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# Phytosociology and Regeneration Status in Different Permanent Preservation Plots across Different Forest Types in Madhya Pradesh, Central India

**Sanjay Singh[1], Harish Bahadur Chand*[2], Pavan Kumar Khatri[3], Dheerendra Kumar[4], Anil Kumar Kewat[5], Abhishek Kumar[6], Kangujam Premkumar Singh[7]**

[1]Indian Council of Forestry Research and Education, Dehradun, India. Email: sanjaysingh83@gmail.com
[2]Forest Research Institute, Dehradun, India. Email: charish0136@gmail.com
[3]Tropical Forest Research Institute, Madhya Pradesh, India. Email: khatripk31@gmail.com
[4]Botany Division, Forest Research Institute, Dehradun, India. Email: dheeru167@gmail.com
[5]Forest Research Institute, Dehradun, India. Email: akewat26@gmail.com
[6]Forest Research Institute, Dehradun, India. Email: abhishek259kumar@gmail.com
[7]Forest Research Institute, Dehradun, India. Email: premkang.pk9@gmail.com
*Corresponding author | ORCID: 0000-0002-3098-152X*

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## Abstract

Tropical forests are a global biodiversity centre providing enormous ecosystem services to the humankind. The present study was undertaken to examine and analyze the phytosociology and regeneration status of tree species in 39 permanent preservation plots spread across 22 different forest sub-types in Madhya Pradesh, India. A total of 975 quadrats were laid with a sampling intensity of 2.42% of the total area under study. 109 tree species were recorded. Density range varied from 516 individuals/hectare (ind/ha) in southern tropical dry deciduous forests to 3,412 ind/ha in dry grassland forests. Most of the forest sub-types showed log normal distribution owing to relatively high species richness, diversity and evenness, but a low dominance. Out of 62,228 live stems recorded, 68.52% were poles followed by saplings (26.39%), young trees (5.01%) and mature trees (0.08%). The result also showed high seedling density in each forest sub-type ranging from 1,040 ind/ha to 51,124 ind/ha, indicating a healthy population of mature reproducing adults. The diameter distribution in all the forest sub-types showed negative slope and followed the classic inverse J-shaped curve frequently observed in natural forests. Most of the forest sub-types in these preservation plots are regenerating successfully owing to the absolute protection given to the studied sites. It is recommended to study carbon sequestration in these permanent preservation plots over a time, which will inform climate policymakers about the true potential of Indian tropical forests as carbon sink.

## Keywords

Tropical forests; Biodiversity; Log-normal distribution; Carbon sequestration

## Introduction

Tropical forests occupy 7% of the Earth's surface and cater a significant proportion of world's biodiversity (Baraloto *et al.*, 2013, Naidu and Kumar, 2016). These forests are centre of global biodiversity and are the largest repository of global terrestrial carbon (Sullivan *et al*., 2017; Klein *et al.,* 2015; Pan *et al*., 2011). Tropical forests share distinct climatic parameters, floristic composition and forest structure even in a small area (Gallery, 2014). The tropical ecosystems are among the world's most threatened ecosystems. Due to its species richness, high species diversity and standing biomass (Sullivan *et al*., 2017) and greater productivity (Joshi and Dhyani, 2018), much attention is being paid to tropical forests. In India, for conducting ecological studies in different forests including tropical forests, permanent preservation plots were introduced.

Permanent preservation plots act as mi nature labs for observing and understanding the interaction of plant species and communities with climatic variables. These preservation plots provide an opportunity to study the temporal changes in the vegetation of different forest types and sub-types in response to changes in climatic factors. According to the recommendations of the 3$^{rd}$ All India Silvicultural Conference (Anon, 1929), preservation plots of chief forest types in their representative areas were marked. As per Tewari (2016), there are 309 preservation plots in India, of which 187 are located in natural forests and 122 in plantations covering a total area of 8,500 ha. State Forest Department of Madhya Pradesh has established 39 preservation plots in representative forest types across the state, of which 26 are of recent origin (SFRI, 2020). These preservation plots are spread over 22 different forest types. These plots are being maintained for ecological, silvicultural and other scientific studies. Due to a random distribution of tree species in undulating terrains of Central India, tropical forests largely show irregular diversity of trees (Chaturvedi *et al.,* 2011). Floristic, phytosociological, and size class distribution (SCD) studies are necessary to understand the development of a forest, especially where there is great diversity (Dos Santos *et al.,* 2017).

The study of plant communities helps acquire information about habit, habitat, niche, and vegetation structure as well as various interactions among them (Khan *et al.,* 2017). A phytosociological survey is an important tool for studies of successional stages since succession of forest species occurs in a continuity of floristic and structural changes that occur in the ecosystem. Phytosociological studies in tropical forests of India are common but often limited to the study of one forest type at a time (Sharma *et al.,* 1986; Sukumar *et al.,* 1992; Krishnamurthy *et al*., 2010; Joshi and Dhyani, 2018; Naidu and Kumar, 2016). The present study was undertaken to examine and analyze the phytosociology and regeneration status of tree species in 39 permanent preservation plots spread across 22 different forest sub-types of Madhya Pradesh, India.

## Material and Methods

*Profile of study area*

The study was carried out in Madhya Pradesh, India, during 2013-14. Madhya Pradesh is India's second-largest state, covering 308,252 km$^2$ (or 9.38 percent of the country's total geographical area). It is situated between the latitudes of 21°17' N and 26°52' N, and the longitudes of 74°08' E and 82°49' E. There are 4 distinct physiographical regions in the state i.e., the low-lying areas in the north and north-west of Gwalior, Malwa Plateau, Satpuda, and Vindhyan Ranges. Most of the region has a sub-tropical climate having average annual rainfall varying in the range of 800-1,800 mm and mean annual temperature ranging between 22-25°C (FSI, 2019).

According to the Census of India (2011), the state's total population is 72.63 million, or 6% of India's total population, with a population density of 236 people per square kilometer. 72.37 percent of the population lives in rural areas, while 27.63 percent lives in urban areas. The state's tribal population is significant, accounting for more than one-fourth of the state's total population and 14.7 percent of India's total tribal population (Bhanumurthy *et al.,* 2016). The major occupation is agriculture followed by industry and services. The 19$^{th}$ Livestock Census (2012) reported 36.33 million livestock population in the state. The per

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capita income is around Rs. 91,000 (US$ 1250) which is lower than the per capita income of the country i.e., Rs 126,000 (US$ 1731) (SRD, 2020).

*Scenario of forest*

Madhya Pradesh is biologically diverse state and has the largest forest area among all states of India. As per the revised Champion and Seth (1968) classification of forest types, it has 5 forest type groups that are further divided into 25 forest sub-types. The total forest area is 94,689 $km^2$ of which 61,886 $km^2$ (65.36%) is Reserved Forests, 31,098 $km^2$ (32.84%) is Protected Forests and 1,705 $km^2$ (1.80%) is Unclassed Forests (FSI, 2019). The state has 25.15% i.e., 77,482.49 $km^2$ of the total geographical area under forest cover. In terms of forest canopy density classes, the largest share is of open forest (47.06%) followed by moderate dense forest (44.32%) and very dense forest (8.62%) (FSI, 2019). The forest cover map of the state is shown in figure 1.

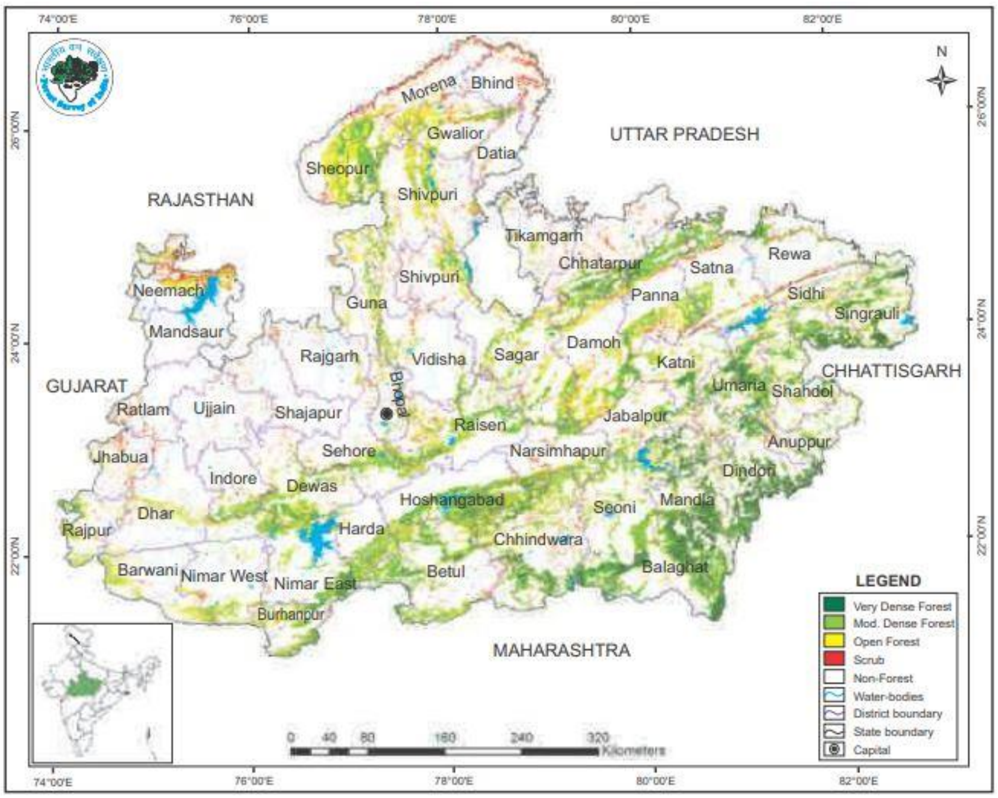

Figure 1: Forest Cover Map of Madhya Pradesh (FSI, 2019)

*Preservation plots of study area*

The study was undertaken in 39 preservation plots of Madhya Pradesh, 24 preservation plots were established after year 2000, while 15 preservation plots were established before 1931. The details of each preservation plots distributed over 22 different forest sub-types are presented in table 1.

*Sampling*

The total area under study is 394 ha, which is distributed in 39 preservation plots across 22 sub-forest types of Madhya Pradesh. In this study, 975 quadrats were laid for the forest inventory. Using equal allocation method, 25 quadrats were laid out in each preservation plot with a sampling intensity of 2.42 percent. Except for preservation plots 1 and 39, the size of a quadrat in all the preservation plots was 100$m^2$ (10m x 10m).

A smaller size of quadrat (5m x 5m) was used in the inventory of preservation plots 1 and 39 due to their limited size.

Table 1: Details of Preservation Plots in Madhya Pradesh

| *Forest sub-type* | *PP no.* | *Forest Division* | *Forest Range* | *Compart-ment no.* | *Year of Formation* | *Area (ha)* |
|---|---|---|---|---|---|---|
| Slightly moist teak forest (3B/C1C) | 2 | Hoshangabad | Banapura | 261 | 1931 | 10 |
| Southern moist mixed deciduous forest (3B/C2) | 4 | North Betul | Amla | 327(Old), 508 (New) | 1947 | 10 |
| Southern moist mixed deciduous forest (3B/C2) | 5 | Bori Sanctuary | Bori | 52 | 1947 | 37.6 |
| Southern moist mixed deciduous forest (3B/C2) | 6 | Bori Sanctuary | Bori | 45 | 1947 | 31.6 |
| Southern moist mixed deciduous forest (3B/C2) | 7 | Alirajpur | Kathiwara | 137(Old), 525 (New) | 1953 | 10 |
| Southern moist mixed deciduous forest (3B/C2) | 13 | South Seoni | Kurai | 181 | 1980 | 4.45 |
| Moist peninsular Sal forest (3C/C2) | 14 | Bandhavgarh National Park | NA | 324 | 1999 | 10 |
| Riparian fringing forest (4E/RS1) | 19 | North Betul | Shahpur | P 419 | 2002 | 10 |
| Khair forest (5/1S1) | 27 | North Sagar | Khurai | RF 71 | 2004 | 10 |
| Khair forest (5/1S1) | 31 | Shivpuri | Pohri | P75/P765 | 2004 | 10 |
| Khair forest (5/1S1) | 34 | Guna | Raghavgarh | 458 | 2004 | 10 |
| Khair forest (5/1S1) | 35 | Guna | North Guna | P473/P481 | 2004 | 10 |
| Secondary dry deciduous forest (5/2S1) | 28 | North Sagar | Khurai | P 69 | 2004 | 4 |
| Dry deciduous scrub (5/DS1) | 37 | Rajgarh | Rajgarh | 314 | 2004 | 10 |
| Dry Savanah (5/DS2) | 25 | Indore | Indore | 256 | 2003 | 10 |
| Dry grassland (5/DS4) | 21 | Sheopur | Sheopur | RF 229 | 2002 | 10 |
| Dry grassland (5/DS4) | 36 | Raisen | Raisen | 387 | 2004 | 10 |
| *Anogeissus pendula* forest (5/E1) | 20 | Sheopur | Karhal | P528 | 2002 | 10 |
| *Anogeissus pendula* forest scrub (5/E1/DS1) | 38 | Datia | Seonda | 115 | 2004 | 10 |
| *Boswellia* forest (5/E2) | 24 | South Sagar | Garhakota | 896 | 2003 | 10 |
| *Boswellia* forest (5/E2) | 26 | Sheopur | Badhar | 213 | 2004 | 10 |
| *Boswellia* forest (5/E2) | 30 | S. Shahdol | Gopharu | 295 | 2004 | 10 |
| *Hardwickia* forest (5/E4) | 12 | West Chhidwara | Jhirpa | 35 | 1961 | 4 |
| Dry bamboo brake (5/E9) | 18 | Panna National Park | Madla | 227 | 2001 | 10 |
| Very dry teak forest (5A/C1A) | 33 | Guna | Guna | 404 | 2004 | 10 |
| Dry teak forest (5A/C1B) | 3 | North Betul | Betul | 248 | 1937 | 10 |
| Southern tropical dry deciduous forest (5A/C3) | 8 | Badwaha | Badwaha | 910/284 | 1955 | 10 |

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| *Forest sub-type* | *PP no.* | *Forest Division* | *Forest Range* | *Compart-ment no.* | *Year of Formation* | *Area (ha)* |
|---|---|---|---|---|---|---|
| Southern tropical dry deciduous forest (5A/C3) | 9 | Dewas | Udainagar | 633 | 1955 | 10 |
| Southern tropical dry deciduous forest (5A/C3) | 10 | West Chhindwara | Delakhari | P157 | 1961 | 4.5 |
| Southern tropical dry deciduous forest (5A/C3) | 11 | West Chhindwara | Delakhari | P163 | 1961 | 4.5 |
| Southern tropical dry deciduous forest (5A/C3) | 16 | Panna | Hinouta | 521 | 2001 | 10 |
| Southern tropical dry deciduous forest (5A/C3) | 39 | West Chhindwara | Delakhadi | 89 A | 2006 | 1 |
| Dry peninsular Sal forest (5B/C1C) | 1 | Narsinghpur | Gadarwara | 418/309 | 1931 | 2 |
| Dry peninsular Sal forest (5B/C1C) | 15 | Satpura National Park | Pachmarhi | 302 | 1999 | 10 |
| Dry peninsular Sal forest (5B/C1C) | 23 | Satpura National Park | Pachmarhi | 298 | 2002 | 10 |
| Dry peninsular Sal forest (5B/C1C) | 29 | S. Shahdol | Gopharu | RF 281 | 2004 | 10 |
| Northern dry mixed deciduous forest (5B/C2) | 17 | Noradehi Wildlife Sanctuary | Mohli | RF 107 | 2001 | 10 |
| Ravine thorn forest (6B/C2) | 22 | Datia | Goraghat | 202 | 2002 | 10 |
| Ziziphus scrub (6B/DS1) | 32 | Shivpuri | Pohri | P 69 | 2004 | 10 |

(PP= Preservation Plot)

*Phytosociology*

Phytosociological survey was carried out during 2013-14 in all the preservation plots. The vegetation survey was conducted using nested quadrat method (Cottam and Curtis, 1956). Data of species abundance, collar diameter, and height were collected for each individual tree/plant having girth > 9cm in the quadrat of 10mx10m, and seedlings of tree species were counted in each 1m x 1m quadrat. To express the dominance and ecological success of any species, the Important Value Index (IVI) was calculated by adding the relative values of the three parameters: density, frequency, and basal area (Curtis and McIntosh, 1950, 1951; Mishra, 1968, Greig–Smith, 1964). Following indices indicating the phyto-diversity were calculated for each forest sub-types.

Species richness: Species richness was simply taken as a count of the total number of species present in that particular forest type.

Species diversity: Species diversity (H') was estimated using the Shannon - Wiener Index (Shannon and Wiener, 1963). $H' = -\sum \left(\frac{ni}{N}\right) \log\left(\frac{ni}{N}\right)$ where, $n_i$ is the total number of species in forest type, and $N$ is the number of individuals of all species in that forest type.

Species dominance: Species dominance ($D$) was calculated following the equation by Simpson (1949). $D = \sum \left(\frac{ni}{N}\right)^2$ where, $n$ is the number of individuals of a species and $N$ is total number of species.

Species evenness: Equitability of evenness (J') was estimated using the formula given by Pielou (1966).

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J'= H'/ lnS where, S = number of species in the particular forest type.

*Size Class Distribution (SCD)*

The data from each preservation plot was pooled to its respective forest sub-type. The data thus obtained was tallied into eight stem diameter classes as follows: <10cm, 10-40, 40-70, 70-100, 100-130, 130-160, 160-190, 190-210 cm, since the number of individual decreases with increasing size class, the class interval of the latter two classes was increased to balance the samples across size class (Condit *et al.*, 1998; Lykke, 1998; Mwavu and Witkowski, 2009). The number of individuals in each size class is divided by the class-width (Lykke, 1998). The number of individuals in each size class ($N_i$) was transformed by ln ($N_i$+1) because some classes have zero individual (Lykke, 1998; Obiri *et al.*, 2002; McLaren *et al.*, 2005; Mwavu and Witkowski, 2009). Density of seedling for each forest type was calculated by extrapolating the data collected from 1m x 1m quadrat. For each forest type logarithmic regression was performed with the size class midpoint as an independent variable and the mean number of individuals in that class ($N_i$) as the dependent variable. The slope values were used to summarize the shape of size class distribution in a single value. The interpretation of SCD slopes was based on the types of SCD.

*Cluster analysis*

A hierarchical cluster analysis using the Ward method (Ward, 1963) and squared Elucidian distance was run on the studied stands responding to IVI of species in each stand (Gautam, 2007). The classification aims to detect the relation between different forest sub-types by analysis of the groups formed by the cluster analysis corresponding to IVI. The forest sub-types based on species composition were broadly classified into two clusters, group 'A' that consisted of the forest sub-types where one species or a group of species dominated the canopy while the group 'B' consisted of species-rich forest sub-type, with even distribution of the species in the community. SPSS (Statistical Package for Social Science) was used to perform cluster analysis.

## Results and Discussion

*Forest Structure*

Species composition was one of the major criteria on which Champion and Seth (1968) classified the forests of India. A total of 109 species having Girth at Breast Height (GBH) >9cm were recorded from 39 preservation plots, distributed in 22 different forest sub-types of Madhya Pradesh. Apart from the tree species, two species of lianas i.e., *Hiptage benghalensis* and *Ventilago maderspanata*, were also recorded from the preservation plots. The phytosociological parameters of different preservation plots under different forest types are enlisted in table 2.

Table 2: Phytosociological parameters of the preservation plots in different forest sub-types

| *Forest Types* | *PP No* | *Species richness* | *Total Density (ind/ha)* | *Diversity (H')* | *Dominance (D)* | *Evenness (J')* |
|---|---|---|---|---|---|---|
| 3B/C1C | 2 | 14 | 1072 | 0.61 | 0.16 | 0.53 |
| 3B/C2 | 4 | 21 | 1364 | 2.50 | 0.11 | 0.82 |
| 3B/C2 | 5 | 26 | 808 | 2.91 | 0.08 | 0.90 |
| 3B/C2 | 6 | 28 | 1252 | 2.71 | 0.09 | 0.81 |
| 3B/C2 | 7 | 34 | 1012 | 3.12 | 0.07 | 0.89 |
| 3B/C2 | 13 | 15 | 1264 | 1.73 | 0.34 | 0.64 |
| 3C/C2 | 14 | 15 | 948 | 2.21 | 0.17 | 0.82 |
| 4E/RS1 | 19 | 23 | 1540 | 2.65 | 0.09 | 0.84 |
| 5/1S1 | 27 | 7 | 1192 | 1.57 | 0.27 | 0.81 |

| *Forest Types* | *PP No* | *Species richness* | *Total Density (ind/ha)* | *Diversity (H')* | *Dominance (D)* | *Evenness (J')* |
|---|---|---|---|---|---|---|
| 5/1S1 | 31 | 28 | 2464 | 2.89 | 0.07 | 0.87 |
| 5/1S1 | 34 | 10 | 1392 | 1.58 | 0.28 | 0.69 |
| 5/1S1 | 35 | 22 | 2076 | 2.49 | 0.13 | 0.81 |
| 5/2S1 | 28 | 6 | 716 | 1.46 | 0.30 | 0.82 |
| 5/DS1 | 37 | 14 | 1308 | 1.72 | 0.14 | 0.65 |
| 5/DS2 | 25 | 7 | 808 | 1.28 | 0.38 | 0.66 |
| 5/DS4 | 21 | 5 | 516 | 1.41 | 0.27 | 0.88 |
| 5/DS4 | 36 | 6 | 536 | 1.48 | 0.27 | 0.82 |
| 5/E1 | 20 | 9 | 1924 | 1.47 | 0.35 | 0.67 |
| 5/E1/DS 1 | 38 | 6 | 1156 | 0.92 | 0.59 | 0.51 |
| 5/E2 | 26 | 14 | 1252 | 2.26 | 0.14 | 0.86 |
| 5/E2 | 30 | 11 | 1988 | 1.55 | 0.34 | 0.65 |
| 5/E4 | 12 | 17 | 1448 | 2.44 | 0.12 | 0.86 |
| 5/E5 | 24 | 5 | 520 | 1.21 | 0.36 | 0.75 |
| 5/E9 | 18 | 13 | 2128 | 1.59 | 0.29 | 0.62 |
| 5A/C1A | 33 | 18 | 2496 | 2.06 | 0.24 | 0.71 |
| 5A/C1B | 3 | 22 | 1268 | 2.85 | 0.09 | 0.92 |
| 5A/C3 | 8 | 14 | 3412 | 1.86 | 0.25 | 0.71 |
| 5A/C3 | 9 | 11 | 760 | 1.75 | 0.30 | 0.73 |
| 5A/C3 | 10 | 18 | 2708 | 2.44 | 0.13 | 0.84 |
| 5A/C3 | 11 | 20 | 2196 | 2.61 | 0.10 | 0.87 |
| 5A/C3 | 16 | 25 | 2996 | 2.71 | 0.12 | 0.84 |
| 5A/C3 | 39 | 28 | 1980 | 1.71 | 0.29 | 0.51 |
| 5B/C1C | 1 | 20 | 2796 | 2.66 | 0.09 | 0.89 |
| 5B/C1C | 15 | 14 | 1976 | 1.92 | 0.26 | 0.73 |
| 5B/C1C | 23 | 12 | 2304 | 1.48 | 0.41 | 0.60 |
| 5B/C1C | 29 | 11 | 900 | 1.71 | 0.29 | 0.71 |
| 5B/C2 | 17 | 17 | 2096 | 2.34 | 0.14 | 0.83 |
| 6B/C2 | 22 | 3 | 1028 | 0.83 | 0.49 | 0.75 |
| 6B/DS1 | 32 | 13 | 1676 | 1.81 | 0.28 | 0.71 |

The value for the stem density per hectare was found to be the highest in southern tropical dry deciduous forest (5A/C3) recorded in 6 preservation plots and lowest in dry grassland forest (5/DS4) recorded in 2 preservation plots. The tree density ranged from 516 to 3412 ind/ha. Density values were found within the range of the values (349-1875 ind/ha) recorded from tropical dry deciduous forests of India (Joshi and Dhyani, 2018; Chaturvedi *et al*., 2011; Visalakshi, 1995; Krishnamurthy *et al*., 2010; Sukumar *et al*., 1992; Singh and Singh, 1991), and the tropical forests of Mexico (Castellanos *et al*., 1991; Duran *et al*. 2006). The tree density in the current study was found to be higher than that reported for moist tropical forests (Baishya *et al*., 2009; Borah *et al*., 2013; 2015) and tropical evergreen forests (Chittibabu and Parthasarathy, 2000). Similarly, the tree density in Himalayan forests (Bohara *et al*., 2018; Kumar and Bhatt, 2006; Sharma *et al*., 2010) and tropical sal forests (Chand *et al*., 2018; Haripriya, 2000) was also found to be relatively low. Higher density in the forest indicates higher proportion of individuals in lower diameter class. The preservation plots mentioned in the study are protected by the Forest Department; that may be one of the reasons for the high density of trees in the study sites.

Shannon-Weiner Diversity Index in different forest types under the study ranged from 0.61 to 3.12, which is consistent with the diversity reported from different tropical forest types of Madhya Pradesh (0.32 to 3.76) by Joshi and Dhyani (2018), and Prasad and Pandey (1992). High species diversity is an indication of

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maturity in the ecosystem (Marglef, 1963; Odum, 1969), which in turn, indicates the stability of the community (Khatri *et al.*, 2004). In tropical forests, values of species diversity are generally high, between 5.06 and 5.40 (Knight, 1975; Simpson, 1949), as compared to overall Indian forests falling between 0.00 and 4.21 (Bisht and Sharma, 1987; Visalakshi, 1995; Pande, 1999, Agni *et al.*, 2000; Chauhan, 2001; Chauhan *et al.*, 2001; Kumar *et al.*, 2010; Khatri *et al.*, 2004). The value of the Simpson index in different forest types varied from 0.09 to 0.59, which is consistent with the average value of the concentration of dominance in tropical forest presented by Knight (1975). However, the degree of dominance is lower than that recorded in India's tropical dry deciduous forest (Joshi and Dhyani, 2018) and tropical evergreen forest (Visalakshi, 1995), suggesting that the study sites are more diverse.

The relationship between species richness, diversity and evenness i.e., SHE analysis was determined as per Magurran (1988). In the studied community it was observed that Shannon-Wieners Diversity Index (H') for tree species was influenced by species richness i.e., with the increase in richness, the diversity also increased. Contrary to the observations of Gautam (2007), there was negligible effect of evenness on the Shannon diversity index. Plotting of SHE also showed that the diversity and species richness increased from *Ziziphus* scrub forest (6B/DS1) to slightly moist teak forest (3B/C1C). The diversity and richness of species have increased with the increasing moisture through the forest type as shown in figure 2.

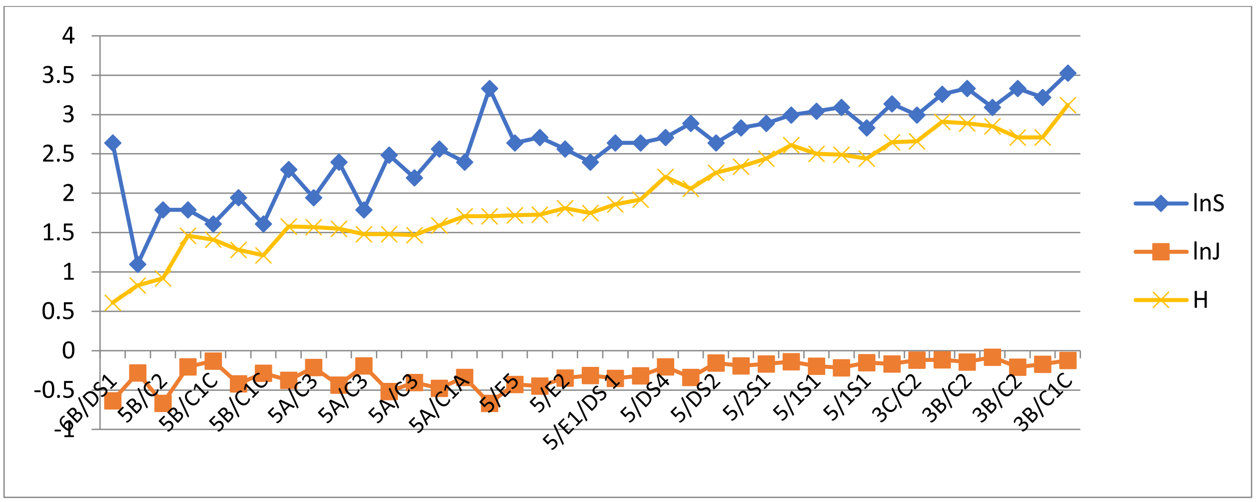


Figure 2: Changes in SHE as we move from dry to moist forest types

*Size Class Distribution*

A total of 62,228 live stems (GBH > 9cm) were counted (excluding seedlings) in which 26.39% were saplings, 68.52% were poles, 5.01% were young trees and 0.08% were mature trees. Forest type-wise size class distribution is presented in the Table 4. Mature trees were recorded only in 3BC2, accounting for 0.6% of the total stem count. Most of the stems recorded in the study were identified as pole. The percentage distribution of poles in different forest sub-types ranged between 43.6% and 85.8%. The highest density of pole was recorded for forest sub-type 5E2, while the lowest density of the pole was recorded for 6BC2. The percentage distribution of saplings recorded from the preservation plot ranges from 1.53% to 56.42%, with the highest value for 6BC2, and the lowest for 5E5. All the forest sub-types in the current study showed a high density of seedlings ranging from 1,040 to 51,124 seedlings/ha. High density of seedlings indicates a healthy population of mature reproducing adults in the population.

Regeneration in the community is often determined by many factors like canopy gap (Prakasham *et al.*, 2016), seed collection (Chandra *et al.*, 2015), environmental condition during seed germination and establishment (Prakasham *et al.*, 2016), edaphic characters (Gupta, 1953), biotic disturbance (Chaubey and Jamalludin, 1989), standing crop (Chaubey and Sharma, 2013), shrubby growth and ground flora. The poles, saplings, and seedlings in the forest mostly comprised few dominant species, and all the species were not represented in all the size classes. The results of the current study are similar to that of Mwavu and Witkowski (2009) and West *et al.* (2000) who reported a significant positive correlation in seedling and adult density. High density of the adults of any species in the community ensures higher proportion of seeds in the soil seed bank, and thus high seedlings (Mwavu and Witkowski, 2009).

Table 4: Size Class Distribution of stems in different forest sub-types (ind/ha)

| *Particulars* | *3B/C1C* | *3B/C2* | *3C/C2* | *4E/RS1* | *5/E1* | *5/E2* | *5/E4* | *5/E5* | *5/E9* | *5/1S1* | *5/2S1* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Seedlings | 1040 | 7448 | 5068 | 6740 | 7924 | 47240 | 5528 | 4720 | 47332 | 51124 | 5516 |
| Sapling (<10) | 320 | 3760 | 176 | 1872 | 1968 | 1504 | 1232 | 32 | 1952 | 12672 | 960 |
| Pole (10-40) | 2800 | 17248 | 2864 | 4048 | 5712 | 11120 | 4512 | 1472 | 6368 | 15600 | 1888 |
| Young (40-70) | 1152 | 5056 | 720 | 240 | 16 | 320 | 48 | 576 | 192 | 224 | 16 |
| young (70-100) | 16 | 368 | 32 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 0 |
| Mature (100-130) | 0 | 64 | 0 | 0 | 0 | 16 | 0 | 0 | 0 | 0 | 0 |
| Mature (130-160) | 0 | 64 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mature (160-190) | 0 | 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Matrue (190-220) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Particulars* | *5A/C1A* | *5A/C1B* | *5A/C3* | *5B/C1C* | *5B/C2* | *5/DS1* | *5/DS2* | *5/DS4* | *5/E1/DS1* | *6B/C2* | *6B/DS1* |
| Seedlings | 7296 | 6068 | 11252 | 48376 | 7296 | 6108 | 5048 | 4812 | 4756 | 4628 | 5676 |
| Sapling (<10) | 4384 | 224 | 18416 | 2640 | 1744 | 2752 | 480 | 1200 | 2432 | 2320 | 2640 |
| Pole (10-40) | 5584 | 4336 | 37056 | 27088 | 6640 | 2480 | 2752 | 2944 | 2192 | 1792 | 4064 |
| Young (40-70) | 16 | 496 | 640 | 2144 | 0 | 0 | 0 | 48 | 0 | 0 | 0 |
| young (70-100) | 0 | 16 | 64 | 32 | 0 | 0 | 0 | 16 | 0 | 0 | 0 |
| Mature (100-130) | 0 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mature (130-160) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mature (160-190) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mature (190-220) | 0 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The SCD of all the forest sub-types showed a negative SCD slope (Figure 3) with high density in smaller size classes. All the forest types showed a classic inverse J-shaped curve. The classic inverse J-shaped curve is expected for populations that recruit fairly enough overtime (Mwavu and Witkowski, 2009; Sano, 1997, Wanga *et al.,* 2004), and hence have a stable size class structure (Silvertown, 1982). Size distribution of long-lived tree populations growing under near optimum conditions often show a reverse 'J' shape due to initial high mortality of juvenile trees in the smallest size class (Svensson and Jegulum, 2001; Pennuleas *et al.,* 2007). The proportional composition of the stems in different forest sub-types indicates that all the stands under study have a fair number of recruits (seedlings and saplings) and are thus regenerating successfully (Table 4).

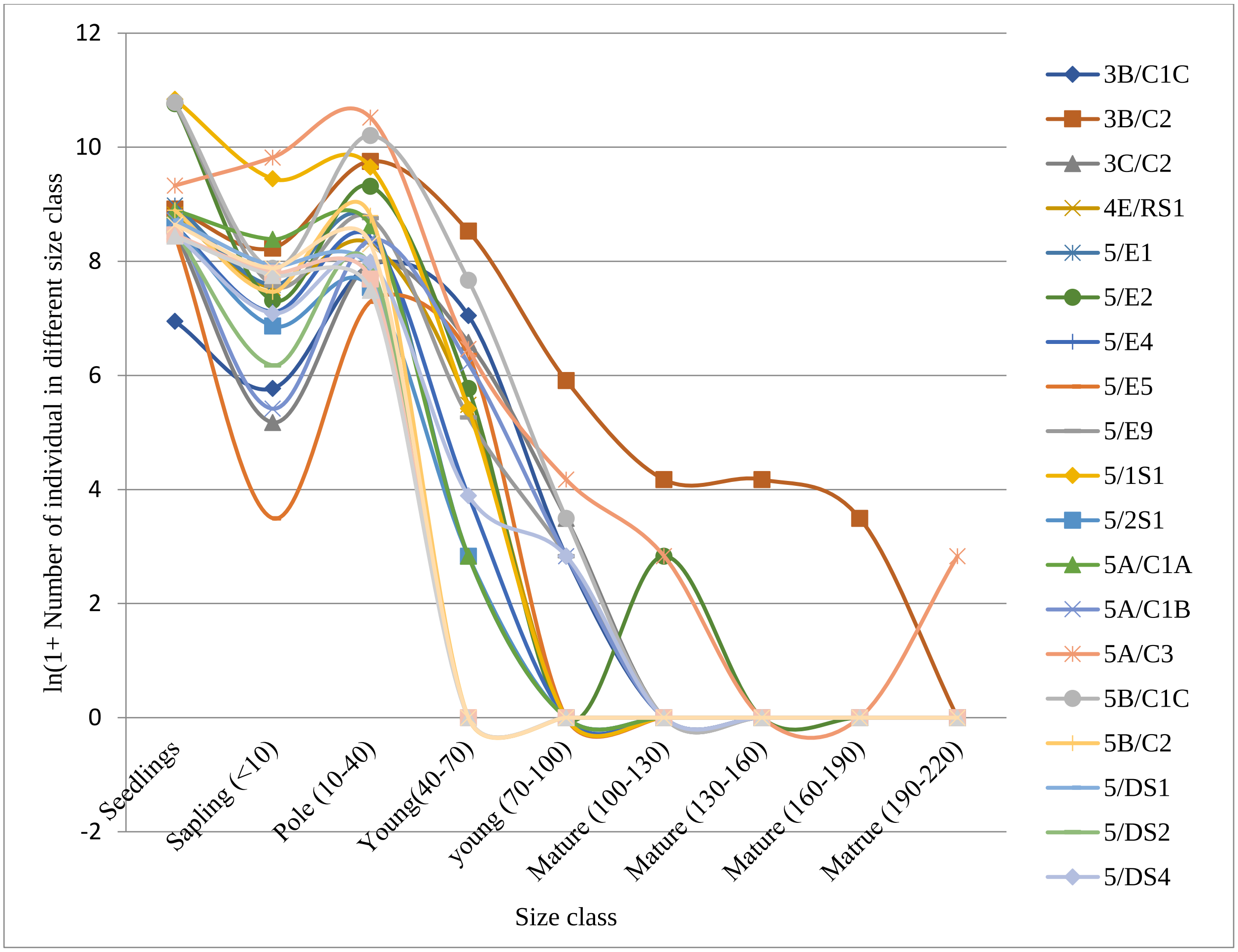


Figure 3: Status of regeneration in different forest sub-types of Madhya Pradesh

Based on the density of seedlings, saplings, and poles, the forest sub-types were clustered in two groups using the Ward method and squared Elucidian distance as per Singh (2012). Majority of forest sub-types were clustered together in Group 'A', characterized by lower seedling density as compared to the forest sub-types classified in Group 'B' (Figure 4). High density of reproducing individuals in the higher size class led to a higher density of seedlings in the community. The pole stage was represented by a fair number of individuals in all the forest sub-types, indicating favorable growing conditions. However, the distribution of the species in different size class is not proportionate (Figure 4). One or the few dominant species in the sapling and poles were in higher proportion, indicating the successful regeneration of these species in the forest community. This trend was observed throughout the preservation plots in all forest sub-types. The distribution of seeds and seedlings of a species is determined by the distributions of seed-producing parents, the behavior of seed and seedlings feeding herbivores, and the spatial distribution of suitable germination sites (Hutchings, 1997; Prakasham *et al*., 2016). Established plants of many species suppress seedlings in the immediate vicinity by casting deep shade, competing vigorously for water and other nutrients in the upper layer of the soil, and producing inhibitory chemicals (Hutchings, 1997). Successful establishment of seedlings from seed requires gaps in the vegetation cover (Fenner, 1978; Swaine and Whitmore, 1988; Fisher *et al.,* 1991). Seedling recruitment process (i.e., growth survival and establishment) varies with species, light intensity, and other habitat characteristics (Clark, 1990; Bazzaz, 1991; Teketay, 1996; Saha and Howe, 2006; Corrado *et al.,* 2007).

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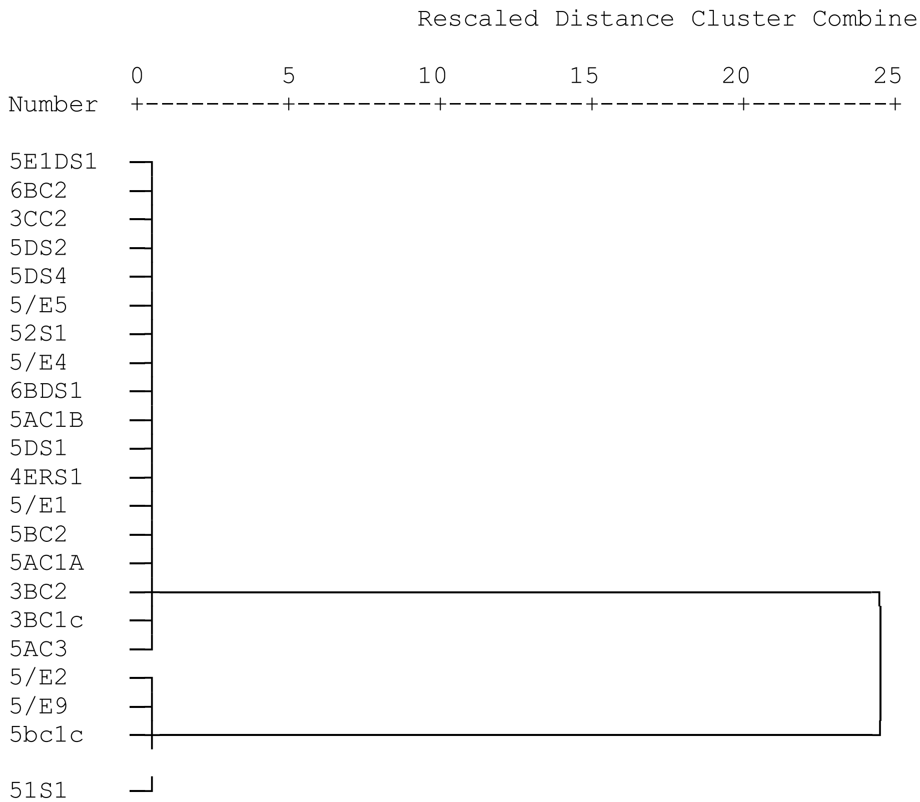


Figure 4: Hierarchal cluster analysis of forest sub-types responding to density of seedling saplings poles young and mature trees type using wards method

*Dominance Diversity Curve*

The dominance-diversity curve of 16 forest sub-types showed log-normal distribution, while 6 forest sub-types showed log-series distribution of the species in the community (Figure 5). Most of the forest sub-types showed log-normal distribution owing to relatively high species richness, diversity, evenness, and low dominance (Table 1). In these forest communities, more than one factor was responsible for determining the distribution and dominance of the species (May, 1975). Random variation in these factors led to a normal distribution of the species. The majority of large assemblage studied by ecologists appears to follow a log-normal pattern of species abundance (May, 1975; Sugihara, 1980; Gaston and Blackburn, 2000; Longino *et. al*., 2002; Singh, 2012).

Log-series distribution of species in the community is typical in old-growth forests of tropical regions (Pitman *et al*., 1999; Huang *et al*., 2003). Log-series distribution is found in the communities having few abundant species (Pande, 1999). Log series distribution in the current study was exhibited by 5/2S1, 5/DS4, 5/E5, 3B/C1C, 5A/C1A, and 6B/DS1 forest sub-types where the species richness varied from 5 to 18 (Table 1). The preservation plots in these forest sub-types showed a high concentration of dominance, one or group of two to three species were dominant and had access to most of the resource. Other species were represented in very few numbers. Most of these forests are dry forest with little moisture, species with adaptation for such climatic conditions are found in abundance, while the others are restricted to the niche where conditions are suitable for growth.

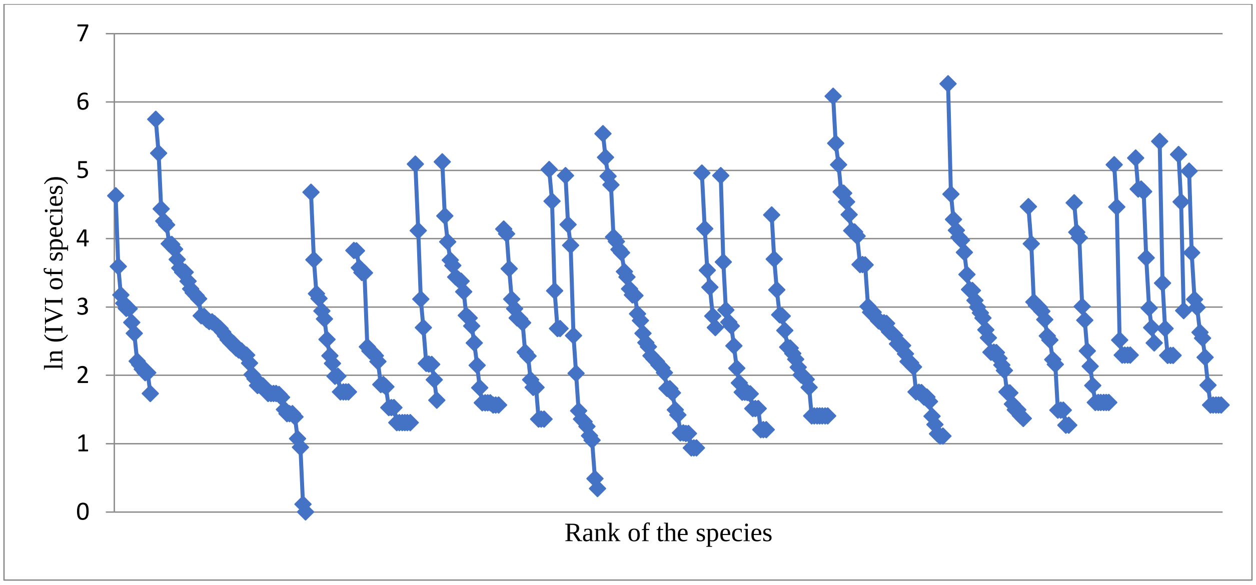


Figure 5: Dominance diversity curve of different forest sub-types (3BC1C, 3BC2, 3CC2, 4ERS1, 5E1, 5E2, 5E4, 5E5, 5E9, 51S1, 52S1, 5AC1A, 5AC1B, 5AC3, 5BC1C, 5BC2, 5DS1, 5D2S2, 5DS4, 5E1DS1, 6BC2 and 6BDS1)

*Hierarchical Cluster Analysis*

This classification aimed to detect the relationship between different forest sub-types by analysis of the groups formed by the cluster analysis with respect to IVI of species recorded across different forest sub-types. The forest sub-types based on species composition were broadly classified into two clusters; the Group 'A' consisted of the forest sub-types where one species or a group of species dominated the canopy. While the Group 'B' consisted of species-rich forest sub-type, with even distribution of the species in the community (Figure 6). Group A was further divided into two sub-groups. Sub-group '1' consisted of teak dominant preservation plots of forest sub-types (5/E5, 5/DS2, 5/E9, 5/2S1, 3B/C1C, 5A/C1A, and 5A/C1D). Most of the *Tectona grandis* dominated forests showed similar community structure and composition. *Tectona grandis* dominated the community, contributing the major proportion of IVI.

Sub-group '2' consisted of mixed forest which was further divided in 6 clusters based on dominant species (Figure 6). 5/DS4 and 6B/C2 were found to be clustered separately. 5/DS4 (dry grassland forest) was dominated by *Diospyros melanoxylon* and *Butea monosperma*, while 6B/C2 (ravine thorn forest) was dominated by *Prosopis juliflora* and *Acacia leucopholea*. Group B was subdivided into two sub-groups i.e., sub-group 1, consisted of mixed forests where *Tectona grandis* dominated the forest community. However, the forests were different from the teak forest of Group 'A" in terms of distribution of the species in the forest community (Figure 6). The species dominated the forest type, but the distribution of the species in the community was determined by more than one factor. Likewise, sub-group 2 consists of the mixed Sal-forest with high species diversity.

## Conclusion

Tropical forests exhibit rich biological diversity. These forests provide numerous environmental benefits and supports regulation of biogeochemical cycles. The high species richness, diversity index, and evenness in the studied sites are the characteristic of tropical forests, and the lower values for concentration of dominance indicate sharing of dominance by more than one species. All the forest sub-types demonstrated a classical inverse J-shaped curve indicating healthy regeneration status. Communities in the drier forest mostly showed log-series distribution which was dominated by one or sometimes more than one dominant species which determine the distribution of other species in the community. The results show that most of

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the forest sub-types have been successfully regenerating owing to the absolute protection of the preservation plots. Other ecological studies, such as carbon sequestration, should be carried out in these preservation plots to assist policymakers and forest managers in understanding the true potential of the Indian tropical forests as carbon sinks.

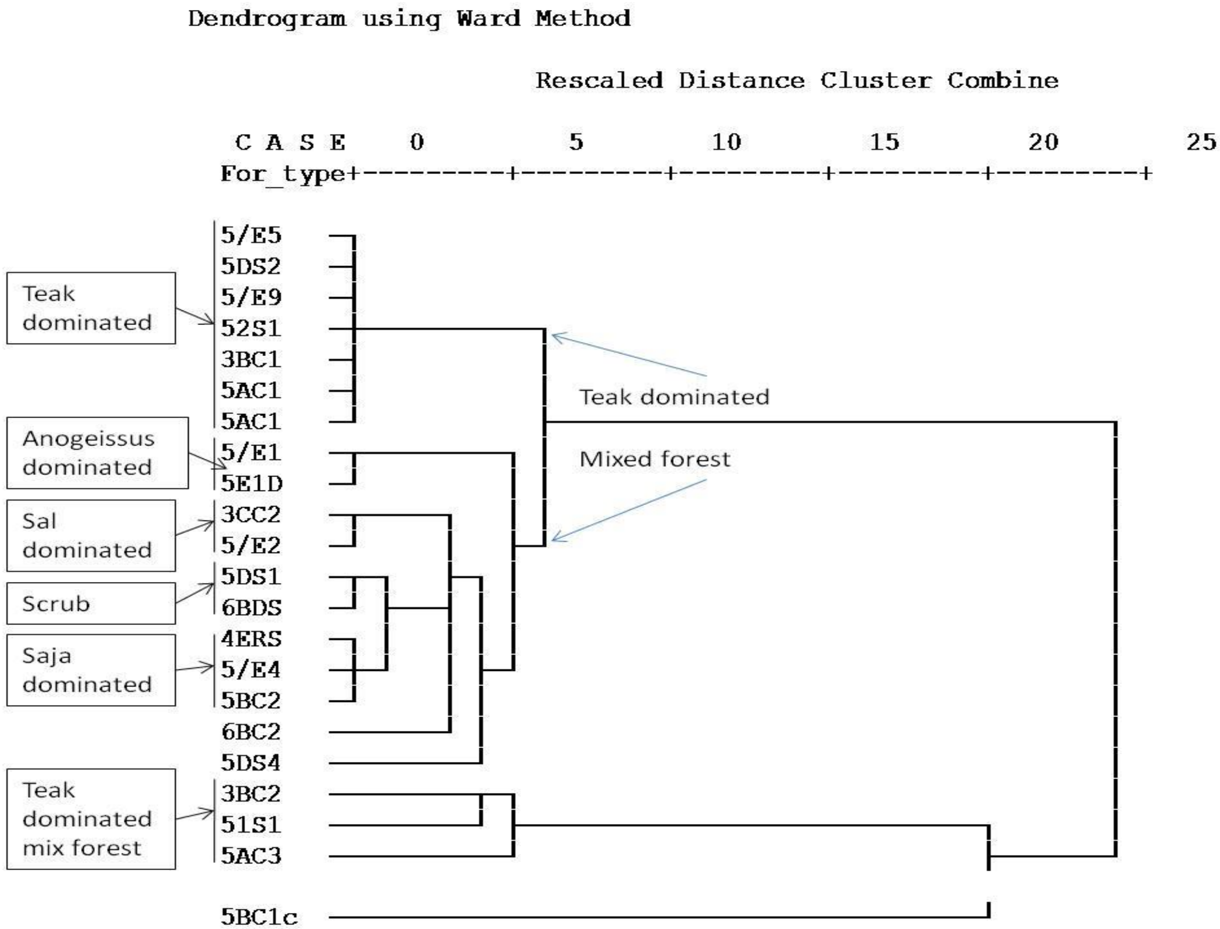


Figure 6: Hierarchal cluster of the forest sub-types responding to IVI of species using wards method

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## Authors' Declarations and Essential Ethical Compliances

*Authors' Contributions (in accordance with ICMJE criteria for authorship)*

| Contribution | Author 1 | Author 2 | Author 3 | Author 4 | Author 5 | Author 6 | Author 7 |
|---|---|---|---|---|---|---|---|
| Conceived and designed the research or analysis | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Collected the data | Yes | No | Yes | No | No | No | No |
| Contributed to data analysis & interpretation | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Wrote the article/paper | Yes | Yes | Yes | No | Yes | No | No |
| Critical revision of the article/paper | Yes | Yes | No | No | Yes | No | No |
| Editing of the article/paper | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Supervision | Yes | Yes | Yes | No | No | No | No |
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