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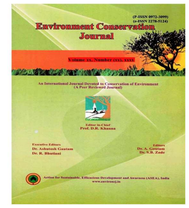

Assessment of woody plant species composition in secondary deciduous forests of Odisha, India

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ABSTRACT

Plant species composition according to their functional types, distribution pattern are crucial for biodiversity conservation in tropical deciduous forest. The study assessed the woody plant species diversity, stand structure and population density in the secondary deciduous forest of Chandaka wildlife sanctuary, Odisha, India. A total of 70 species belonging to 63 genera and 35 families were documented in this study.The stem density was found to be 1080 stems/ha with reverse J-shaped population structure indicating good regeneration potential of the forests. Shannon diversity Index varied from 0 to 2.31 whereas Simpson's index varied from 0 to 0.85. The correlation study between Importance Value Index and basal area were significant (p=40.63). The present study would be helpful for conservation and management of biodiversity in secondary dry deciduous forests of Chandaka Wildlife Sanctury in particular and tropical dry forests in general.

Introduction

Tropical forests are vital for sustainable development, and significant natural habitat for species conservation (Djuikouo, 2010). The global forest account approximately 31% of its land area (FRA, 2020). The tropical forest occupies around 60% of the biotic species within its 7% land cover (Galley, 2014). The forest primary vegetation that comes under the plant functional types (PFTs) is representing the variety and heterogeneity of the hierarchy of life and stability of the vegetation. The tree vegetation here is the principal structural and functional basis and indicators of changes at the landscape level. On the contrary, Deforestation due to traditional slash, industrial expansions, illegal logging, and mining activities, the building of wood fiber products causes 35 % of forest loss simultaneously the loss of biodiversity and change ecosystem balance (Chazdon and Guariguata, 2016). This has disrupted the forest structure, changes in species composition, and reduces the frequency and density of tree species. The deforestation and forest degradation account 25 % (8.2Gt CO_2 emission per year) of total world CO_2 emission (Pearson *et al.,* 2017). During 1990 the loss of forest was 420 million ha, but the rate has been declined extensively to 10 million ha in the recent years 2015-2020 due to the addition of 93% regenerating forest and 7 % planted area (FAO, 2020). These also resulted the increase of the secondary forest mostly around the tropical region which are a rich source of medicinal, economically important plants (Armentaras *et al.,* 2009; Haripriya, 2000) and provide forest products and fodder, cultural values, and carbon regulatory services (Lazos-Chavero *et al.*, 2016; Tauro *et al.*, 2018). Hence, the assessments of species compositional and functional dimensions of forest area are necessary. The potential understanding of

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plant diversity and composition are the fundamental attributes of forest conservation management and are the quantitative derivation of plant diversity. The diversity indices assess the ecological mechanisms that are affecting biodiversity. There is no single and specific index to quantify and summarize the concept of species composition and assessments. Some of the matrices like Species richness (Purvis and Hector, 2000), Shannon diversity and Simpson diversity indices are convenient method for the theoretical interpretation of species diversity of the forest. Several qualitative assessments had conducted in the tropical forest of Western Ghats (Chittibabu and Parthasarathy, 2000; Jayakumar and Nair, 2003). But the information regarding the plant distribution, structure and composition of tree species, and their plant functional types including above-ground biomass in the tropical deciduous forest of Eastern Ghats is lacking (Panda, 2013; Reddy *et al.,* 2011; Sahu *et al.,* 2007). The part of Eastern Ghats spread from the north-west of Mayurbhanj to the south-west of Malkangiri of Odisha, India. Chandaka forest is located in the North-eastern edge of Eastern Ghats, India, and was classified as a semi-evergreen forest (Biswal *et al.,* 2005).

Due to anthropogenic activities, several patches within the Chandaka forest transformed into shrub jungles and thorny bushes. Thus in the year 1983, the Chandaka forest is declared as a sanctuary for restoration and cited as a secondary regenerated deciduous forest. The present study aimed to the species diversity among the six plant functional types (PFTs) and analyzed different structural parameters for a better ecological understanding of tropical secondary deciduous forests. The study could establish the significance and differences of plant basal area, stem density influencing Importance Value Index (IVI)and forest stand structure.

Material and Methods

Study area

Chandaka Wildlife Sanctuary (CWS) covers with small sprawling hillocks of Khurdha and Cuttack districts of Odisha. It is situated between 20° 12' 30"N to 20° 26' 03"N latitude to 85° 49' 35" E to 85° 34' 42"E longitude (Fig.1). Basing on the species composition, vegetation type, and dominant species prevailing areas, the forest is divided into the following Plant Functional Types (PFTs) namely: Northern Secondary Moist Mixed Deciduous Forest (MMDF), Peninsular Sal Forest (PSF), Semi-evergreen Forest (SEF), Planted Teak Forest (PTF), Bamboo brakes (BB) and Degraded Thorny Shrubby Forest (DTSF) (Figure 1).

Sampling sites and plant collection:

Plants were collected every month from May 2015 to March 2017. A total of 24 sampling plots (50 m x 20 m size) were laid randomly, and the size of sampling plots was decided based on the species-area curve (Mueller-Dombois and Ellenberg, 1974). The entire woody plant species ≥10 cm Girth at Breast Height (GBH) was measured. The spatial plot locations (latitude and longitude of each plot) were tagged by GARMIN- Global Positioning System (GPS).The collected Plants' twigs (leaves, flowers, fruits, etc.) from the sampling plots brought to the laboratory for their species-level identification and herbarium preparation using Flora of Orissa (Saxena and Brahmam, 1996).

Vegetation structure analysis and distribution

The density, basal area, and Importance Value Index of the trees and shrubs were calculated. Likewise, species distribution was determined through the ratio of abundance and frequency. The value < 0.025 is for regular, 0.025-0.05 for random and >0.05 for contagious distribution (Ndah *et al.,* 2013). The formulas are mention below

$$\text{Density} = \frac{\text{No.of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

$$\text{Frequency (\%)} = \frac{\text{No.of quadrats in which a species occur}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Abundance} = \frac{\text{No.of individuals of a species in all quadrats}}{\text{No.of quadrats in which species occur}}$$

$$\text{Distribution pattern} = \frac{Abundance}{Frquency}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Number of occurrence of species}}{\text{Number of occurrence of all the species}} \times 100$$

$$\text{Relative Density (RD)} = \frac{\text{Number of Individual of the species}}{\text{Number of individuals of all species}} \times 100$$

$$\text{Relative Dominance (RDo)} = \frac{\text{Total basal area of the species}}{\text{Total basal area of all the species}} \times 100$$

Importance Value Index (IVI) = RD+ RDo +RF

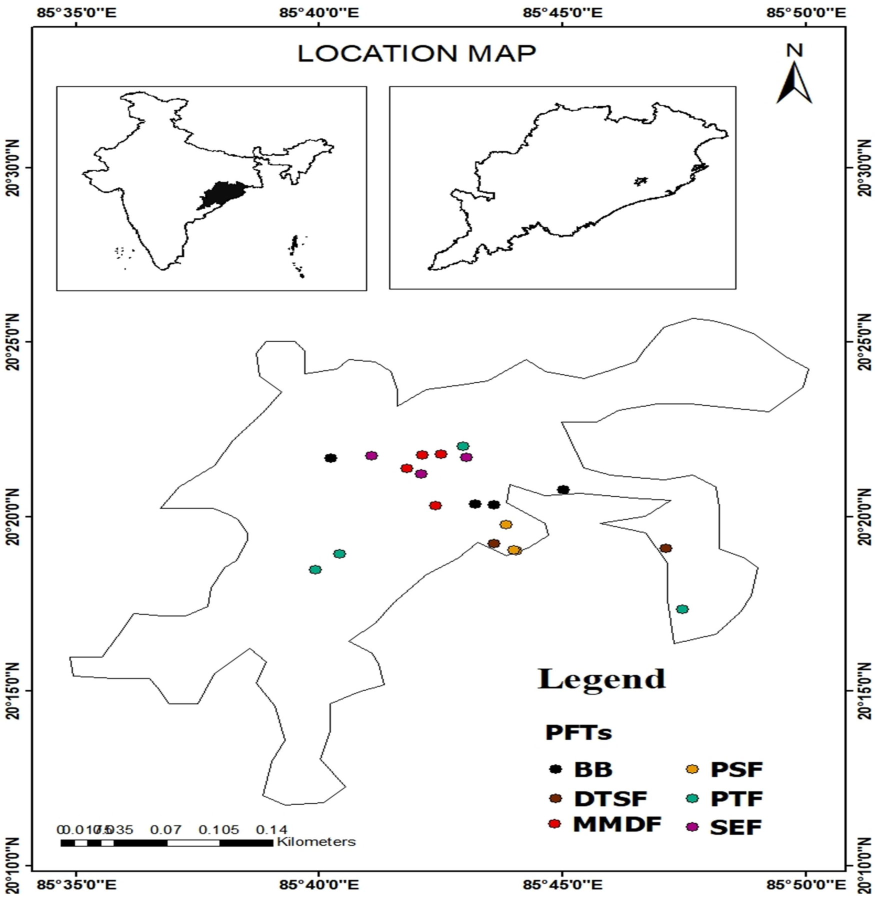

Figure 1: Map of Chandaka Wildlife Sanctuary

Population structure of woody plant species

The available GBH data determined the population structure of different plant functional types. The total number of individuals of different girth classes was calculated species-wise for the different plant functional types. From these data, the percent proportion of the population structure of each girth class was calculated for various plant species as:

$$\text{Percent of Proportion} = \frac{\text{No.of individuals in each girth class}}{\text{Total no.of individuals in all the girth classes}} \times 100$$

Species diversity indices

The community structure and its complexity level were evaluated through Shannon–Wiener's Index or species diversity index (H′) and Simpson's Index (D) (Whittaker, 1975). Margalef's index (Aslm, 2009) and Pielou's evenness index (Pielou, 1966) were considered for richness, and evenness.

Results and Discussion

Frequency, density, dominance, IVI, and diversity indices values of six PFTs of 2261 stems were measured. A total of 70 woody plant species belongs to 63 genera, and 35 families (53 trees, 17 shrubs, and 01 herb species) are taken into account for analyzing the vegetation structure, density of different plant functional types and resulting heterogeneous composition among them (Table 1). The dominant families were Rubiaceae > Rutaceae > Euphorbiaceae > Ebenaceae > Combretaceae > Anacardiaceae > Sapotaceae > Fabaceae. A liana C. album exhibited luxuriant growth over tree species and a gymnosperm C. sphaerica commonly observed in all PFTs. The introduced species like Senna siamea, Tectona grandis, Simarouba amara have been successfully adopted in individual pockets of the forests constituting specific plant functional types.

Table 1: List of plant species having Girth at breast height ≥10 cm along their family and habit identified in Chandaka Wildlife Sanctuary

BOTANICAL NAME	FAMILY NAME	HABIT
1. *Aegle marmelos* (L.)Corr.	Rutaceae	Tree
2. *Alangium salvifolium* (L.f.) Wang.	Alangiaceae	Tree
3. *Anacardium occidentale* L.	Acanthaceae	Tree
4. *Antidesma ghaesembilla* Gaertn.	Euphorbiaceae	Small Tree
5. *Azadirachta indica* A Juss.	Meliaceae	Tree
6. *Bambusa bambos (L.) Voss.*	Poaceae	Woody herb
7. *Bauhinia racemosa* Lam.	Caesalpiniaceae	Tree
8. *Benkara malabarica* (Lam.)Tirveng.	Rubiaceae	Thorny Shrub
9. *Bridelia retusa* (L.) A.Juss.	Euphorbiaceae	Small Tree
10. *Buchanania lanzan* Spreng.	Anacardiaceae	Tree
11. *Careya arborea* Roxb.	Barringtoniaceae	Tree
12. *Casearia elliptica* Willd	Flacourtiaceae	Shrub
13. *Cassia fistula* L.	Caesalpiniaceae	Tree
14. *Chloroxylon swietiana DC.*	Rutaceae	Small Tree
15. *Cipadessa baccifera* (Roth) Miq.	Meliaceae	Shrub
16. *Cleistanthus collinus* (Roxb.)Benth.exHok.f.	Euphorbiaceae	Small tree
17. *Combretum album* Pers..	Combretaceae	Shrub
18. *Crateva magna* (Lour.)Dc.	Capparaceae	Tree
19. *Cycas sphaerica* Roxb.	Cycadaceae	Shrub
20. *Diospyros ferrea* (Willd.) Bakh.	Ebenaceae	Shrub
21. *Diospyros melanoxylon* Roxb	Ebenaceae	Tree
22. *Diospyros montana* Roxb.	Ebenaceae	Tree
23. *Diospyros sylvatica Roxb.*	Ebenaceae	Tree
24. *Gliricidia sepium* (Jacq.)Kunth ex Walp.	Fabaceae	Tree
25. *Glochidion zeylanicum* (Gaertn.)Juss.	Euphorbiaceae	Tree
26. *Glycosmis pentaphylla* (Retz.)DC.	Rutaceae	Shrub
27. *Grewia tilifolia* Vahl	Tiliaceae	Small tree
28. *Haldinia cordifolia* (Roxb.)ridsd.	Rubiaceae	Tree
29. *Helicteres isora* L.	Malvaceae	Shrub
30. *Holarrhena pubescens* (Buch-Ham.)Wall.	Apocynaceae	Tree
31. *Hymenodictyon orixense* (Roxb.)Mabb.	Rubiaceae	Small Tree
32. *Ixora parviflora* Vahl.	Rubiaceae	Shrub
33. *Ixora undulata* Roxb.	Rubiaceae	Shrub
34. *Lagerostroemia parviflora* Roxb.	Lythraceae	Tree
35. *Lannea coromandelica* (Houtt.)Merr.	Anacardiaceae	Tree
36. *Lepisanthes tetraphylla* Radik	Sapindaceae	Tree
37. *Madhuca indica* J.F.Gmel.	Sapotaceae	Tree
38. *Mimosa himalayana* Gamble.	Mimosaceae	Shrub
39. *Mimusops elengi L.*	Sapotaceae	Tree
40. *Morinda pubescens* Sm.	Rubiaceae	Tree
41. *Murraya paniculata* (L.) Jack	Rutaceae	Shrub
42. *Naringi crenulate* (Roxb.)Nicolson.	Rutaceae	Shrub
43. *Nyctanthes arbour-tristis* L.	Oleaceae	Small Tree
44. *Olax scandens* Roxb.	Olacaceae	Shrub
45. *Pavetta crassicaulis* Bremek	Rubiaceae	Small Tree
46. *Peltophorum pterocarpum* (DC.)Baker ex K.Heyne	Caesalpiniaceae	Tree
47. *Polyalthia cerasoides* (Roxb.)Bedd.	Annonaceae	Tree
48. *Pongamia pinnata* (L.)Pierre.	Fabaceae	Tree
49. *Pterocarpus marsupium* Roxb.	Fabaceae	Tree

50. *Pterospermum acerifolium* (L.)Willd.	Sterculiaceae	Tree
51. *Semecarpus anacardium* L.f.	Anacardiaceae	Tree
52. *Shorea robusta* Gaertn.f.	Dipterocarpaceae	Tree
53. *Spondias pinnata(L.f.)Kurz*	Anacardiaceae	Tree
54. *Stereospermum colais* (Buch Ham.ex Dillw.) Mabberley	Bignoniaceae	Tree
55. *Streblus asper* Lour.	Moraceae	Small Tree
56. *Strychnos nux-vomica* L.	Strychnaceae	Tree
57. *Strychnos potatorum* L.	Strychnaceae	Tree
58. *Syzygium cumini* (L.)Skeels.	Myrtaceae	Tree
59. *Tamilnadia uliginosa* (Retz.)Tirveng. And Sastre	Rubiaceae	Thorny Tree
60. *Tarenna asiatica* (L.)Kuntze ex Schum.	Rubiaceae	Shrub
61. *Tectona grandis* L.f.	Lamiaceae	Tree
62. *Terminalia alata* Heyne ex Roth.	Combretaceae	Tree
63. *Terminalia bellirica* (Gaertn) Roxb	Combretaceae	Tree
64. *Terminalia chebula* Retz.	Combretaceae	Tree
65. *Toddalia asiatica (L.)Lam.*	Rytaceae	Shrub
66. *Vitex pinnata* L.	Verbenaceae	Shrub
67. *Wrightia arborea (Dennst.)Mebb.*	Apocynaceae	Small Tree
68. *Xantolis tomentosa* (Roxb.)Rafin	Sapotaceae	Tree
69. *Xylia xylocarpa* (Roxb.)Taub.	Mimosaceae	Tree
70. *Ziziphus xylopyrus* (Retz.)Will.	Rhamnaceae	Tree
Total Species-70, Genus-63 Family – 35 Tree-53,Shrub-17		

Different Plant Functional Types (PFTs)

The sanctuary vegetation has divided into six plant functional types. The species Bambusa bambos mostly prevailed all the ranges of CWS .This species was introduced by the forest department Govt. of Odisha in the fringe of Sanctuary, but now it occupies 50% of the total forest areas and become dominant in bamboo brake, plant functional type. Besides a thin population of tree and shrub species like *Diospyros melanoxylon*, *Holarrhena pubescens*, *Ziziphus oenopolia*, *Helicteres isora*, and *Combretum album*, etc were intermixed with the *B. Bamboo*.

The DTSF (Degraded Thorny Shrubby Forest) type of forest is mostly found in a degraded form and the area is covered by some invasive species like Chromolaena odorata, Hyptis sauveolens, and Lantana camara. These forests harbor a very less number of species viz. *Ziziphus xylopyrus*, *Casearia graveolens*, *Cipadessa baccifera*, and *Phoenix acqualis*, etc. The plotting data on MMDF (Moist Mixed Deciduous Forest) type point out some intermingled species like *Xylia xylocarpa*, *Combretum album*, *Strychnos nux-vomica*, *Syzygium cumini*, *Tectona grandis*, *Careya arborea*, *Holarrhena pubescens*, *Polyalthia cerasoides*, *Woodfordia fruticosa*, *Aegle marmelos*, *Casearia graveolens* and *Tarenna asiatica* , etc. The PSF (Peninsular Sal Forest) type is dominated by Shorea robusta associated with species like *Benkara malabarica, Bauhinia recemosa*, *Buchanania lanzan*, *Chloroxylon swetenia*, *Cleiostanthus collinus*, *Carissa spinarum*, *Cipadessa baccifera*, *Diospyros meneoxylon*, *Holarrhena pubescens*, *Mitragyna parviflora*, *Madhuca longifolia*, *Terminalia alata*, and *Vitex pinnata*, etc. PTF (Planted Teak Forest) type of vegetation was covered the plantation zone of around 30-35 years. This type was dominated with T. grandis associated with some natural species such as *A. marmelos*, *B. retusa*, *Diospyros sylvatica,* and *Ziziphus mauritiana* etc.Some patches of SEF (Semi-Evergreen Forest) type vegetation was endorsed by large shrubs and small trees. The notable tree species associated with this PFT were *Alangium salvifolium*, *Bridelia retusa*, *Careya arborea*, *Diospyros sylvatica*, *Lagerstroemia parviflora*, *Lepisanthes tetraphylla*, *Naringi crenulate*, *P. cerasoides*, *Pterospermum xylocarpum*, *Shorea robusta*, *S. nux-vomica*, *S. cumini*, *Terminalia alata*, and *Terminalia bellerica* etc. The shrubby elements, namely *H. pubescens*, *Flacourtia indica*, *Meyna spinosa* and climbers like *Combretum album*, was also frequently observed here. These areas were dominated by *X. xylocarpa* (Table 1). The IVI of individual species were sparsely distributed along with different PFTs (Figure 2). Considering IVI of species like *X. xylocarpa* (18.45)*, A. marmelos* (2.95)*, C. arborea* (4.59)*, C. eliptica* (3.05)*, C. ruxburgii* (7.29)*, L.parviflora* (7.26)*, M. indica* (8.50)*, N. crenulata* (2.30)*, P. emblica* (2.76)*, P cerasoides* (5.23)*, S.cumini* (3.37)*, and Z. xyloparus* (2.34) etc. were frequent in the 5 functional types except BB type (Figure 3).

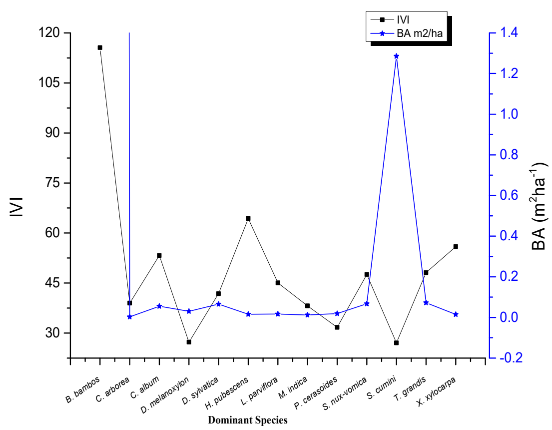

Figure 2: Comparison of IVI and basal area (BA) of some dominant species of the sanctuary

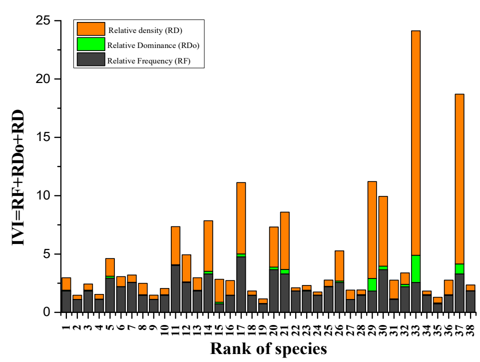

Figure 3: IVI (Relative Frequency, Relative Dominance and Relative Density) of few dominant plant species observed in Chandaka Wildlife Sanctuary, the rank of species derived from table 2

The estimated basal area in MMDF was 0.23 m^2/ha. However, the basal area of species in SEF and PTF type ranged from 0.007 to 3.12 m^2/ha and 0.016 to 494 m^2/ha respectively. The Bamboo brake (BB) was purely dominated by *B. bamboo* with the highest basal area among all PFTs i.e.663.18 m^2/ha. The Thorny shrubby vegetation of DTSF type obtained lowest basal area ranged from 0.002 to 0.17 m^2/ha. Here some of the species having lower IVI occupied large basal areas due to their high girth values like *M. indica* (0.32 m^2/ha), *L. parviflora* (0.24 m^2/ha), and *P. cerasoides* (0.15 m^2/ha), etc. (Table 2). The A/F ratio ranged from 0.06-2.79 that indicate contiguous distribution of the species along the 6 PFTs.

Species Distribution along GBH range, density and basal area

The population structure analysis revealed that highest percentage (31.79%) of tree population was found in the GBH class of 10-20 cm. While 1% trees were found in 71-80cm GBH class and lower tree percent proportion (0.19%) was observed at GBH range>100 (Figure 4) except Bamboo brake type. Further, the population structure for five PFTs gradually decreased with an increase in girth classes. The percent proportion of five PFTs were in the order of PTF (28.68%) < SEF (23.34%) < MMDF (21.50%) < PSF (21.45%) < DTSF (5%) for all girth classes and were found higher for species like *T. grandis, X. xylocarpa, S. robusta, B. bambo, H. pubescens, L. parviflora, M. indica, D. sylvatica, etc*.

The average density (1637 individuals ha^{-1}.) was highest in the GBH class of 10-20 cm with a basal area of 3.15 m^2 ha^{-1}. Rather highest basal area (11.38 m^{2}ha^{-1}) calculated in the GBH class of 30-40 cm. The species like *T. grandis* (3170 individuals ha^{-1}), *X. xylocarpa* (3060 individuals ha^{-1}), *H. pubescens* (1280 individual ha^{-1}), *S. robusta* (1240 individual ha^{-1}), *S. nux-vomica* (1120 individuals ha^{-1}), *D. sylvatica* (880 individuals ha^{-1}), *B. bambos* (770 individuals ha^{-1}) and *M. indica* (760 individuals ha^{-1}), etc have higher density. The stem densities of PFTs were observed in following order Planted teak forest (PTF) > Semi-evergreen forest (SEF) > Moist mixed deciduous forest (MMDF) > Peninsular sal forest (PSF) > Degraded thorny shrubby forest (DTSF) > Bamboo brakes (BB).In the case of BB type, the density (42 clump ha^{-1}) was highest in 150-200 cm GBH class, but the basal area (149.55 m^2 ha^{-1}) was highest in between the GBH class of 750- 850 cm (Figure 5(B)). The highest number of species observed in the girth class of 10-20 cm. The mean basal area of this was 0.63 m^{2}ha^{-1}. In figure 5(A), it has been seen that the density was highest at the lowest basal area. Similarly, for Bamboo brakes, (Figure 5B) the basal

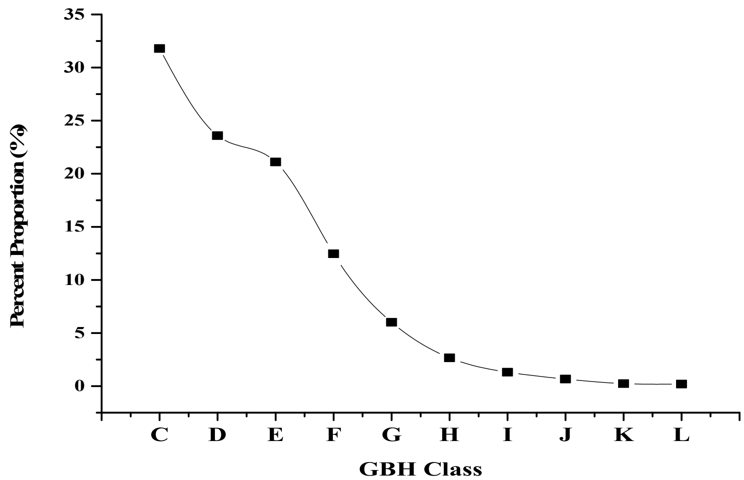

Figure 4: Population Structure of Plant species. The GBH classes were categorized as the following notations C=10-20, D=21-30, E= 31-40, F=41-50, G=51-60, H=61-70, I= 71-80, J=81-90, K=91-100 and L > 101 etc

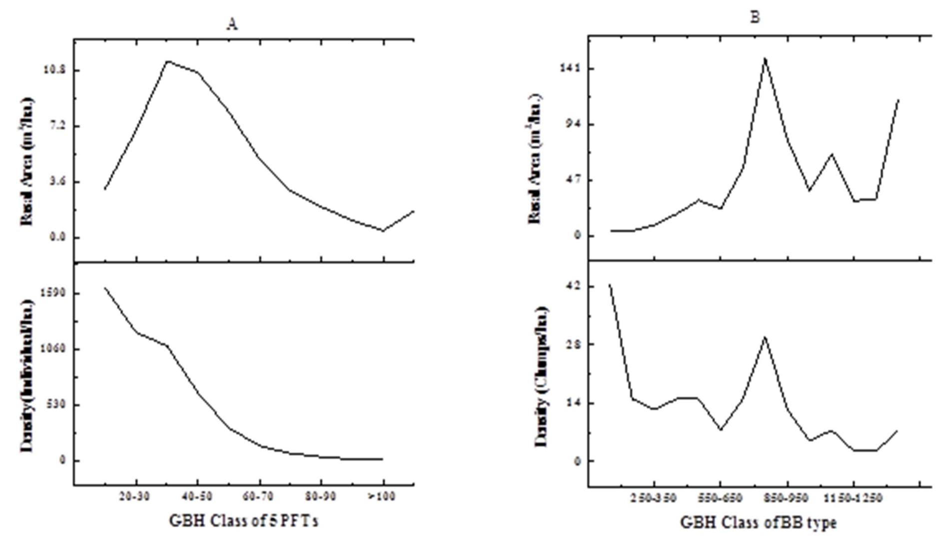

Figure 5: Density and basal area of discrete GBH class of PFTs. A. Five plant functional type's B. bamboo brake type

area was highest at the lower GBH class i.e., 150-200 cm. The ascending order of basal area among 6 PFTs were estimated as DTSF (0.92 m^2 ha^{-1}) < MMDF (8.62 m^2 ha^{-1}) < SEF (11.12 m^2 ha^{-1}) < PSF (11.63 m^2 ha^{-1}) < PTF (18.54 m^2 ha^{-1}) < BB (663.18 m^2 ha^{-1}). The basal areas were higher in the GBH class range of 30-50 cm in all PFTs. The higher basal areas occupying species were *T. grandis* (0.34 m^2 ha^{-1}), *S. nux-vomica* (0.09 m^2 ha^{-1}), *X. xylocarpa* (0.09 m^2 ha^{-1}), *M. indica* (0.08 m^2 ha^{-1}), *S. cumini* (0.06 m^2 ha^{-1}), *P. cerasoides* (0.05 m^2 ha^{-1}), *L. parviflora* (0.05 m^2 ha^{-1}), *D. montana* (0.04 m^2 ha^{-1}), *A. marmelos* (0.03 m^2 ha^{-1}), *P. acerifolium* (0.02 m^2 ha^{-1}), *B. retusa* (0.02 m^2 ha^{-1}), *D. melanoxylon* (0.02 m^2 ha^{-1}), *T. bellirica* (0.01 m^2 ha^{-1}), *C. elliptica* (0.004 m^2 ha^{-1}).

Species diversity indices

The species composition patterns and distribution through measuring GBH, IVI, and species diversity indices were calculated to establish the structural and compositional attributes of several species at different Plant Functional Types. The concentration of species richness (Margalef index) was highest in Semi-Evergreen forest (SEF) type and lowest in bamboo brakes (BB). However, Evenness was lower at PTF (0.4) indicated that only a few dominant species, while higher evenness observed at BB type (1.0), SEF type (0.58) exposed an equal number of individuals belong to each species. The species richness among PFTs were SEF > MMDF > PSF > PTF > DSTF > BB, whereas evenness was BB > DTSF > MMDF > SEF > PSF > PTF. The number of species found in each PFTs were MMDF > SEF > PSF > DTSF > PTF > BB and the ascending order of stem densities were PTF > SEF > MMDF > SEF > PSF > DTSF > BB. The Shannon–Wiener Index for BB was lower (H′ ~ 0) reflecting low community complexity, whereas, for SEF, it was H′ = 2.31 indicating higher community complexity. Both the Shannon diversity (0-2.20) and Simpson's index (0-0.85) among all PFTs were following the order of SEF > MMDF > DTSF > PSF > PTF > BB (Table-3). The range of species richness was 0-3.69 in five PFTs, and for the Bamboo Brakes type, it was 0.

The degrees of predicting individual species of a community are uncertain. The environmental factors such as temperature, precipitation , elevation and land topology etc. affect the species composition of the different forest types. The IVI value was measured highest for the species viz. *T. grandis* , *X. xylocarpa* , *H. pubescens* , *S. nux-vomica*, *C. roxburghii* , *B. bambos, L. parviflora*, *M. indica*, *P. cerasoides* contributing higher basal area. However, species like *T. grandis* (23.80), *S. robusta* (11.07) *and B. bambos* (97.34) were predominant in their specific vegetation group occupied higher IVI values. The Abundance to frequency ratio (table-2) of species indicated the contiguous distribution range of species and was in between 0.05-2.79 which was common in nature. Few species show random distribution consequence uneven distribution of vegetation pattern in all the plant functional types (Sahu *et al.,* 2012).

The stand density of six PFTs ranged from 420-1477 individual/ha with an average value of 883 individual/ha. The stem densities of PFTs were observed in following order Planted teak forest (PTF) > Semi-evergreen forest (SEF) > Moist mixed deciduous forest (MMDF) > Peninsular sal forest (PSF) > Degraded thorny shrubby forest (DTSF) > Bamboo brakes (BB).The estimation was similar to the deciduous forest of Similipal biosphere reserve, Odisha (848-957 ind. ha^{-1}, Mohanta *et al*., 2020), tropical dry deciduous forest of central India (702-1671 ind. ha^{-1},Joshi *et al*., 2019) moist deciduous forest of Eastern India (355-741 ind. ha^{-1}, T. Sahoo *et al.,* 2017), fragmented moist deciduous forest of Tripura, India (428-884 ind. ha^{-1}, K. Majumdar, 2014). The value is much higher than the tropical deciduous forest of North-central Eastern Ghats, India (395-573 ha^{-1}, Naidu *et al.,* 2018). Eastern Ghats of Northern Andhra Pradesh (639-836 ha^{-1}, Reddy *et al.,* 2011). The differences in the present and previous studies were attributable to the inequality distribution of species in different plant functional types. The average stand density in each plot was 82 individuals/plot and it has controlled the GBH. In our study the low density GBH distribution resulted more heterogeneous condition found under high stand density (Threon, 2004).The average number of species present in all plots was observed as 10 species that were similar to the deciduous forest of Andhra Pradesh, the southern of Eastern Ghats (Naidu *et al.,* 2016). Here the structure and composition of forests related to species diversity and higher species diversity is directing more complex forest structures (Huang et al., 2003).The population structure of tree species distribution graph reveals a reverse J-shaped curve. Among the 5 PFTs, the GBH ranged from 10-110 cm except for Bamboo Brake(BB) type (ranged 50-1450 cm). The curve implied the lower GBH class (10-20cm) has large number of individual inferred good regeneration potential and lead to profound environmental changes. Hence, the regular evaluation of vegetation structure analysis of these forests is required.

The different altitude species densities, age of woody species, girth class, and their distribution regulate the basal area. The density and basal area were indicated a similar pattern of alignment with the increased GBH range for the five plant functional types. In fig. 5(A), it has been seen that the density was highest at the lowest basal area. Similarly, for Bamboo brakes, (Fig.5B) the basal area was highest at the lower GBH class i.e., 150-200 cm. After the GBH class of 450-550 cm, the density and basal area referred to a similar kind of alignment along with the increase of the GBH class. The ascending order of basal area among 6 PFTs

Table 2: IVI, BA and distribution pattern of dominant species in different plant functional types of Chandaka Wildlife Sanctuary

Rank of sp.	Species	BA(m2/ha)	A/F	IVI
1.	*Aegle marmelos*	0.08	0.23	2.95
2.	*Alangium salvifolium*	0.01	0.21	1.46
3.	*Bambusa bambos*	110.53	1.14	97.34
4.	*Bridelia retusa*	0.08	0.12	2.43
5.	*Buchanania lanzan*	0.05	0.24	1.54
6.	*Careya arborea*	0.20	0.13	4.59
7.	*Casearia eliptica*	0.02	0.13	3.05
8.	*Cassia fistula*	0.02	0.07	3.19
9.	*Chloroxylon swietenia*	0.06	0.33	2.48
10.	*Cipadessa baccifera*	0.02	0.21	1.47
11.	*Cleistanthus collinus*	0.05	0.18	2.04
12.	*Combretum roxburghii*	0.07	0.14	7.29
13.	*Diospyros melanoxylon*	0.07	0.25	4.90
14.	*Diospyros montana*	0.08	0.23	2.95
15.	*Diospyros sylvatica*	0.27	0.29	7.78
16.	*Gliricidia sepium*	0.17	2.64	2.80
17.	*Helicteres isora*	0.02	0.42	2.71
18.	*Holarrehena pubescens*	0.29	0.19	11.02
19.	*Ixora undulata*	0.02	0.12	1.83
20.	*Kigelia africana*	0.04	0.54	1.16
21.	*Lagerostroemia parviflora*	0.26	0.18	7.26
22.	*Madhuca indica*	0.46	0.33	8.50
23.	*Morinda pubescens*	0.02	0.06	2.11
24.	*Naringi crenulate*	0.09	0.09	2.30
25.	*Olax scandens*	0.02	0.09	1.74
26.	*Phyllanthus emblica*	0.04	0.08	2.76
27.	*Pollyalthia cerasoides*	0.15	0.28	5.23
28.	*Pongamia pinnata*	0.01	0.48	1.90
29.	*pterospermum xylocarpum*	0.07	0.14	1.92
30.	*Shorea robusta*	1.29	1.79	11.07
31.	*Strychnos nux-vomica*	0.35	0.32	9.84
32.	*Strychnos potatorum*	0.07	0.96	2.74
33.	*Syzygium cumini*	0.25	0.15	3.37
34.	*Tectona grandis*	2.78	2.11	23.80
35.	*Terminalia bellerica*	0.07	0.11	1.83
36.	*Terminalia chebula*	0.09	0.66	1.29
37.	*Xantolis tomentosa*	0.06	0.42	2.74
38.	*Xylia xylocarpa*	1.02	0.97	18.45
39.	*Ziziphus xyloparus*	0.03	0.11	2.34

A= Abundance, F = Frequency

Table 3: Diversity Indices for six Plant Functional Types

Diversity Indices	PFTs					
	BB	DTSF	MMDF	PSF	PTF	SEF
Species richness	1	9	15	11	10	18
Stem density ind./ha)	190*	503	1107	1090	1500	1202
Species Number	1	26	38	29	24	37
GBH range (cm)	50-1432	10-40	20-90	10-70	10-100	10-90
Basal Area (m^2 ha^{-1})	265.27 ± 11.2	0.93±1.7	8.64±0.58	9.24±0.9	77.27±16.8	11.12±1.0
Dominance_D	1	0.21	0.12	0.23	0.43	0.14
Simpson's index (1-D)	0	0.78	0.84	0.76	0.56	0.85
Shannon index (H′)	0	1.80	2.20	1.75	1.32	2.31
Evenness e^H/S	1	0.71	0.61	0.53	0.40	0.58
Margalef	0	1.93	4.83	2.13	1.77	3.69
Menhinick	0.23	1.27	1.53	1.00	0.71	1.55

*Clumps/ha

Table 4: Summary of One-Way ANOVA of Basal Area and IVI

Source of Variance		df	SS	MSS	F-value
	BA IVI	62	2.76	2.765	40.63 P<0.05

were estimated as DTSF (0.92 m^2 ha^{-1}) < MMDF (8.62 m^2 ha^{-1}) < SEF (11.12 m^2 ha^{-1}) < PSF (11.63 m^2 ha^{-1}) < PTF (18.54 m^2 ha^{-1}) < BB (663.18 m^2 ha^{-1}). The stem densities of PFTs were observed in following order Planted teak forest (PTF) > Semi-evergreen forest (SEF) > Moist mixed deciduous forest (MMDF) > Peninsular sal forest (PSF) > Degraded thorny shrubby forest (DTSF) > Bamboo brakes (BB). The average basal areas of all the PFTs were estimated as 9.33 ± 1.67 m^2 ha^{-1}).

The estimated basal area was similar to Dry forest of Miombo, Zambia (16.5 m^2ha^{-1}, Kalaba *et al.,* 2013). However, the result was much lower in comparison to other forests of India as in Deciduous and semi-evergreen forest of Similipal biosphere reserve (35.74 m^2ha^{-1}, Mahanta et al., 2021) ,Temperate Forest of Kashmir and Mandal-Choota Garhwal Himalaya (35.65 m^2 ha^{-1} and 59.66 m^2 ha^{-1}, Dar and Sundarpandian, 2016,Gairola *et al.,* 2012), Tropical moist deciduous forest of Uttar Pradesh (35.19 m^2 ha^{-1}, Tripathi & Singh, 2009), Semi-evergreen forest of Cambodia (22.2 m^2 ha^{-1}, Chheng *et al.,* 2016).

The one-way ANOVA of IVI and Basal area obtained f-value 40.63 have significant differences resulting in the existence of a mean difference between basal area and IVI. The correlation between basal Area and IVI values among all species was significant at 0.001 levels. The mean of the basal area increased with the IVI values. But in cases, the higher basal area obtained lower IVI that may happen due to the high GBH of the species. The coefficient of correlation of Basal area and species density were 0.89 and 0.35 was significant at 99% and 95% respectively. This could be predicted the basal area and species density have a joint contribution to species distribution. The calculated r^2 (1.0) has very minutely differed with adjusted r^2 values. Hence, the dependent variables basal area and density may be used significantly for the determination of IVI and species distribution.

Both the Shannon diversity (0-2.20) and Simpson's index (0-0.85) among all PFTs were following the order of SEF > MMDF > DTSF > PSF > PTF > BB (table-3). The range of species richness was 0-3.69 in five PFTs, and for the Bamboo Brakes type, it was 0. This results were equivalent to Temperate forest of Mandal-Choota Garhwal, Himalaya (Gairola *et al.,* 2012), Community temperate forest Nepal (Kunwar and Sharma, 2004), Temperate forest Garhwal, Himalaya (Raturi, 2012), Sub-tropical forest, and North-Western Himalaya (Sharma & Raina, 2013).Species richness were lower in comparison to the tropical evergreen forest of Western Ghats of Karnataka, India (Sathish, 2013).

The species richness and composition be affected by the age structure of forest types, climatic conditions, and anthropogenic disturbances, etc. (Padalia *et al.,* 2004). The forest with high tree diversity revealed higher diversity indices (Adekunle *et al.,* 2013). The Menhinick index 0.23-1.77, indicates regeneration woody species. The range of biodiversity and abundance of species could be assessed through the biodiversity indices. The Shannon- Wiener diversity index ranged from 0.81-4.1 (Sahu *et al.,* 2012), Undarpandian & Swamy, 2000) denotes moderate community complexity of a forest and the study estimated the 1.33-2.32 fall within this range (Table 2). Whereas the Shannon–Wiener Index of deciduous forest of Andhra Pradesh, the southern of Eastern Ghats 3.76 - 3.96 was indicating higher species diversity in comparison to our study. The lower Shannon–Wiener Index of Bamboo brakes was reflecting low community complexity and higher index observed in Semi-evergreen forest (H′ = 2.32) indicating higher community complexity. Both the Shannon diversity and Simpson's index among all PFTs were following the order of Semi-Evergreen Forest (SEF)> Moist Mixed Deciduous Forest (MMDF)> Degraded Thorny Shrubby Forest (DTSF) > Peninsular Sal Forest (PSF) > Planted Teak Forest (PFT) > Bamboo Brakes (BB). The Simpson index within the range of 0.21-1.34 of forests discriminated the mixed nature of vegetation with more species diversity (Lalfakawma *et al.,* 2009) was observed in the 5 PFTs i.e. MMDF, SEF, DTSF, PSF, and TPF, etc. The resulted margalef index (0-3.69) has lower value than tropical forests (Sathish *et al.,* 2013).

Conclusion

The study region is now under the protection of the State Government; still, it faces the overexploitation of wood for commercialization and forest fires during summer. This Quantitative information on the forest structure and composition of CWS will be implemented for the conservation and management of CWS. The presence of low species richness, moderate stand density, and diversity indices indicated the heterogeneous species composition of the forest. The Shannon diversity and Simpson's Index stated moderate phyto-diversity of Chandaka wildlife sanctuary mainly dominated by *B. bamboo, T. grandis, X. xylocarpa, S. robusta, H. pubescens, Diospyros* species, etc. and the Menhinick index inferred this as a regenerated forest with species heterogeneity The study of the interrelationship among basal area, stem density, and IVI through ANOVA, correlation, and regression may predict that they have a significant correlation with each other and these parameters may significantly apply for the determination of linear models. Hence, this interpreted data is one of the primary inputs for conserving this secondary regenerated forest.

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