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Abstract- Western Ghats is one of the biodiversity 'hotspots' of the world and currently, there is limited evidence on the status and dynamics of tropical forests in the context of human disturbance and climate change. This study presents the findings of the study conducted under a citizen science programme. The biomass and carbon stocks in the evergreen and deciduous forests of the study area are comparable to the standing biomass of other tropical forests and range from 344-417 tC. There are no major differences between carbon stocks in less and more disturbed forests, which is of significance, given the large dependence of communities on the more disturbed forests. Periodic and long-term monitoring of forests is necessary in the context of potential increased human pressure and climate change to plan and manage forests for mitigation as well as adaptation in a synergistic manner.

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Biomass and Carbon Stock Dynamics in Forests of Western Ghats

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Abstract- Western Ghats is one of the biodiversity 'hotspots' of the world and currently, there is limited evidence on the status and dynamics of tropical forests in the context of human disturbance and climate change. This study presents the findings of the study conducted under a citizen science programme. The biomass and carbon stocks in the evergreen and deciduous forests of the study area are comparable to the standing biomass of other tropical forests and range from 344-417 tC. There are no major differences between carbon stocks in less and more disturbed forests, which is of significance, given the large dependence of communities on the more disturbed forests. Periodic and long-term monitoring of forests is necessary in the context of potential increased human pressure and climate change to plan and manage forests for mitigation as well as adaptation in a synergistic manner.

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I. Introduction

Tropical forests play an important role in the global carbon cycle. The future role of tropical forests in the global carbon cycle and the climate system is a function of future deforestation rates and the degree to which remaining forests will be sustainable or even increase their carbon stock (Grace, 2004). Tropical biome conversion is estimated to be a source of 1.3 GtC/year to the atmosphere during the period 1990-2005, whereas the intact tropical biomes are estimated to be a net carbon sink of 1.1 GtC/year, with a net source of 0.2 GtC/year for the same period (Malhi, 2010). However, the carbon balance of the world's terrestrial ecosystems is uncertain, especially that of tropical forests.

Carbon is stored in forests predominantly in live biomass and in soils, with smaller amounts in coarse woody debris (Malhi et al., 2009). In tropical forests world wide, about 50% of the total carbon is stored in above ground biomass and 50% is stored in the top 1 m of the soil (Dixon et al., 1994). In this context, secondary forests are of particular significance with the proportion of tropical secondary forests projected to increase due to increasing anthropogenic pressure and movement of populations towards urban centers (Wright, 2005). It is thus important to assess carbon stocks and uptake in secondary forests.

Western Ghats is one of the biodiversity 'hotspots' of the world. Forests in the Western Ghats like elsewhere in India are on the one hand protected under the Forest Conservation Act of 1980, from conversion, and on the other hand subjected to human use and disturbance. Studies by Ravindranath et al., 2006 and Chaturvedi et al., 2011 have shown that forests are likely to be adversely impacted by climate change in the coming decades. Further, studies by Rosenzweig, 1995 and Jandl et al., 2007 have shown that disturbed, fragmented and monoculture forests are likely to be more vulnerable to projected climate change compared to undisturbed forests. Currently, there is limited evidence on the status and dynamics of tropical forests in the context of human disturbance and climate change. Understanding of the forest dynamics is essential in order to arrive at precise rates of carbon fixation by a community and then applying it on a regional and global level for estimating the change of CO_2 in the atmosphere (Bhat et al., 2003). This study presents the findings of the study conducted under a long-term programme involving Indian Institute of Science, Earthwatch Institute and volunteer investigators from HSBC (Hongkong and Shanghai Banking Corporation Limited).

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II. Materials and Methods

a) Study area

The Western Ghats in south-India is identified as one of the 34 biodiversity hot spots (Myers, 1990) and are important for providing multiple ecosystem services. In recent years, the Western Ghats have been subjected to intensive human disturbances apart from natural calamities leading to erosion of species richness, disruption of closed canopy, spread of invasive species, changes in structure and function. There are descriptive studies dealing with the qualitative aspects of the forests of the Western Ghats (Champion and Seth 1968, Rai and Proctor 1986, Pascal and Pellisier 1996), but very few studies that have attempted quantitative assessment and dynamics of this region (Bhat et al., 2000a, Pomeroy et al., 2003 and Bhat et al., 2000b).

Uttara Kannada district lies between 13° 55' to 15° 31' N lat., 74° 9' to 75° 10' E long (Figure 1). A detailed description of the physical environment of Uttara Kannada district is available in Bhat et al (2000a). This district is richly endowed with forests and about 75% of the total land area (10,291 km^2) is forested. The vegetation of the district is of evergreen/semi-evergreen type along the slopes and towards the east of the ridge, it is moist deciduous (Pascal 1982, 1984, 1986).

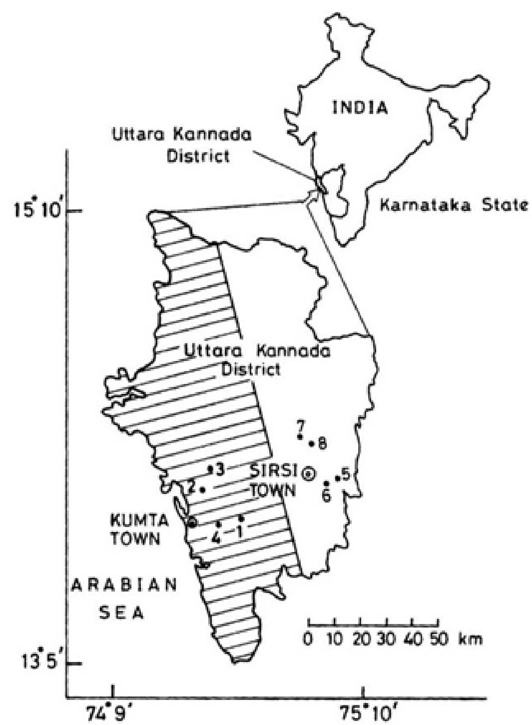

Fig. 1 : Uttara Kannada district showing broad vegetation

b) Permanent plots

Forest structure, species composition, and growth data was from 12 permanent plots established in representative areas in two forest categories namely, the evergreen and deciduous in Uttara Kannada district. In each forest category, plots measuring 100 m x 100 m (1-ha) were demarcated and in all, six 1-ha forest plots in three locations, representative of evergreen forest zone (Ekkambi, Tattikai and Hosur) and another six 1-ha plots (in three locations namely, Malgi, Hudelkoppa and Ogralli), representative of deciduous forest zone were studied. At each location, two 1-ha plots were laid representing:

a) Less disturbed system – farther from settlements or human habitation
b) More disturbed system – in proximity to human habitation

In the plots, woody plants, including tree saplings, lianas, and climbers >10 cm in Girth at Breast Height (GBH) were mapped and identified to the species level following Cooke (1967), and in case of uncertainty identified up to genera or family level. When there were branches, the branches with a GBH >10 cm were noted as stems and marked respectively as A, B, C etc., and GBH measured and recorded. A red strip was painted on each tree and stem at the breast height. Each tree was numbered with an embossed metal tag. GBH was measured at 1.3 m, except for trees with buttresses, where diameter was measured 10 cm above the buttresses to minimize errors in biomass estimates

(Murali et al., 2005). Girth measurements in the study plots were conducted during 2009-10 and 2011-2012.

Basal area was calculated for the 12 one-ha forest plots located in evergreen and deciduous zones in Uttara Kannada district. Above ground standing biomass was estimated from basal area data following Murali et al. (2005). The carbon stock at each forest site was estimated assuming that it forms 45% of the biomass. Belowground biomass was estimated using the IPCC default factor of 0.26. Changes in biomass and carbon stock in the forest plots were computed by deducting the benchmark year values from the final year values. This included the contribution from recruits.

III. Results

a) Basal area

Basal area is an indicator of growing stock and biomass production. Here we discuss the basal area across different forest types and disturbance regimes.

Evergreen forest type: The basal area recorded across the 6 evergreen plots range from a high of 43.53 m^2/ha in less disturbed Hosur plot to 34.68 m^2/ha in Tattikai less disturbed plot for the base year-2009. However during 2011, highest basal area is recorded in less disturbed plot of Ekkambi. Across all the plots in evergreen forest type, higher basal area is recorded in the less disturbed plots as compared to more disturbed plots during 2009 as well as 2011, except in Tattikai where slightly higher basal area has been recorded in the more disturbed plot, only during 2009 (Figure 2).

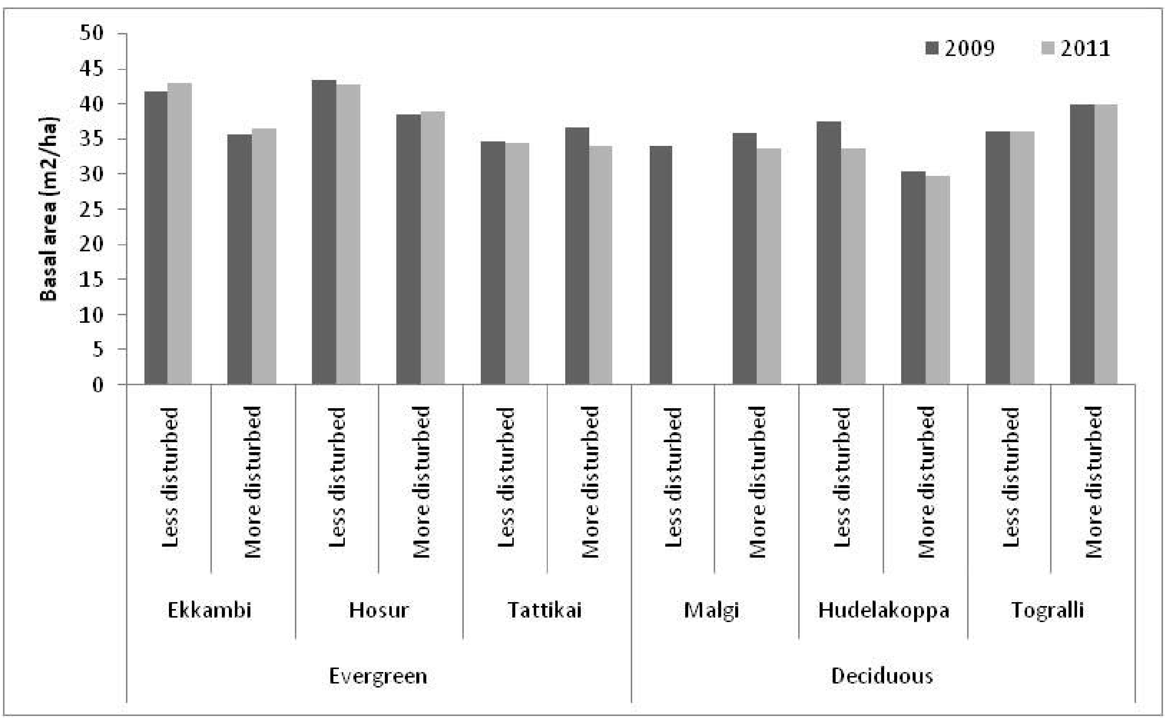

Fig. 2 : Basal area recorded in evergreen and deciduous plots during 2-enumeration periods

Deciduous forest type: Among the deciduous plots, 2-time enumeration has been carried out in all the plots, except Malgi less disturbed plot. In these plots, there is no clear pattern in that the basal area is higher in less or more disturbed plots during both the enumeration years. Highest basal area has been recorded in the more disturbed plot of Togralli during 2009, (Figure 2) while during 2011 Hudelakoppa less disturbed plot has the highest basal area. This is lesser than the maximum basal area recorded in Togralli during 2009.

A comparison of basal area recorded during the two enumeration periods indicates increase in 4 of the 11 locations while in others there is a very small to medium decrement in basal area, except Tattikai more disturbed plot among evergreen plots, wherein a 2.6 m^2 decrease in basal area is recorded and among the deciduous plots, this decrease is about 2 m^2 in Malgi and Togralli more disturbed plots. Thus in all, increase in basal area is recorded in about one-third of the locations while in others there is a decrease, indicating mortality or loss of trees due to natural causes or removal by communities.

Differences in basal area are mainly related to both the frequency of individuals and their size. In both the forest types across the 12 plots, trees >30 cm account for about 20% to 43% in evergreen plots, while in the deciduous plots, it is 18% to 49%. A comparison of change in basal area between less and more disturbed plots indicates the following:

i. *Evergreen plots*
- *Less disturbed:* There is an increase in basal area in only one of the 3 less disturbed plots, no change in another and a slight decrement in Hosur. This possibly could be attributed to increase in access to the location where the plot was laid, as a result of a road laid.
- *More disturbed:* There is an increase in basal area in 2 of the 3 locations and as mentioned above, there is a large decrement in Tattikai. The increase in basal area in 2 of the more disturbed plots could be attributed to disturbance-mediated accelerated succession (Dale et al., 2011, Bhat et al., 2011 and Marc and Michael, 1989). The decrease in basal area in Tattikai could be attributed to greater access of the plot by the communities, which supports several commercially important NTFP species such as *Garcinia cambogea, Syzigium cuminii and Ziziphus rugosa*.

ii. *Deciduous plots*
- *Less disturbed:* Of the 2 plots re-enumerated, an increase in basal area is recorded in one while in the other there is a decrease.
- *More disturbed:* A decrease in basal area in all the 3 plots have been recorded indicating mortality and loss due to natural as well as anthropogenic reasons.

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 and Swamy et al., 2010). According to Brown and Lugo (1990), recovering forests after previous disturbance accumulate more biomass and carbon. In this study, there is evidence to indicate both, probably due to difference in the intensity of pressure.

b) Biomass

Biomass is calculated using the Murali et al. (2005) equation based on basal area.

$$Biomass = 50.66 + 6.52 \times (Basalarea)$$

The biomass so calculated is the aboveground biomass. Using an IPCC default factor of 0.26 (IPCC, 2006), the belowground biomass was estimated and the total living biomass calculated.

i. *Evergreen plots*

The biomass estimates for the evergreen plots ranges between 349 tonnes in Tattikai less disturbed plot to 408 tonnes per ha in Ekkambi less disturbed plot during the baseline enumeration year of 2009. However during 2011, least biomass is recorded in Tattikai more disturbed plot and the highest is in both Ekkambi and Hosur less disturbed plot (Figure 3).

A comparison of biomass during the two enumeration periods indicates increase in biomass over a 2-year period by about 0.7 (Hosur more disturbed) to 2.3% (Ekkambi less disturbed) in 3 of the 6 plots while in the remaining three a decrement in biomass by a negligible 0.1% (Tattikai less disturbed) to as high as 6% (Tattikai more disturbed) is recorded.

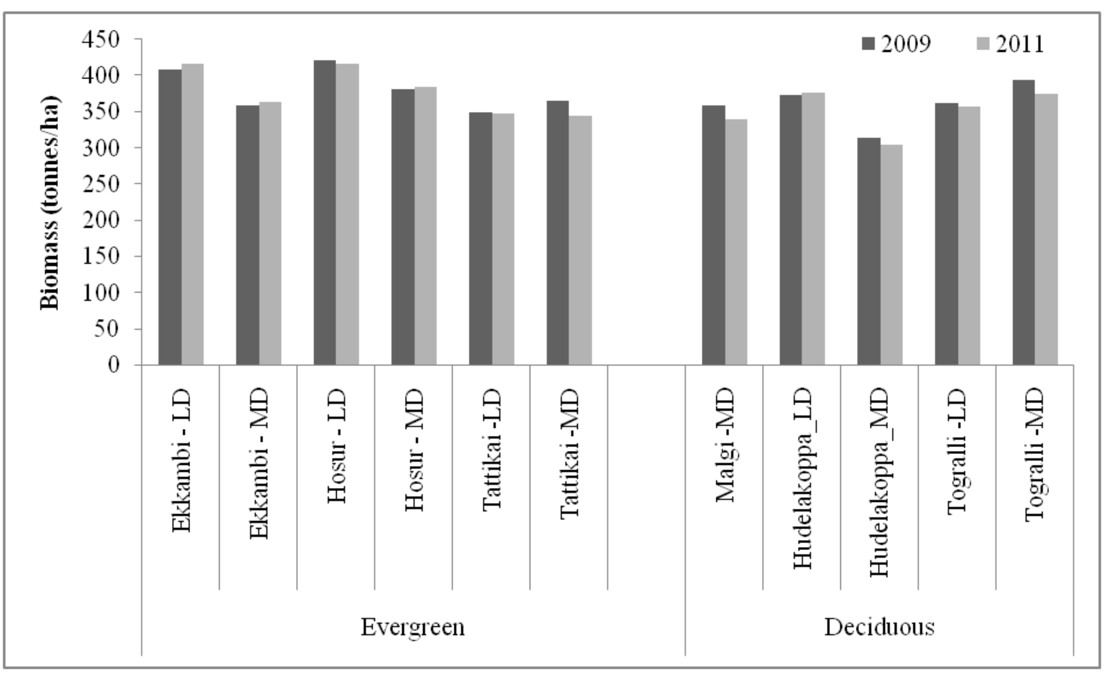

Fig. 3 : Biomass estimates of evergreen and deciduous forest plots

The average biomass stocks across the less disturbed evergreen plots during 2009 is 393 tonnes/ha and the same is slightly higher at 394 tonnes/ha during 2011. Conversely in the more disturbed evergreen plots, as one would expect the average biomass is lower than that of less disturbed plots (368 tonnes/ha) and the same decreases to 364 tonnes/ha by 2011. Overall the biomass stocks in the evergreen plots was 381±28.8 tonnes/ha during 2009 while in 2011 it is 379±32.6 tonnes/ha.

ii. *Deciduous plots*

Among the deciduous plots, the highest estimated biomass is in more disturbed Togralli plot (393 tonnes/ha) and the least is in Hudelakoppa more disturbed plot (314 tonnes/ha) during 2009. The same trend continues even in 2011 (Figure 3).

Among the less disturbed deciduous plots, the average biomass is about 367 tonnes/ha and the same shows a very slight decrease over the 2-year period of 2009 to 2011. However in the more disturbed deciduous plots, the average biomass recorded in 2009 is 355 tonnes/ha and the same decreases to 339 tonnes/ha in 2011. Overall, the average biomass recorded in the deciduous plots is 360±29.0 tonnes per ha during 2009 and the same decreases to 350±29.7 tonnes per ha during 2011.

c) *Carbon*

Forests provide several goods and services that are crucial to human survival. They are one of the world's major carbon stores, containing about 80% of above-ground terrestrial biospheric carbon and 40% of terrestrial below-ground carbon (Kirschbaum et al., 1996). Forests play an important role in the global carbon cycle. Forests, like other ecosystems, are affected by climate change and are either negatively or positively impacted. Forests in turn influence the climate and climate change process. Quantifying the role of forests as carbon stores, as sources of carbon emissions and as carbon sinks has become one of the keys to understanding and influencing the global carbon cycle.

In the forest plots of Uttara Kannada, carbon stocks are estimated from the biomass values calculated using the biomass equation, following Murali et al. (2005). Carbon is calculated using the IPCC default factor of 0.45.

As can be seen from Table 1, the biomass carbon in the evergreen forest plots ranges from 157 tC/ha in Tattikai less degraded plot to 183 tC/ha in Ekkambi less disturbed plot during 2009. During 2011, the carbon stocks in the same plots range from 155 tC/ha (Tattikai more disturbed plot) to 188 tC/ha in both Ekkambi as well as Hosur less disturbed plots. It is to be noted that in Tattikai more disturbed plot, the carbon stocks have remained stable at 157 tC/ha, indicating no additional loss that could not be compensated by recruits.

Table 1 : Carbon stocks in aboveground and belowground biomass during 2009 and 2011 in evergreen and deciduous forest plots

Location	Stem density		Aboveground biomass carbon		Belowground biomass carbon		Total biomass carbon	
	2009	2011	2009	2011	2009	2011	2009	2011
Evergreen forest plots								
Ekkambi - LD	1131	1087	146	149	38	39	183	188
Ekkambi - MD	1692	1656	128	130	33	34	161	164
Hosur - LD	1457	1409	151	149	39	39	190	188
Hosur - MD	2146	2089	136	137	35	36	172	173
Tattikai -LD	2184	2131	125	124	32	32	157	157
Tattikai -MD	3219	2920	130	123	34	32	164	155
Deciduous forest plots								
Malgi -MD	451	468	128	121	33	32	161	153
Hudelakoppa_LD	1288	1382	133	134	35	35	168	169
Hudelakoppa_MD	1573	1489	112	109	29	28	141	137
Togralli -LD	1566	1647	129	127	34	33	163	160
Togralli -MD	1388	1515	140	134	37	35	177	168

Similarly in the deciduous forest plots, the carbon stocks range from 141 tC/ha (Hudelakoppa more disturbed) to 177 tC/ha in Togralli more disturbed plot during first enumeration in 2009. During the second enumeration in 2011-12, the stocks in Hudelakoppa more disturbed plot have further reduced to 137 tC/ha, indicating disturbance, that led to loss of biomass and this loss has not been compensated by the recruits as in the case of evergreen plots. In Togralli more disturbed plot that recorded highest biomass during the year 2009 also, there is a decrease in the carbon stocks (loss of 9 tC/ha over a 2-year period). Highest stocks are estimated to be in the Hudelakoppa less disturbed plot.

Interestingly, the average carbon stocks in the less disturbed evergreen as well as deciduous plots are stable over the 2 enumeration periods. It is 177 tC/ha in evergreen and 165 tC/ha in deciduous plots during 2009 as well as 2011. However there are differences in the carbon stocks in more disturbed forest plots of both evergreen as well as deciduous; a decrease in stocks is recorded. Overall, the stocks in the evergreen plots (both less and more disturbed plots together) have remained stable at 171 tC/ha while in the deciduous plots, there is a loss of about 4 tC/ha over the 2-year period, with the loss being highest in Togralli more disturbed plot.

IV. Discussion and Conclusion

Tropical forests are one of the richest and complex terrestrial ecosystems supporting a variety of life forms and have a tremendous intrinsic ability for self-maintenance. However, many of these forests are losing this ability due to excessive biotic interferences such as anthropogenic perturbations and uncontrolled grazing. Consequently, these forests are disappearing at an estimated rate of 15–17 Mha/year (FAO, 1995). Furthermore, this comes at a time when our knowledge of their structure and functional dynamics is woefully inadequate (Hubbel et al., 1992 and Sundarapandian and Swamy, 2000). The conservation of biological diversity has become a major concern for the human society. Generation of structural status and functional dynamics of forests is essential for biodiversity conservation and sustainable management of fragile ecosystems. This study is a step towards generation of such information needed for planning, management and conservation of forests.

The biomass and carbon stocks estimated in the evergreen and deciduous forests show that tropical secondary forests are indeed storehouses of carbon. The biomass estimates of the evergreen forests in the present study (344-417 t/ha) are comparable to the standing biomass of other tropical forests such as that reported by Proctor et al. (1983) for tropical rainforests of Sarawak in Malaysia and tropical wet evergreen forests of the Western Ghats (439-587 t/ha) by Swamy et al. (2010). These estimates are all also within the range of values reported for other primary neotropical forests (Brown et al., 1995, Gerwing and Farias, 2000, Chave et al., 2001 and Keller et al., 2001).

Interestingly, the stocks in the less and more disturbed forests are not very different despite the greater dependence of communities on the more disturbed forests. This is a very important finding in the context of the region which is reported to have about 50% of households to be dependent on forests for a range of forest products (Murthy et al., 2005 and Murthy et al., 2014). This is an indication that communities are not over or unsustainably extracting forest produce. Periodic and long-term monitoring of the status and dynamics of the forests is however necessary in the context of potential increased human pressure and climate change in order to plan and manage the forests for mitigation as well as adaptation in a synergistic manner.

V. Acknowledgement

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