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Carbon sequestration in different pools of tiger reserves and territorial forests of Madhya Pradesh, India

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Abstract
Carbon stock in different pools *viz.* trees, ground flora, litter, deadwood and soil was estimated in Panna, Pench and Satpura tiger reserves (TRs) and for comparison in adjoining territorial forests (TFs), Balai and Hingana of Madhya Pradesh, India. Annual carbon sequestration was assessed by the difference of carbon stocks of two consecutive years. Tree density in TRs was higher than TFs and number of trees ha^{-1} under different girth classes represented good reverse J-shaped curve for TRs where more than 90 percent trees belong to smaller GBH range of 30-120cm. TFs have staggered curve due to unnatural management of forests leading to around 20 percent of trees of GBH>120 cm. The annual carbon sequestration by the trees was found maximum by the trees in Pench, followed by Satpura. *Tectona grandis* supremely dominated species-wise contribution in the carbon stock of the studied forests, followed by *Lannea coromandelica*, *Lagerstroemia parviflora* and *Terminalia tomentosa*. However, annual carbon sequestration was reported maximum in *Flacourtia indica* and *Bombax ceiba*. Carbon in herbaceous and litter pools of protected TRs was observed more than TFs. Soil Organic Carbon (SOC) contributed the maximum among all the carbon pools. Pench TR reported maximum SOC (42.84 t ha^{-1}), followed by Satpura (40.10 t ha^{-1}). The total carbon in all the pools in TRs was recorded greater than TFs and in the order; Pench (79.68 t ha^{-1}) >Satpura (73.84 t ha^{-1}) >Panna (63.37 t ha^{-1}).

Keywords: Carbon sequestration, Panna tiger reserve, Pench tiger reserve, Satpura tiger reserve, territorial forest, Madhya Pradesh

Introduction

Anthropogenic emissions from land use, land use change and forestry (LULUCF) contribute 9-11% of greenhouse gas (GHG) emissions owing to large scale deforestation and forest degradation in developing countries globally (IPCC, 2014) [13]. Forests form the second largest land use after agriculture system in India covering 21.67% of the country's geographical area (FSI, 2019; MoEFCC, 2018) [8, 20]. Forests sequester maximum carbon from the atmosphere than any other terrestrial ecosystem and are reported to have a net carbon sink offsetting of 252.5 million tonnes of CO_2 eq, which is 12% of India's total GHG emission (MoEFCC, 2015) [19]. Recognizing mitigation potential, richness and importance of forests, India has always been at forefront for REDD + (Reducing Emissions from Deforestation and Forest Degradation), which is an incentive mechanism for developing countries requiring estimation of carbon stocks in the forests in order to determine accurate financial incentives by achieving low-carbon sustainable growth. REDD+ includes biodiversity conservation, sustainable management of forest and enhancement of carbon stocks (Gibbs *et al*., 2007) [10]. India's Nationally Determined Contributions to UNFCCC targets to create additional forest carbon sink by 2.5 to 3 billion tonnes of CO_2 equivalent by 2030.

Protected areas play major role in carbon sequestration accounting for 5 percent of the geographical area of the country and cover 16 mha of forest land. By avoiding emissions from deforestation and forest degradation through conservation of existing protected areas, an additional carbon sink of 47 Mt CO_2 eq can be created (Planning Commission, 2014) [24]. In spite of the importance of protected areas as carbon reserves (Walker *et al*., 2014) [28], estimates of carbon in different pools is lacking.

Given the imminent global threat to shrinking biodiversity in tropical forests, it is often argued that protected areas like tiger reserves are forming islands of carbon stock and biodiversity and importance should be given to improve outside these areas. Although few studies are available (Gurung *et al*., 2015; Nogueira *et al*., 2018) [11, 23], but lacks in comparative analysis of protected forests with the adjacent territorial forests, especially in central India.

Hence, this study was undertaken to estimate carbon in different pools in Panna, Pench and Satpura Tiger Reserves (TRs) of Madhya Pradesh and compared with their adjacent disturbed Hingana and Balai Territorial Forests (TFs).

Materials and Methods

Study area

Panna, Pench and Satpura are the major Tiger Reserves (TRs) of central Indian state, covering an area of 543, 293 and 585 sq.km, respectively. Panna TR is situated in the SW-NE striking Vindhyan hill ranges with 24°35'25.80"N latitude and 79°56'30.12"E longitude and forms the watershed for many streams to join the main system of the Ken river. It is home to an incredible variety of fauna with prime attractions for the Royal Bengal Tiger and the long-nosed gharial. Due to the prevalence of hot and dry climate, the vegetation in this region is dry deciduous type characterized by thorny woodlands, shrubs and tall grasses. *Aegle marmelos, Madhuca longifolia, Phyllanthus emblica, Sterculia urens, Buchanania lanzan, Boswellia serrata, Terminalia tomentosa* and *Diospyros melanoxylon* are among the common trees of Panna TR.

Pench Tiger Reserve is located in Seoni and Chhindwara districts of Madhya Pradesh with 21°38'58.20"N latitude and 79°14'42.36"E longitude. Pench is named after pristine river Pence, which flows through the park and has its mention in the famous story of 1894, 'The Jungle Book', penned by renowned English Author Rudyard Kipling. This TR serves as cosy nest of numerous wild creatures including Royal Bengal tiger, jackal, wild dog, wild boar, sloth bear, Indian leopard, fox, striped hyena, gaur, barking deer, four-horned antelope and Indian wolf. Its major tree species includes *Madhuca longifolia, Sterculia urens, Boswellia serrata, Pterocarpus marsupium, Anogeissus latifolia* and *Cassia fistula*.

Satpura Tiger Reserve is located in Satpura range of Hoshangabad district of Madhya Pradesh with 22°30'11.88"N latitude and 078°26'09.24"E longitude. This park, along with the adjoining Bori and Pachmarhi wildlife sanctuaries, provides 2200 km^2 of unique central Indian highland ecosystem. The terrain of this national park is extremely rugged and consists of sandstone peaks, narrow gorges, ravines and dense forests having altitude ranging from 300 m (Churna) to 1,352 m (Dhoopgarh peak). The major wildlife of this park leopard, sambar, chital, Indian Muntjac, Nilgai, four-horned antelope, chinkara, wild boar, bear, black buck, fox, porcupine, flying squirrel, mouse deer, and Indian giant squirrel. *Tectona grandis, Shorea robusta, Diospyros melanoxylon, Madhuca longifolia, Aegle marmelos* and Bamboos are the main tree species of Satpura TR.

Two Territorial Forests (TFs), namely Balai and Hingana of west Mandla forest division were also selected adjacent to the TRs ranging from 22°52'27.7"N to 22°58'10.2"N and 80°5'18.6"E to 80°18'0.2"E (Figure 1).

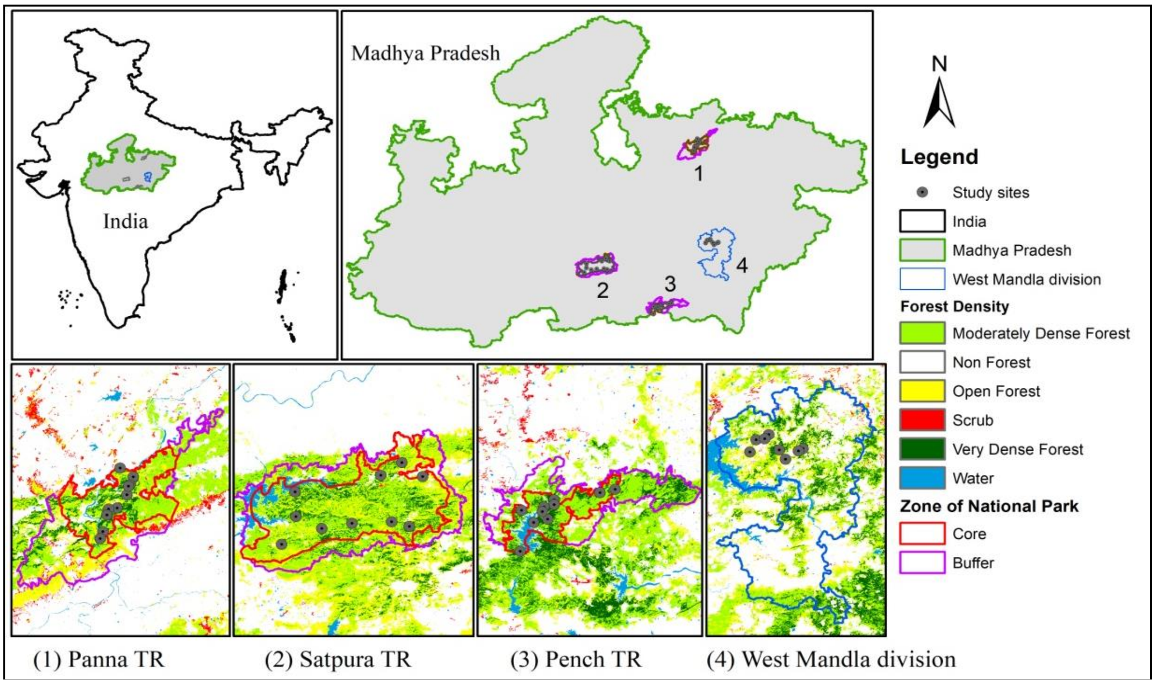

Fig 1: Map showing selected sites in TRs and TFs of Madhya Pradesh

Sampling design and laying of quadrats

In order to cover maximum vegetation and soil types in the TRs and TFs, random sampling was adopted after detailed survey and discussion with forest field officials. Thirty eight nested quadrats were laid in the study area wherein, 30 quadrats in TRs (10 in each TR) and 8 quadrats in TFs (4 in each TF) were laid (Muller-Dombois and Ellenburg, 1974; Bonham, 1989)[21,3]. Tree quadrats of 0.1 ha (31.62m x 31.62m) size were laid, except in Bori of Satpura TR, where a quadrat of 0.5 ha was laid covering old teak plantation. Therefore, the selected quadrats of Satpura consisted the total area of 1.4 ha whereas 1 ha each was selected in Panna and Pench tiger reserves. The quadrats in Balai and Hingana TFs covered an area of 0.4 ha each. Four quadrats for herbaceous biomass of 1m x 1m size and five quadrats for litter biomass of 0.5m x 0.5m size were laid inside each tree quadrat (FSI, 2002) [7]. Hence, a total 120 quadrats in TRs and 32 quadrats in TFs for herbaceous biomass and 150 quadrats in TRs and 40 quadrats in TFs for litter estimation were laid.

Tree biomass and carbon stock estimation

Trees (GBH > 30 cm) inside the selected tree quadrats were enumerated and tagged giving unique identification number to each tree. Girth at Brest Height (GBH) of each tree was measured at 1.37 m from the ground level using measuring tape. Above Ground Biomass (AGB) of trees was calculated using $AGB_{trees} = 0.007\ x^2 + 1.053\ x$ allometric equation suggested for tropical deciduous forests, where, x= GBH of trees (cm). Below Ground Biomass (BGB) was calculated as per the guidelines of IPCC (2006), i.e. BGB_{trees}= 0.25xAGB. Total biomass in trees were calculated by summing up AGB and BGB or Total $Biomass_{trees}$=1.25xAGB. Carbon in trees was considered 0.5xTotal Biomass (IPCC, 2006) [12]. Annual carbon sequestration was calculated by the difference of carbon stocks of two consecutive years.

Herbaceous vegetation biomass
Vegetation besides trees and litter within herbaceous quadrats was harvested 3 times in a year *i.e.* September, November and March and a well-mixed 500g sample from each quadrat was oven dried to determine dry biomass. The annual cumulative biomass data was extrapolated to t ha^{-1} and carbon content in herbaceous vegetation was considered 0.5 times its biomass.

Litter biomass
Litter representing dead leaves, twigs, branches, grasses and dead wood was collected from litter quadrats 5 times in a year *i.e.* September, November, January, March and May and evenly mixed sample of 500g was oven dried to determine dry biomass. The annual cumulative litter data was extrapolated to t ha^{-1} and carbon content was considered 0.5 times its weight.

Soil organic carbon (SOC)
Surface (0-30 cm) soil samples were collected from all the quadrats and analysed at TFRI soil analysis laboratory. The samples were air dried and passed through 2 mm sieve. SOC was estimated by Walkley and Black (1934) [29] Rapid Titration Method and converted to t ha^{-1} considering weight of soil as 3658 t ha^{-1}.

The total carbon stock per hectare were calculated by summing up carbon in trees, herbaceous vegetation, litter and soil.

Results and Discussion
In the selected quadrats, a total of 371, 479 and 550 trees were found at Panna, Pench and Satpura TRs whereas, only 111 and 101 number of trees were found in Balai and Hingana TFs, respectively. Tree density in TRs *viz.* Pench (479 trees ha^{-1}), Panna (371 trees ha^{-1}) and Satpura (393 tress ha^{-1}) was higher than TFs *viz.* Balai (278 trees ha^{-1}) and Hingana (253 trees ha^{-1}); while in contrast average GBH of the trees in TFs was higher (83.28cm in Balai and 91.02cm in Hingana) as compared to TRs. Among TRs, GBH of Satpura (68.24cm) was maximum followed by Pench (67.28cm) and Panna (62.67cm). Pench had maximum basal area (17.26 m^2 ha^{-1}) followed by Hingana (16.65 $m^2.ha^{-1}$), Balai (15.32 m^2 ha^{-1}), Satpura (14.57 m^2 ha^{-1}) and Panna (11.60 m^2 ha^{-1}) (Table 1).

Table 1: Structural composition of trees in tiger reserves and territorial forests of Madhya Pradesh

Tree estimates		Tiger Reserves			Territorial Forests	
		Panna	**Pench**	**Satpura**	**Balai**	**Hingana**
Number of individuals		371	479	550	111	101
Density (trees ha^{-1})		371	479	393	278	253
Basal area (m^2 ha^{-1})	Year-1	11.08	16.37	13.69	15.09	16.01
	Year-2	11.60	17.26	14.57	15.32	16.65
GBH (cm)	Year-1	61.24	65.51	66.16	82.63	89.23
	Year-2	62.67	67.28	68.24	83.28	91.02
AGB (t ha^{-1})	Year-1	33.67	47.43	39.41	37.41	37.80
	Year-2	34.68	49.11	41.04	37.81	38.84
Carbon (t ha^{-1})	Year-1	21.04	29.64	24.63	23.38	23.63
	Year-2	21.68	30.69	25.65	23.63	24.28

The number of trees ha^{-1} under different girth classes represented good reverse J-shaped curve for TRs where more than 90 percent trees belong to smaller GBH range of 30-120cm. Whereas, TFs has staggered curve due to unnatural management of forests leading to around 20 percent of trees of GBH>120 cm (Figure 2).

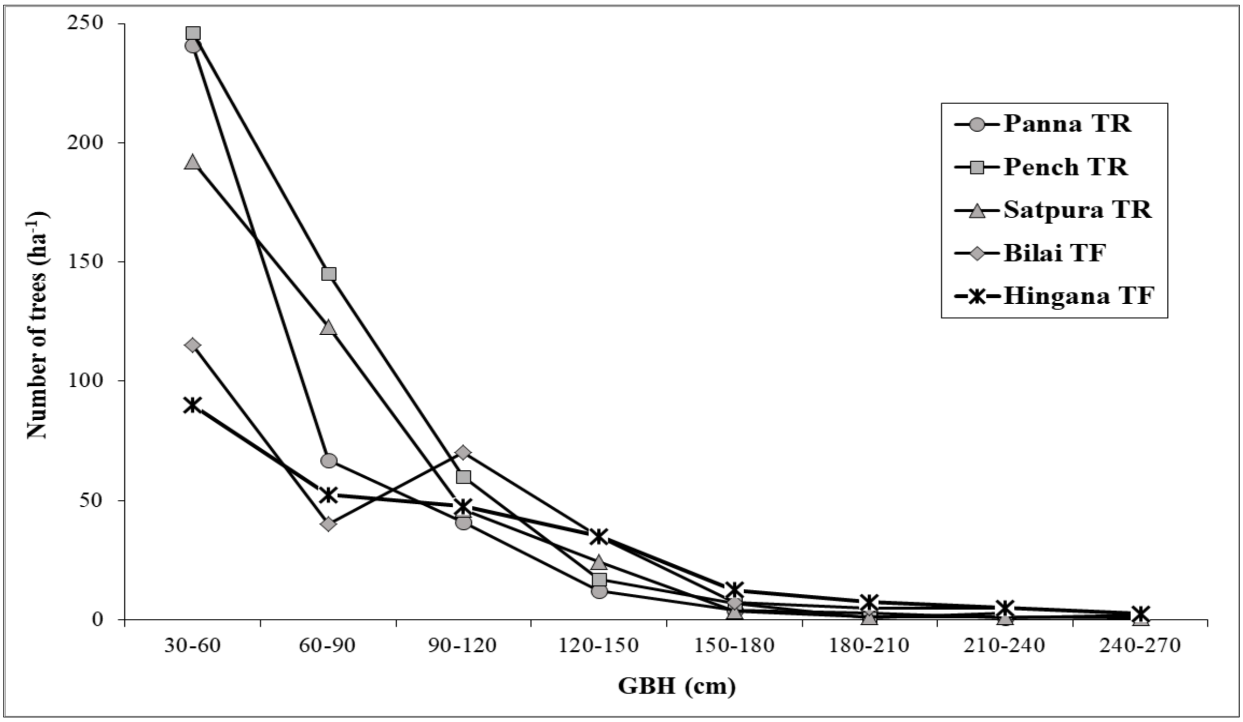

Fig 2: Number of trees ha^{-1} under different girth classes in TRs and TFs

Among the selected TRs, carbon in trees was recorded maximum in Pench (30.69 t ha^{-1}) and Satpura (25.65 t ha^{-1}), whereas tree carbon in human intervened TFs ranged between 23.63 to 24.28 t ha^{-1}. Panna TR trees stocked least carbon of

21.68 t ha^{-1} (Figure 4). The annual carbon sequestration by the trees was also found maximum by the trees in Pench, followed by Satpura i.e., 1.05 and 1.02 t ha^{-1}, respectively. Although, Balai TF sequestered least carbon of 0.25 t ha^{-1} annually during the assessment, the annual carbon stocked by Panna TR (0.63 t ha^{-1}) and Hingana TF (0.65 t ha^{-1}) was almost at par with each other (Figure 3).

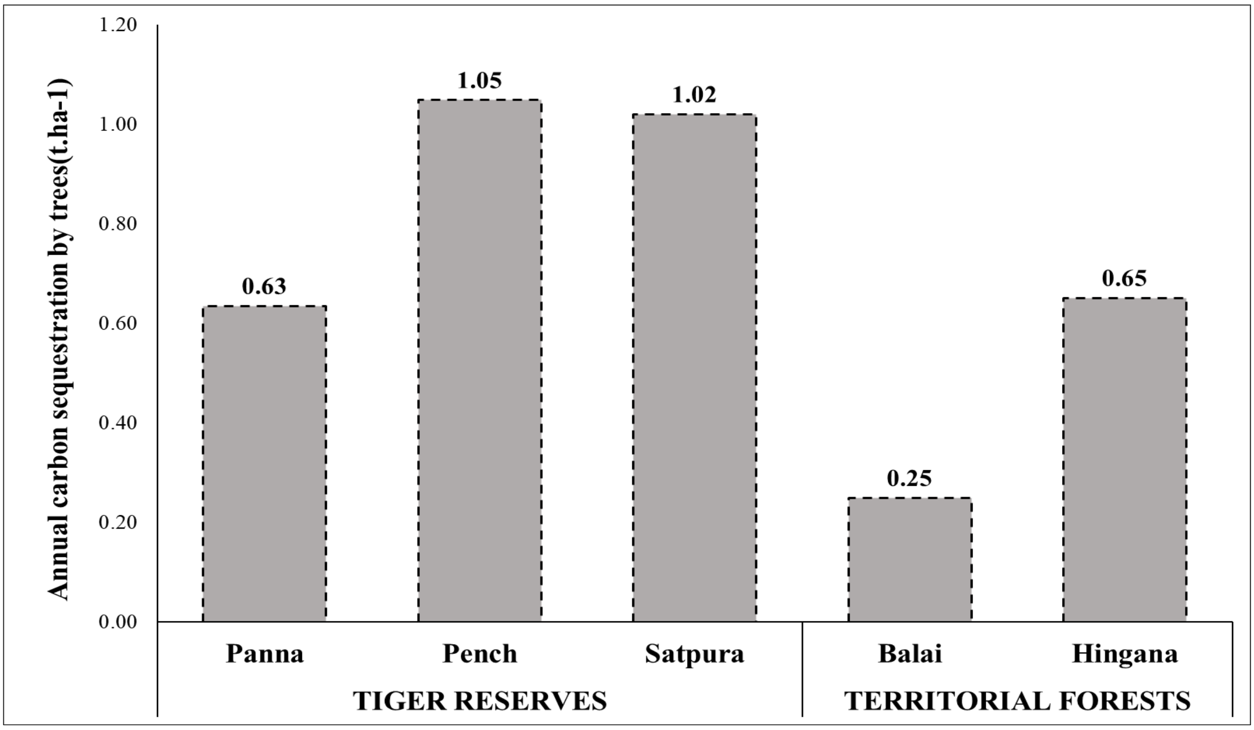

Fig 3: Annual carbon sequestration by trees in TRs and TFs

Tectona grandis (39.86 t) supremely dominated species-wise contribution in the carbon stock of the studied forests, followed by *Lannea coromandelica* (6.89 t), *Lagerstroemia parviflora* (4.61 t), *Terminalia tomentosa* (4.55 t) and *Madhuca longifolia* (4.49 t). However, annual carbon sequestration was reported maximum in *Flacourtia indica* (0.0026 t), *Bombax ceiba* (0.0024 t), *Hardwickia binata* (0.0023 t) and *Nyctanthes arbortristis* (0.0022 t). *Diospyros melanoxylon* (0.0002 t) and *Bauhinia vahlii* (0.0003 t) were found to sequester minimum annual carbon from the atmosphere (Figure 4).

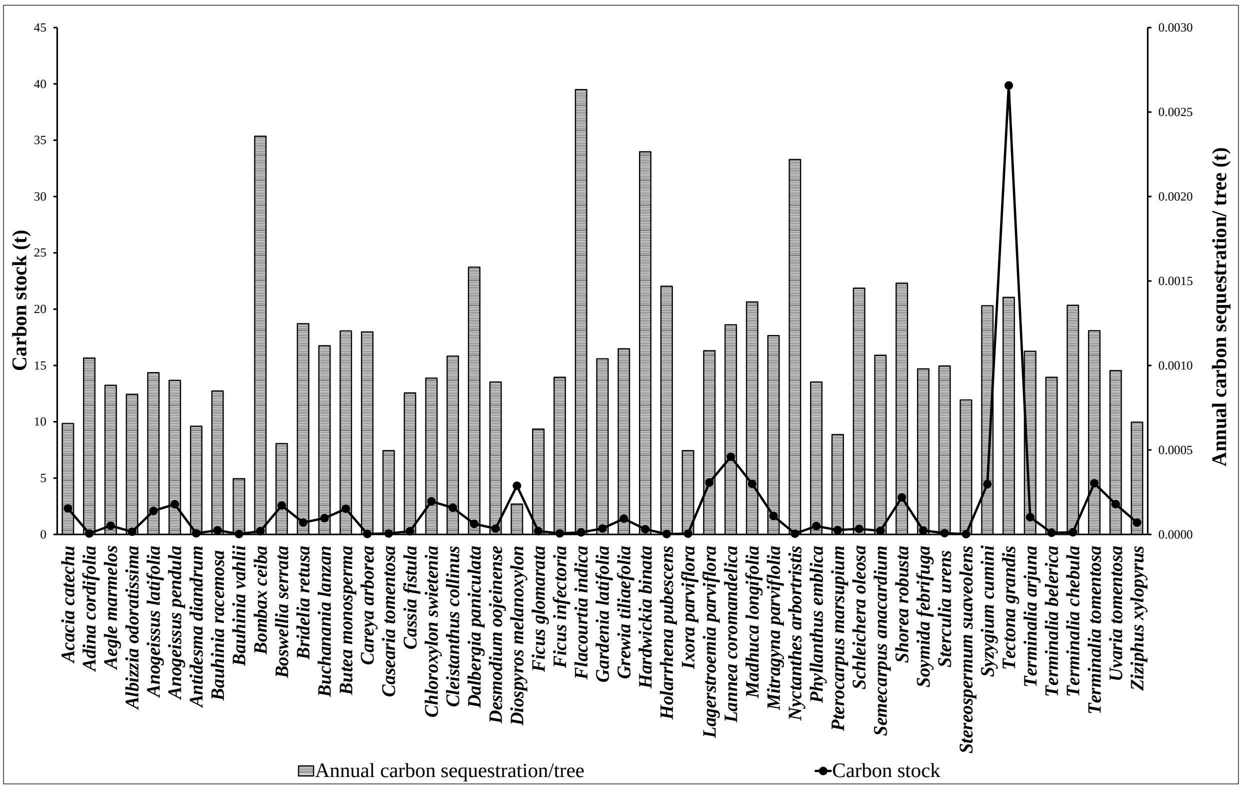

Fig 4: Tree species wise carbon contribution in the forests

Carbon in both herbaceous and litter pools of protected TRs (1.41 t ha^{-1} and 5.07 t ha^{-1}, respectively) was observed more than TFs (0.82 t ha^{-1} and 2.05 t ha^{-1}, respectively). Among TRs, maximum herbaceous carbon was reported in Panna having least litter carbon, while maximum litter carbon was found in Satpura having least herbaceous carbon. The herbaceous followed by litter contributed minimum to the total carbon stock in each of the forests. SOC contributed the maximum among all the carbon pools. Pench TR reported maximum SOC (42.84 t ha^{-1}), followed by Satpura (40.10 t ha^{-1}). SOC in Balai and Hingana was reported as the lowest *i.e.*, 29.45 and 31.89 t ha^{-1}, respectively. Cumulating carbon in all the pools, it was observed that TRs have greater carbon stock than TFs. Among TRs, total carbon was found maximum in Pench (79.68 t ha^{-1}), followed by Satpura (73.84 t ha^{-1}) and Panna (63.37 t ha^{-1}) (Figure 5).

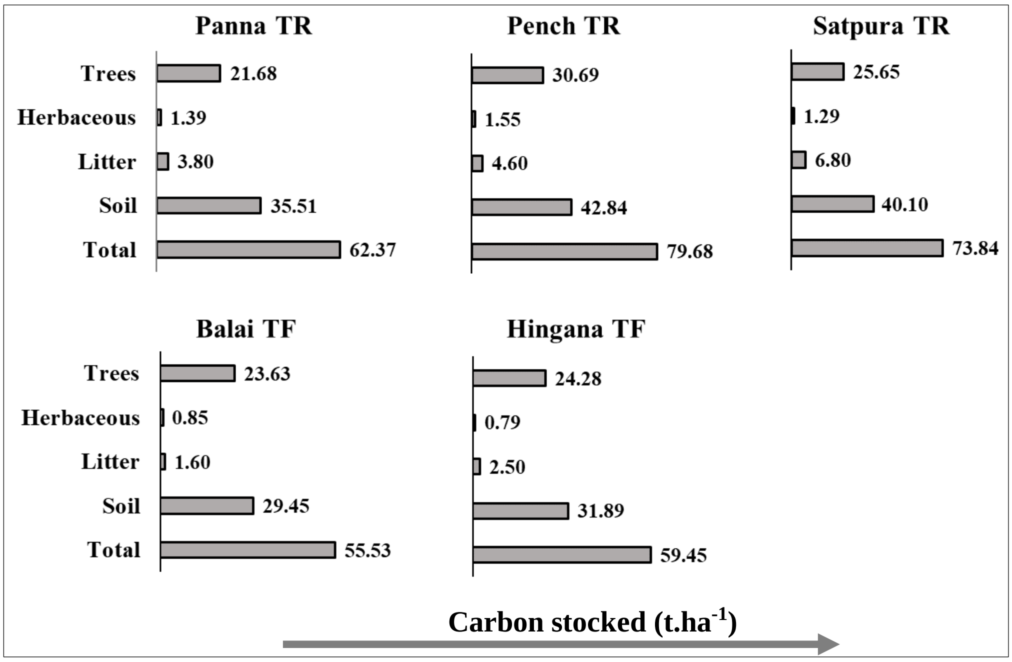

Fig 5: Carbon stock in different pools of TRs and TFs of Madhya Pradesh

Higher tree density and basal area in TRs as compared to TFs is attributed to low anthropogenic pressure, conservation of population, species and genetic diversity, protection and management for reducing the rate of biodiversity loss (Naro-Maciel *et al*., 2008; Geldmann *et al*., 2013)[22, 9]. Likewise, comparatively low density of trees in TFs is due to forest fragmentation, unsustainable harvest of forest produce and illegal tree felling for timber (Brockerhoff *et al*., 2017; Suchiang *et al*., 2020) [4, 26]. Khatri (2000) [16] reported 17.37 to 26.28 m^2 ha^{-1} total basal areas in Satpura National Park. Other authors have also reported total basal area of the tropical forests to range between 6.83-17.21 m^2 ha^{-1} (Jha and Singh, 1990; Thakur and Khare, 2015) [14, 27]. In spite of higher GBH in TFs their carbon stock was poor then TRs due to low tree density. Various forest management practices and human intervention in TFs seem to affect the curve and balance with which trees exist in natural forests. Panna showed low carbon stock and annual sequestration which can be attributed to the presence of low number of trees in young and mature stages *i.e.*, GBH between 60-150 cm as compared to Pench and Satpura due to semi-arid and dry sub-humid climate of the region and shallow Vindhyan soil (EPCO, 2011) [6]. It is also evident from the study that younger trees contributed more to carbon stock as compared to older trees, contrast to studies of Kohl *et al*. (2017) [17], who suggested that old growth trees in tropical forests not only contribute to carbon stocks by long carbon resistance times, but maintain high rates of carbon accumulation at later stages of their life time.

Higher contribution of *Tectona grandis* in overall carbon stock of the forests is due to higher number of individuals or domination in the forests of central India indicating its ecological success, profuse regeneration ability and greater ecological amplitude (Chaubey *et al*., 2015; Thakur and Khare, 2015) [5, 27]. Dominance of teak indicates rightful protection and regulation on its felling by the government due to its exceptional contribution in increasing carbon stock of dry deciduous forests of central India. Various studies report co-domination of *Lannea coromandelica, Lagerstroemia parviflora* (Majumder *et al*., 2013; Khan *et al*., 2019) [18, 15], *Madhuca indica* and *Terminalia tomentosa* (Shrivastava *et al*., 2017) [25] corroborating the results for their significant contribution in the carbon stock in the studied forests.

Protection from livestock grazing and anthropological interference has significantly contributed to higher litter and herbaceous biomass production in TRs. The results are in conformity with Atsbha *et al*. (2019) [1], who concluded to derive multiple benefits like biodiversity conservation and climate change mitigation in natural vegetation. Subsequently, decomposition of higher vegetation, litter and herbaceous biomass in TRs has raised the SOC in these areas. Such impact of higher SOC in protected area as compared to grazing lands have also been reported in studies conducted by Bikila *et al*. (2016) [2].

Conclusion

Out of 47 TRs in India, 6 are in Madhya Pradesh, which is also known as the 'Tiger State' as it harbors nearly 20% of India's wild tiger population and nearly 10% of the world's tiger population as per the current estimates. Protected areas play a vital role in contributing climate change mitigation and adaptation, both on global and regional scales. However, their role is presently insufficiently recognized in national strategies and policies. Forest degradation is one of the main causes of Greenhouse Gas emissions and due to lack of sustainable management, the forests can switch from carbon sinks to carbon sources. Hence, it is the urgent need of the hour to protect forests of high biodiversity and cultural significance, such as tiger reserves, national parks and sanctuaries to conserve the benefits that people and societies get from forests like forest carbon stocks and livelihoods.

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