits also added biomass in all sites in 25 years ranging from 4.29 to 52.28 t/ha and carbon ranging from 2.15-26.14 t/ha. This suggests that all sites are active in sequestering carbon from atmosphere. In the present study it was observed that carbon accumulation rate ranged from 0.31-3.19 t/ha/yr. Vieira et al. (2004) reported addition of carbon to living biomass ranging from 1.9-2.8 t/h/yr in Amazon tropical rain forests. Phillilps et al. (1998) reported accumulation of carbon at the rate of 0.74 ± 0.34 t C/ha/yr in Neotropical forests. In the forests of Uttara Kannada district, the annual rate of carbon sequestration by surviving trees is 0.58 ± 1.18 t/ha/year and by recruits is 0.55 ± 0.33 t C/ha/year (Table 4), indicating that they are active in atmospheric carbon sequestration and enhancing C- sink.

CONCLUSION

Long-term monitoring of forest dynamics in Uttara Kannada district in Western Ghats region of India revealed that closeness to human settlement and easy accessibility led to decrease in tree density, reduction in basal area , biomass and carbon stock in forest sites. Removal of more number of trees in lower DBH classes indicates people need them in bulk quantity for frequent use. Higher mortality of trees in lower DBH classes in less disturbed site is attributable to their competitive inability with tall and canopy trees for light, moisture and nutrients. In spite of natural disturbances and harvest of trees by local communities, increase in basal area, biomass and carbon stocks in four forest plots, is on account of stimulatory growth of surviving trees. Loss of trees opened canopy, favoured more recruitment of trees that led to regain the stand tree density, above-ground standing biomass, enhanced C-stocks, there by offset CO_2 emission to some extent. Restocking of tree density, increase in basal area, above-ground standing biomass and carbon stock over a period of 25 years indicates that the forests are in the process of recouperation, sequestering atmospheric carbon and providing environmental service. Recruitment of trees even in sites subjected to greater anthropogenic pressure is suggestive of their potentiality to recover from the past disturbance. Involvement of the community is to be considered while planning for conservation, protection and sustainable management of biologically rich forests of the Western Ghats. There is a need to develop appropriate management systems to increase the carbon stocks in the degraded areas and permitting regulated harvest of biomass to meet the needs of local communities, without altering the forest attributes, functioning and productivity.

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印度西高止山北卡納達區內，不同人為干擾壓力下熱帶雨林之地上部生物量與碳存量動態

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摘要：在印度南部西高止山北卡納達區內，我們從 1984 到 2009 年間，以 25 年的時距監測六個面積一公頃的永久森林樣區，用以瞭解在不同人為干擾壓力下森林地上部的現存生物量與碳存量動態。結果發現，在 25 年過後，每公頃樹木總損失株數可從 97 棵到 761 棵(23.95-60.7%)。其中，人為砍除的株數從每公頃 42 棵到 559 棵(5.5-55.17%)，自然死亡的株數則從每公頃 55 棵到 370 棵(5.52-38.38%)。 其中，有兩個樣區因為死亡個體過多，而造成整體植物底面積減少(-1.81 m^2/ha 及 -1.73 m^2/ha)。另外四個樣區的植物底面積及整體生物量，則因為存活個體的生長，而呈現增加(底面積 0.98 to 22.19 m^2/ha; 生物量 6.40 to 144.67 t/ha)。樹木新增株數範圍，則從每公頃 214 棵到 1,840 棵，這比其中四個樣區因為死亡而損失的植株數還要多，顯示樣區在植株密度上具有快速恢復的能力。在第 25 年時，樣區新增率為 28.34 - 85.06%，佔樣區植物底面積的 1.20-18.47%，以及 1.0 -14.67%的地上部生物量及碳存量，使得我們調查的所有六個樣區都是碳匯。綜合言之，在北卡納達區內森林，碳的累積率約為 1.13 t C /ha /yr，其中有 0.58 ± 1.18 t C /ha/yr 是由存活個體貢獻，0.55 ± 0.33 t C/ha/year 則是由新增個體所貢獻。因此，這片森林碳吸存的潛力，可以在適當的經營及復育策略下提升，使得西高止山地區成為碳匯。所以在計畫及經營森林時，為促使森林中的碳存量增加，必須加以考慮新增個體在森林動態中扮演的角色。

關鍵詞：地上部現存生物量、碳存量動態、印度、熱帶雨林、北卡納達、西高止山。