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Assessment of Forest Composition, Structure and Biomass Dynamics Using Permanent Plot Inventories in Yellapur Forest Division, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study assesses the forest composition, structure and biomass dynamics in the Yellapur Forest Division using permanent plot inventories. Located in the Western Ghats of Karnataka, the Yellapur region features diverse forest types, including tropical dry deciduous and semi-evergreen forests. Permanent plots were established to evaluate tree species distribution, structural attributes and

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biomass dynamics. The volume and biomass were calculated based on species-specific allometric equations. Results revealed significant differences in forest structure across forest types. Tropical dry deciduous forests exhibited lower tree density (250 trees per hectare) and biomass (55 tons per hectare) compared to semi-evergreen forests, which had higher tree density (350 trees per hectare) and biomass (95 tons per hectare). Biomass volume in the tropical dry deciduous forests was reduced by 15-18 percent in areas impacted by anthropogenic activities such as logging and grazing. The semi-evergreen forests showed a higher carbon stock, with biomass volume accounting for 140 tons per hectare, while tropical dry deciduous forests had a reduced biomass volume of 110 tons per hectare. Species composition in semi-evergreen forests was dominated by *Shorea robusta*, *Terminalia arjuna* and *Tectona grandis*, while tropical dry deciduous forests were characterized by species such as *Ziziphus mauritiana* and *Anogeissus latifolia*. The study also highlighted a significant decline in biomass in degraded areas, emphasizing the impact of human-induced disturbances on carbon sequestration. The results suggest that degradation has led to a 12-15 percent reduction in forest biomass volume, with substantial implications for carbon storage and forest health. This research underscores the importance of permanent plot inventories for understanding biomass dynamics and highlights the need for effective forest management strategies to mitigate degradation and enhance carbon storage in these ecosystems.

Keywords: Forest types; permanent plot; volume; tree diversity.

1. INTRODUCTION

Forests play a substantial role in terrestrial ecosystems, encompassing roughly 30 per cent of the Earth's land area (Anon, 2010). By means of photosynthesis, forests absorb carbon dioxide and store it as biomass, making a significant contribution to mitigating global climate change. It is estimated that most of the aboveground carbon (over 80%) and a substantial portion of belowground carbon (about 40%) are held within forest ecosystems (Dixon et al., 1994). Forests have the remarkable ability to absorb double the carbon they release. Globally. they are responsible for absorbing 29 per cent of the carbon emissions generated from the combustion of fossil fuels (Harris et al., 2021). At present, Earth's forests contain 400 PgC (petagrams of carbon) in biomass, with the potential to increase this storage to 772 PgC (Pan et al., 2013), making them a powerful tool for combatting climate change. Among these forests, tropical forests stand out as centres of biodiversity and carbon sequestration. surpassing other forest types in their ability to capture carbon (Martin et al., 2013). In India, tropical forests cover 64 per cent of the total forested area and hold immense significance for local communities relying on them for sustenance (Anon, 2011).

In India's context, the tropical deciduous forest is divided into two categories based on precipitation patterns: moist deciduous forests and dry deciduous forests. Moist deciduous forests are prevalent in regions receiving rainfall between 1000 to 2000 mm annually, with a dry period lasting three to four months. Trees in these forests shed their leaves during winter and regrow them around March-April. These forests account for 19.73 per cent of India's forest types (Anon, 2021). They are widely distributed across states like Tamil Nadu, Arunachal Pradesh, Assam, Meghalaya, Mizoram, Bihar: West Bengal, Odisha and Uttarakhand (Kokila et al., 2024). Characterised by 2 to 3 layers of vegetation, they typically have a lower species diversity compared to tropical evergreen and semi-evergreen forests. Tropical dry deciduous forests encompass roughly 38.2 per cent of India's forested land (Anon, 2021). prevail in regions marked by distinct seasonal rainfall patterns and prolonged droughts during the year. These forests are characterized by trees not exceeding 25 meters in height, featuring a canopy of deciduous trees that thrive in well-lit conditions. Stretching from Kanyakumari to the base of the Himalayas, they thrive in regions receiving 800 to 1200 mm of rainfall, with extensive areas serving as suitable wildlife habitats (Krooks et al., 2014). These forests are primarily dominated by Teak and dry Sal communities in the southern and northern areas, respectively some regions host a blend of tree species such as Anogeissus pendula, *Boswellia serma Hardwickia binata*. Acacia nitric, *Madhuca silica and Batestmor sesperma,* Notably *Acacia catechu* and *Dalbergia sissoo* are prominently found in areas with recently developed soils (Kumar et al., 2011).

India also has a significant stretch of area under Tropical semi-evergreen forests bordering tropical wet evergreen arcas, acting as a transition between evergreen and m deciduous forests. The lower canopy remains evergreen, while the upper canopy species leaves briefly in dry seasons. Covering 13.79 per cent of Indian forest types, they are deme multi-layered, 24-36 m tall, with rainfall between 1500-2500 mm annually (Anon, 2021) Canopies aren't continuous, with lower species diversity compared to evergreen forests. Trees like *Myristica malabarica* and *vitex altissima* display buttressed stems. These forests feature bamboo, canes, ferns, climbers and abundant epiphytes like ferns and orchids. The significant rise in atmospheric carbon dioxide, currently measured at 416 ppm continues to be a major driver of global warming. The storage of carbon across various components within forest ecosystems plays a vital role in counteracting global warming and lessening the negative impacts of climate change. Presently, the total carbon stocks in global forests are approximately 861±66 Pg C (Pan et al., 2011). The collective carbon stored within forest vegetation is roughly estimated at 359 billion tonnes (Allen et al., 2010).

India is ranked fourth globally for its notable CO, emissions (Muntean et al., 2018) However, in a seemingly paradoxical scenario, India also boasts a considerable forest cover spanning an area of 7,12,249 square kilometres. This expansive forest expanse holds a substantial capacity for carbon storage, contributing to mitigating environmental impacts. The total carbon stock within the Indian forest ecosystem is estimated to reach a noteworthy 7.124.6 million tonnes (Anon, 2021). However, it is important to note that these figures encompass not only natural forests but also encompass tree plantations, which are often dominated by non-native species. Turning our focus to the intricate landscapes of the Western Ghats, a region of ecological significance, there exists a notable gap in research assessing the carbon stocks within its natural forests. A study by Seen et al. (2010), discovered that despite acknowledging the mounting pressures of deforestation and land-cover changes, unveiled that the forests of the Western Ghats retain a considerable 0.43 petagrams (Pg) carbon stock. This underscores the resilience of these ecosystems in the face of challenges. However, an alternative perspective emerges from the research by Osturi et al. (2014), indicating that even large, well-protected forest fragments within the Western Ghats showcase a 40 per cent reduction in above-ground biomass carbon (AGBC) when compared to contiguous forests. This reduction can be attributed to alterations in structural attributes, shifts in tree sizes and compositional changes. This brings into focus the intricate dynamics that govern carbon storage in varying environmental contexts. Further insights from Padmakumar et al. (2018) underscore the importance of structural attributes in carbon storage. Their examination of tree carbon stocks in the Chinnar Wildlife Sanctuary within the Western Ghats demonstrated a robust positive correlation between carbon stocks and basal area, a crucial structural metric. However, the broader picture presents a gap in our understanding of ecosystem-level carbon stocks, their intricate relationships with biodiversity, structural attributes and environmental factors in India's tropical forests, specifically in the context of the Western Ghats. Such insights would not only provide a comprehensive perspective on carbon storage mechanisms but would also shed light on the impact of structural attributes on the distribution of carbon among various ecosystem components, including trees. Such insights are invaluable in developing strategies to sustain carbon stocks and safeguard biodiversity within the complex tapestry of tropical forests.

India, an expansive nation teeming with diverse biological richness, features an extensive landscape. In this context, forests occupy the position of the second-largest land use, closely following agriculture. Notably, approximately 275 million rural inhabitants of India draw upon forests as a source of sustenance and a component of their livelihoods, as articulated by the World Bank. Therefore, the quantum of carbon stocked in various forest ecosystems is a priority task. The Semi-evergreen forests exhibit higher tree density and biomass compared to tropical dry deciduous forests, which show signs of degradation due to anthropogenic activities such as logging and grazing. The manuscript also identifies reductions in biomass and carbon stocks in degraded areas, underscoring the long-term impacts of human-induced disturbances on forest ecosystems. By using long-term monitoring data, the study provides empirical evidence that can inform sustainable forest management practices aimed at mitigating degradation and enhancing biodiversity conservation. The findings demonstrate the critical role of permanent plot inventories in understanding forest dynamics and emphasize their importance in developing effective strategies for addressing environmental concerns such as deforestation, climate change, and ecosystem preservation. This research is invaluable for forest managers, policymakers, and researchers working to promote ecological sustainability and biodiversity conservation (Gowda et al., 2024).

2. MATERIALS AND METHODS

The study was carried out in different forest types of Yellapur Forest Division of Uttara Kannada District. The study area map is shown in Fig. 1. The total forest area of the division including Betta lands (protected forest) is 1,68,986.66 hectares. The Yellapur forest division is situated in the eastern part of Uttara Kannada district. It has dry deciduous forest in its eastern part, moist deciduous forests in the central part and semi-evergreen forests in the western part.Major tree species found in tropical dry deciduous forest of Yellapur forest division include *Tectona grandis*, *Terminalia alata*, *Terminalia paniculata*, *Dalbergia latifolia*, *Anogeisus latifolia* and *Lagerstroemia lanceolata*. In tropical moist deciduous forest typeof Yellapur forest division, the floristic composition includes, *Tectona grandis, Terminalia alata, Lagerstroemia lanceolata, Lannea coromandelica, Pterocarpus marsupium, Dalbergia latifolia, Anogeissus latifolia, Mitragyna parviflora, Terminalia bellerica, Bombax ceiba, Grewia tiliaefolia, Terminalia paniculata, Madhuca species, Schliechera oleosa, Adina cardifolia, Xylia xylocarpa* and *Diospyros species*. In the tropical semi evergreen forest type, the diversity of the tree species is high. This region contains species like *Holigarna arontiana*, *Artocarpus hirsutus*, *Myristica malabarica*, *Aporosa lindleyana*, *Polyalthia fragrans*, *Vitex altissima*, *Syzigium lacetum* and *Hopea parviflora*.

A reconnaissance survey was carried out in the study area to identify and finalize the sample site locations for collecting the ground inventory data. The9 permanentplots of 1ha (100 m×100 m) each were laid outas per CEOS (Committee on Earth Observation Satellites) protocol. There were 9 subplots each of size 33.33m×33.33m marked using nylon ropes. A total of 9 permanent plots, three plots each in dry, moist deciduous and semi-evergreen forests were laid 9 (Fig. 2). All the trees having girth at breast height ≥30 cm within the plots were given numbers and marked using permanent paint (Tamilselvan et al., 2021). Each tree within a subplot was measured for its girth at breast height and at base and height (Fig. 2).

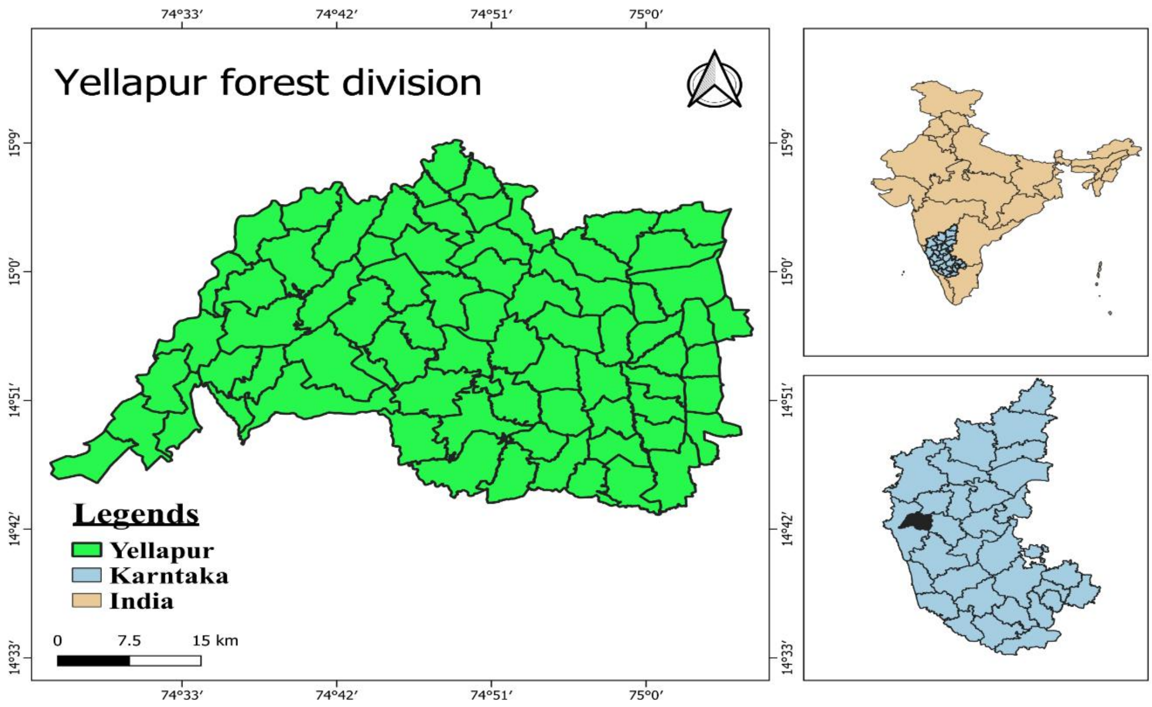


Fig. 1. Study area

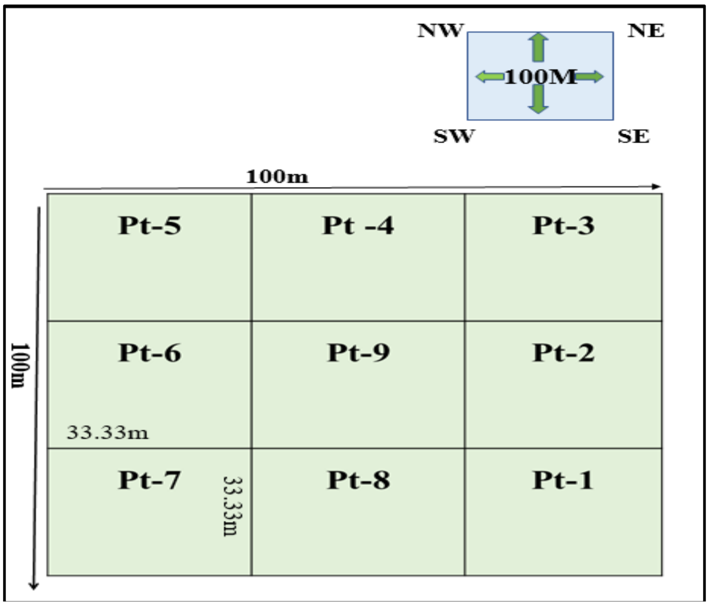


Fig. 2. Layout of permanent plot

The experiment was conducted using a Randomized Block Design (RBD) with three forest types of the Yellapur Forest Division, Uttara Kannada district, serving as the treatments. Each treatment was replicated seven times, with seven subplots sampled from each forest type. The total height of trees was measured using a digital hypsometer, while Girth at Breast Height (GBH) and Girth at Base (GAB) were recorded using measuring tapes.

Basal area measures the collective cross-sectional area of trunk within a defined area in the forest. The basal area of individual trees having girth at breast height ≥ 30cm was calculated using formula (Chaturvedi and Khanna, 1984).

Basal area (m^2ha^{-1}) =G24π

Where, G is the girth at breast height and expressed in meter (m).
Π is constant equal to 3.14

Basal area of individual tree in each quadrat were calculated and summed to get total basal area of the quadrat. Further it was extrapolated to per hectare basis and expressed in m^2ha^{-1}. The form factor is the ratio of volume of a tree or its part to the volume of a cylinder having the same length and cross-sectional area (Chaturvedi and Khanna, 1984). The artificial form factor was calculated using the formula.

Form factor= (Girth at breast height)2(Girth at base)2

The data collected on various parameters like GBH, GAB, tree height was used to estimate the volume of standing tree. The volume of standing tree was calculated using formula stated below as suggested by (Chaturvedi and Khanna,1984) and expressed in m^3. Based on the mean total volume per tree, total volume per hectare was calculated.

Volume of tree (m^3ha^{-1}) = Basal area (m^2) ×Height (m) ×Form factor

2.1 Biodiversity Assessment

The study was conducted in 10 permanent plots, each measuring 1 ha, within the Yellapur forest division, representing various forest types and conditions. Systematic sampling was carried out within each plot, with subplots of fixed dimensions laid out for detailed measurements. All trees within the plots were identified to species level using field guides and local expertise and the dominant and co-dominant species were determined based on relative abundance and basal area. Tree height was measured using a clinometer or laser rangefinder and categorized into classes such as <10 m, 10–20 and>20 m. Diameter at breast height (DBH) was recorded using a diameter tape and classified into categories such as <10 cm, 10–30 and >30 cm.

3. RESULTS AND DISCUSSION

3.1 Results

A total of 4,680 individual trees belonging to 82 species were recorded across 10 plots, highlighting significant species diversity in the study area. *Tectona grandis* was the most dominant species, with 1,728 individuals, followed by *Terminalia paniculata* (374 individuals) and *Myristica malabarica* (310 individuals), collectively accounting for a substantial proportion of the tree population. Other notable species in terms of abundance included Lagerstroemia lanceolata, *Vitex altissima* and *Holigarna arnottiana*, which also demonstrated considerable presence across multiple plots (Table 1).

Table 1. Tree species and their distribution found in the 10 inventoried permanent plots

Name of the species	Total no. of trees	Plot-wise occurrence of tree species and their frequency									
		1	2	3	4	5	6	7	8	9	10
Adina cordifolia	2					*					
Anogeissus latifolia	174	*	*	*		*					
Aporosa lindleyana	116						*	*	*	*	*
Arashinanoga	23									*	*
Artocarpus lakoocha	6							*	*		*
Artocarpus hirsutus	136					*	*	*	*	*	*
Averrhoa carombola	1					*					
Bauhinia spp	4		*		*		*				
Bekkenaucchu	6							*	*		
Bombax ceiba	1										*
Calophyllum apetalum	25							*	*		*
Careya arborea	13			*		*	*				
Carissa carandus	6	*				*	*				
Caryotaurens	8						*		*	*	*
Chandakal	6					*	*				
Cinnamomum malabatrum	6					*					
Cinnamomum Zeylenicum	32							*	*	*	*
Cordia dichotoma	9	*	*	*		*					
Cordia myxa	1			*							
Dalbergia latifolia	90	*	*	*	*						
Dalbergia sissoo	1						*				
Terminalia anogeissiana	6					*					
Dillenia pentagyna	28					*	*				
Diospyros melanoxylon	8			*							
Diospyros microphylla	72							*	*	*	*
Dysoxylon glandulosum	18									*	
Emblica officinalis	3			*			*				
Eugenia utilis	46							*	*	*	
Ficus microphylla	2			*							
Ficus tsjahela	1							*			
Ficus virens	1					*					
Flacourti amontana	3					*					
Gandha garige	1					*					
Garcinia indica	4					*		*			*
Garcia parviflora	2								*		
Glachidion malabaricum	58							*	*	*	
Gmelina arborea	2					*	*				
Grewia tilifolia	8						*		*		
Holarrhena pubescens	6						*				
Holoptelea integrifolia	4						*				
Holigarna arnottiana	145					*		*	*	*	*
Hopea spp	1										*

Name of the species	**Total no. of trees**	**Plot-wise occurrence of tree species and their frequency**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crassula ovata	1					*					
Holiptelea sp.	1					*					
Syzygium cumini	5					*					
Calotropis gigantea	56							*	*	*	
Murraya koenigii	16										*
Camphora officinarum	1										*
Lagerstroemia lanceolata	149	*	*	*	*	*	*				
Lagerstroemia parviflora	10							*			
Lagerstroemia spp	4				*						
Lanneacoromandelica	9	*					*				
Linociera malabarica	41										*
Lophopetalum wightianum	29							*	*	*	*
Machilusmacrantha	3					*					
Mammea suriga	11							*	*	*	
Mangifera indica	7					*		*			*
Michelia champaca	11					*		*	*	*	*
Mimusops elengi	60							*	*	*	*
Mitragyna parviflora	3					*					
Myristica malabarica	310					*		*	*	*	*
Terminalia elliptica	1								*		
Persea macrantha	15								*	*	*
Polyalthia coffeoides	43							*		*	
Polyalthia fragrans	75							*	*	*	
Prosopis cineraria	1					*					
Pterocarpus marsupium	7	*				*					
Sideroxylon tomentosum	4								*		*
Strychnos nux vomica	22					*	*				*
Sygygium zeylanicum	5							*	*		
Syzygiumcumini	24					*	*		*	*	*
Syzygiumlaetum	140							*	*	*	*
Tabernaemontana divaricata	2						*				
Tectona grandis	1728	*	*	*	*	*	*				
Terminalia alata	118	*	*	*			*		*		*
Terminalia bellarica	19					*	*		*		*
Terminalia paniculata	374	*	*	*	*	*	*	*	*		*
Terminalia tomentosa	11	*									
Toona ciliata	65					*	*	*	*	*	*
Vateria indica	3					*				*	
Vitex altissima	103					*	*	*	*		*
Xylia xylocarpa	48						*	*	*	*	*
Moringa olerifera	60										*
Total no. of trees =	4680										

The distribution of species varied, with some, such as *Tectona grandis*, *Terminalia paniculata* and *Lagerstroemia lanceolata*, being widely distributed across most plots, indicating their adaptability to different site conditions. In contrast, species like *Caryota urens, Polyalthia fragrans* and *Mimusops elengi* were observed in fewer plots, reflecting more localized patterns of occurrence. This variation in distribution suggests differences in ecological preferences and potential microhabitat requirements among species. Overall, the findings indicate a diverse and heterogeneous forest composition with both widespread and spatially restricted species, contributing to the ecological complexity (Fig. 3).

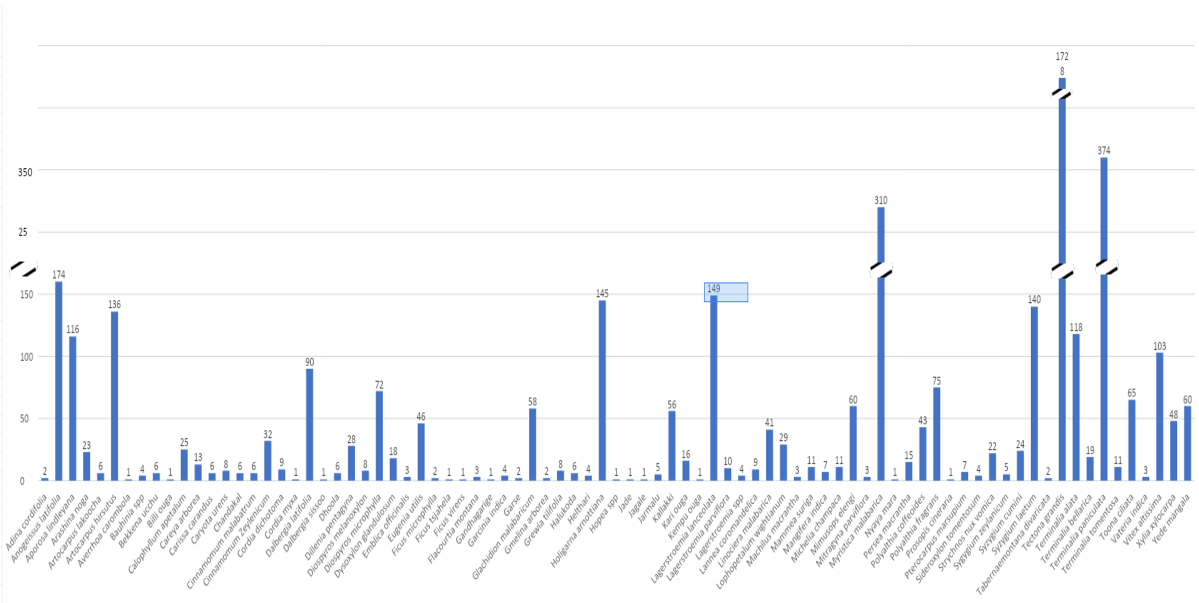


Fig. 3. Tree species and their frequency over 10 plots

Table 2. Average height, Basal area and Volume in different forest types of Yellapur forest division of Uttara Kannada district

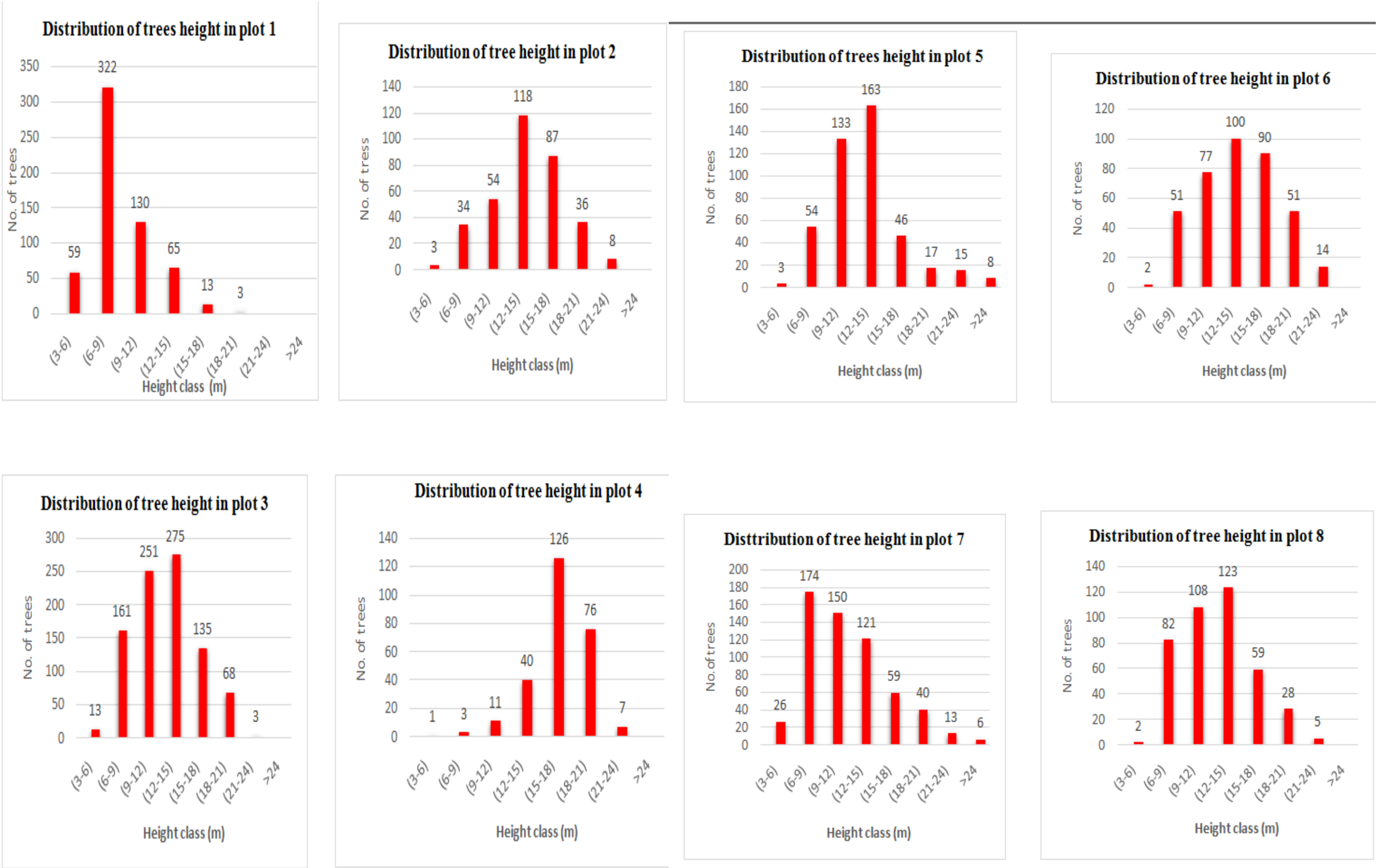
Forest type	Average height (m)	Basal area(m^2/ha)	Volume(m^3/ha)
Dry deciduous	11.76	28.77	289.79
Moist deciduous	15.25	23.59	233.55
Semi evergreen	12.39	31.44	342.35
C.D@5%	NS	NS	NS
SE m ±	1.26	3.99	61.80

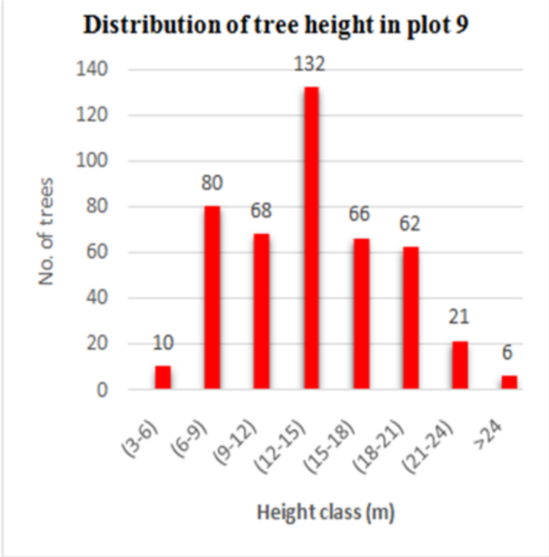
Figures in column are NS = Non-significant, CD **=** *critical difference, SEm - Standard error of mean*

The comparative study of forest types in the Yellapur forest division of Uttara Kannada district revealed notable differences in average height, basal area and volume. Moist deciduous forests recorded the tallest average height at 15.25 meters, followed by semi-evergreen forests at 12.39 meters, while dry deciduous forests had the shortest height at 11.76 meters. In terms of basal area, semi-evergreen forests showed the highest value at 31.44 m²/ha, followed by dry deciduous forests at 28.77 m²/ha. Moist deciduous forests recorded the lowest basal area at 23.59 m²/ha. Similarly, the volume of wood was the highest in semi-evergreen forests (342.35 m³/ha), followed by dry deciduous forests (289.79 m³/ha), with moist deciduous forests showing the lowest value (233.55 m³/ha) (Table 2).

The observed differences in average height, basal area and volume were significant, indicating variability in forest structure among the different forest types. Semi-evergreen forests demonstrated a better growth performance in terms of basal area and volume, while moist deciduous forests excelled in tree height. Dry deciduous forests showed intermediate values for most parameters.

The tree height distribution across all ten inventoried permanent plots reveals a consistent dominance of medium-height trees, primarily in the 12–15 m and 15–18 m height classes. In Plot 1, the 12–15 m class is most prominent, with 322 trees, followed by the 9–12 m class (130 trees), while lower and taller height classes contribute minimally. Similarly, Plot 2 shows a peak of 118 trees in the 12–15 m class, with declining numbers in adjacent classes. Plot 3 also exhibits a strong concentration in the 12–15 m class (275 trees), gradually decreasing toward lower and taller classes. In Plot 4, the 12–15 m height class dominates (126 trees), with a sharp decline in other classes. Plot 5 and Plot 6 show a similar pattern, with the majority of trees in the 12–15 m class (163 and 100 trees, respectively), supported by smaller contributions from the 9–12 m and 15–18 m classes (Fig. 4).


Distribution of trees height in plot 1
No. of trees
59
322
130
65
13
3
(3-6) (6-9) (9-12) (12-15) (15-18) (18-21) (21-24) >24
Height class (m)
Distribution of tree height in plot 2
No. of tress
3
34
54
118
87
36
8
(3-6) (6-9) (9-12) (12-15) (15-18) (18-21) (21-24) >24
Height class (m)
Distribution of trees height in plot 5
No. of trees
3
54
133
163
46
17
15
8
(3-6) (6-9) (9-12) (12-15) (15-18) (18-21) (21-24) >24
Height class (m)
Distribution of tree height in plot 6
No. of trees
2
51
77
100
90
51
14
(3-6) (6-9) (9-12) (12-15) (15-18) (18-21) (21-24) >24
Height class (m)
Distribution of tree height in plot 3
No. of trees
13
161
251
275
135
68
3
(3-6) (6-9) (9-12) (12-15) (15-18) (18-21) (21-24) >24
Height class (m)
Distribution of tree height in plot 4
No. of trees
1
3
11
40
126
76
7
(3-6) (6-9) (9-12) (12-15) (15-18) (18-21) (21-24) >24
Height class (m)
Disttribution of tree height in plot 7
No.of trees
26
174
150
121
59
40
13
6
(3-6) (6-9) (9-12) (12-15) (15-18) (18-21) (21-24) >24
Height class (m)
Distribution of tree height in plot 8
No. of trees
2
82
108
123
59
28
5
(3-6) (6-9) (9-12) (12-15) (15-18) (18-21) (21-24) >24
Height class (m)



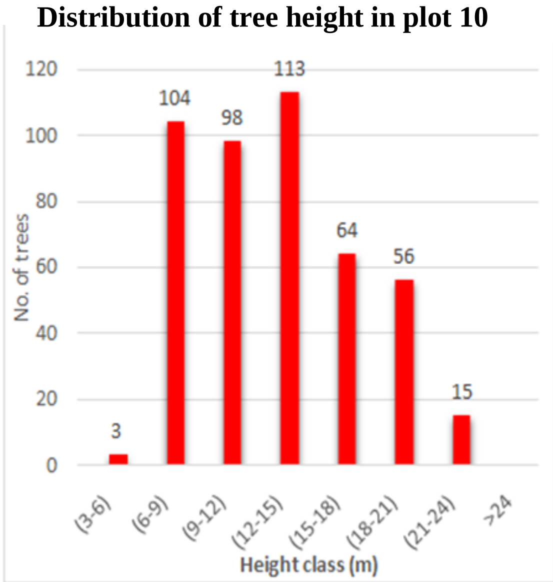


Fig. 4. Distribution of trees in different height (m) classes in the inventoried permanent plots (1-10)

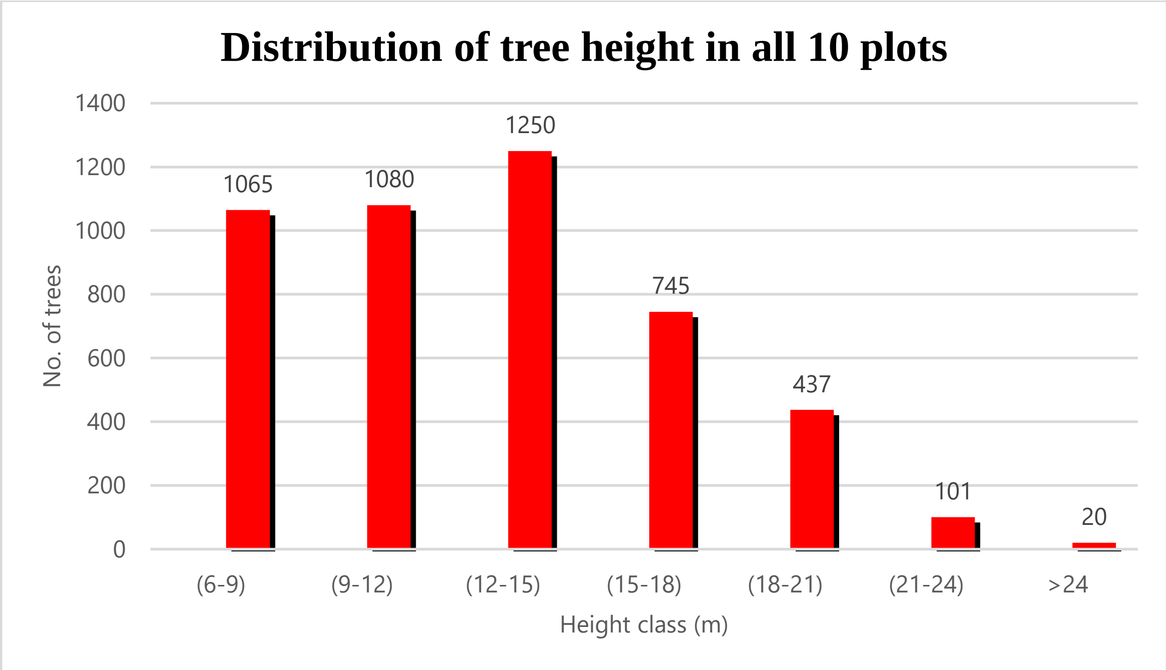


Fig. 5. Distribution of overall tree height (m) classes in all 10 permanent plots


Distribution of tree stem diameter in plot 1
No. of trees
400
350
300
250
200
150
100
50
0
349
145
66
22
4
6
(5-15)
(15-25)
(25-35)
(35-45)
(45-55)
(55-65)
>65
Daimeter class (cm)
Distribution of tree stem diameter in plot 2
No.of trees
120
100
80
60
40
20
0
34
87
114
64
24
8
9
(5-15)
(15-25)
(25-35)
(35-45)
(45-55)
(55-65)
>65
Diameter class (cm)
Distribution of tree stem diameter in plot 5
No. of trees
250
200
150
100
50
0
140
197
39
15
11
15
10
(5-15)
(15-25)
(25-35)
(35-45)
(45-55)
(55-65)
>65
Diameter class (cm)
Distribution of tree stem diameter in plot 6
No. of trees
160
140
120
100
80
60
40
20
0
113
137
72
25
15
12
10
(5-15)
(15-25)
(25-35)
(35-45)
(45-55)
(55-65)
>65
Diameter class (cm)
Distribution of tree stem diametr in plot 3
No. of trees
450
400
350
300
250
200
150
100
50
0
189
426
255
33
1
1
1
(5-15)
(15-25)
(25-35)
(35-45)
(45-55)
(55-65)
>65
Diameter class (cm)
Distribution of tree stem diameter in plot 4
No. of trees
140
120
100
80
60
40
20
0
5
41
125
79
9
1
(5-15)
(15-25)
(25-35)
(35-45)
(45-55)
(55-65)
>65
Diameter class (cm)
Distribution of tree stem diameter in plot 7
No. of trees
300
250
200
150
100
50
0
247
172
96
23
26
13
11
(5-15)
(15-25)
(25-35)
(35-45)
(45-55)
(55-65)
>65
Diameter class (cm)
Distribution of tree stem diameter in plot 8
No.of trees
180
160
140
120
100
80
60
40
20
0
153
132
62
26
10
9
10
(5-15)
(15-25)
(25-35)
(35-45)
(45-55)
(55-65)
>65
Diameter class (cm)

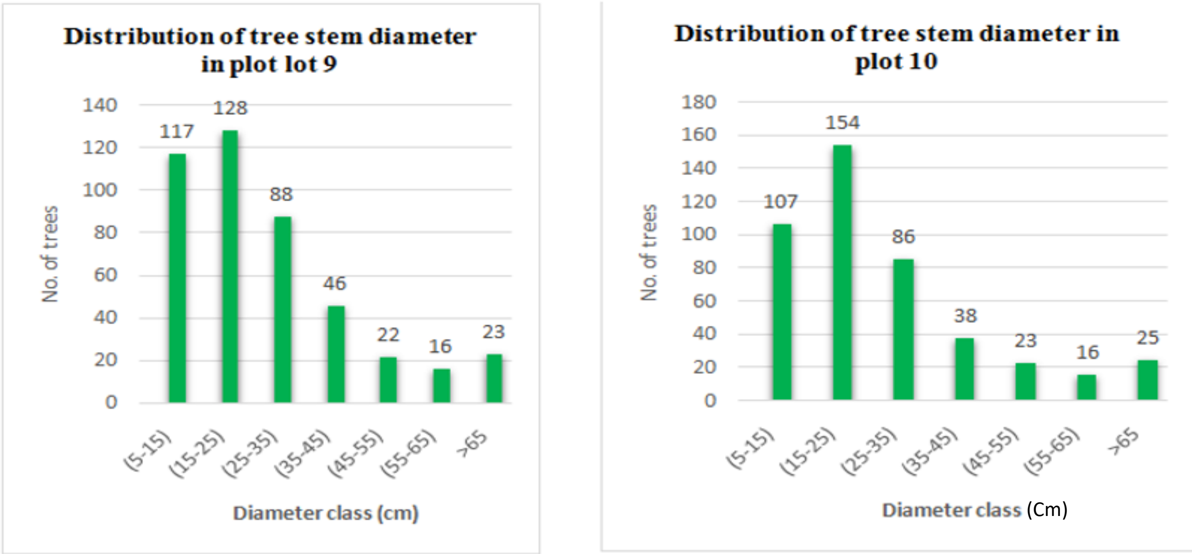


Fig. 6. Distribution of trees in different diameter classes in different inventoried permanent plots (1-10)

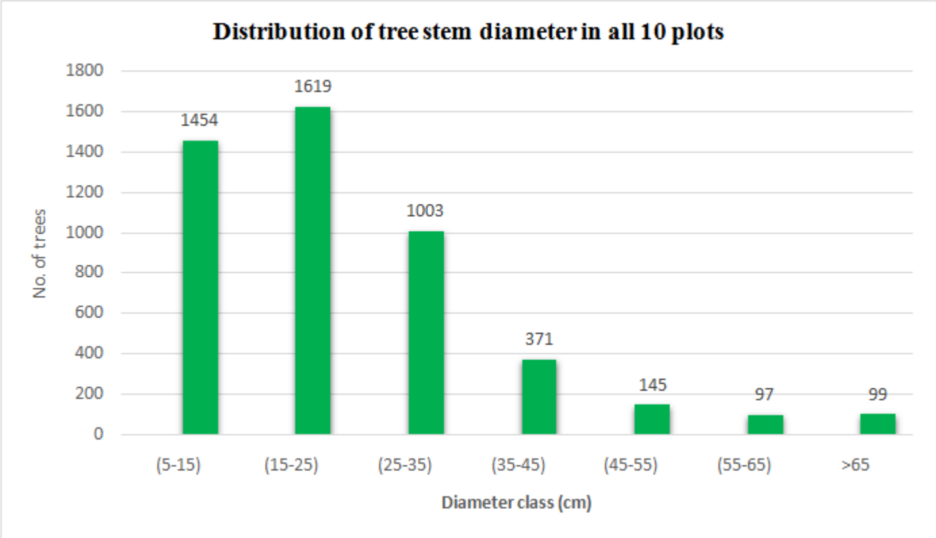


Fig. 7. Distribution of overall tree diameter classes in all ten permanent plots

Plots 7 and 8 also exhibit a dominance of mid-range height classes. Plot 7 peaks at 174 trees in the 12–15 m class, with moderate contributions from the 9–12 m and 15–18 m classes. Plot 8 shows 123 trees in the 12–15 m class and a gradual decrease across other height classes. Plot 9 is characterised by 132 trees in the 12–15 m class, followed by 80 and 68 trees in the 9–12 m and 15–18 m classes, respectively. Lastly, Plot 10 displays a similar trend, with 113 trees in the 12–15 m class and a gradual decrease in both lower and higher height classes.

The graph represents the overall distribution of tree heights across all ten inventoried plots. The majority of trees are concentrated in the 12–15 m height class, with 1,250 trees, followed by the 9–12 m (1,080 trees) and 6–9 m (1,065 trees) classes. These three height classes together make up the largest portion of the forest, indicating a predominance of medium-sized trees. The 15–18 m class has 745 trees and the taller height classes (18–21 m, 21–24 and>24 m) show a noticeable decline, with 437, 101and 20 trees, respectively. The 3–6 m class also has relatively fewer trees (122). This overall distribution suggests that the forest is primarily made up of trees in intermediate growth stages, with few very young or mature trees. The results indicate a forest structure that is likely in a phase of growth, with a significant proportion of trees yet to reach their full height potential and fewer older, tall trees (Fig. 5).

The tree distribution across diameter classes in ten permanent plots. In Plot 1, the highest number of trees is in the 10–20 cm diameter class (approximately 200), with numbers gradually declining across larger diameter classes and fewer than five trees in the >60 cm class. Similarly, in Plot 2, the 10–20 cm class dominates with about 160 trees, while larger diameter classes show progressively fewer trees, indicating a regenerating forest structure. Plot 3 also exhibits a similar trend, with around 150 trees in the 10–20 cm class, followed by a sharp decline in larger classes, indicating early regeneration. In Plot 4, the 10–20 cm diameter class has about 120 trees and the numbers steadily decrease, with fewer than 10 trees in the >50 cm classes, suggesting a comparable regeneration stage but with fewer younger trees.

Plot 5 has around 140 trees in the 10–20 cm class the numbers drop to around 70 in the 20–30 cm class, with very few trees beyond the 40 cm diameter, indicating a regenerating forest with limited older trees. In Plot 6, the 10–20 cm diameter class has approximately 110 trees, with numbers decreasing to around 60 in the 20–30 cm class and continuing to decline across larger diameter classes. In Plots 7 and 8, a similar pattern is observed, with the 10–20 cm diameter class being dominant, followed by a steady decline in the number of trees as the diameter increases. Plot 9 shows a slightly different trend, with 128 trees in the 10–20 cm class and relatively higher numbers in the medium diameter classes (e.g., 86 in 20–30 cm and 46 in 30–40 cm), suggesting a mix of younger and older trees. Finally, Plot 10 has 154 trees in the smallest class, with a noticeable presence of trees in medium and larger diameter classes, indicating a more mature forest structure than other plots (Fig. 6).

The tree diameter distribution across all ten permanent plots highlights a forest ecosystem predominantly in a regenerating phase. Most plots exhibit a reverse J-shaped diameter distribution, with a higher concentration of trees in smaller diameter classes (5–15 cm and 15–25 cm) and a progressively lower number in larger diameter classes (>35 cm). Collectively, the overall distribution indicates that the majority of trees fall within the smaller and medium diameter classes, with 1619 trees in the 15–25 cm range and 1454 in the 5–15 cm range, compared to only 99 trees in the >65 cm class.The pattern reflects active regeneration and recruitment processes within the forest, as younger trees dominate most plots. Several factors could contribute to this structure, including favourable climatic and soil conditions for seedling establishment, successful natural regeneration and low levels of anthropogenic disturbance, which allow younger trees to flourish. Additionally, the relatively lower numbers of large-diameter trees suggest a limited representation of older or mature trees, possibly due to historical disturbances, selective logging, or natural tree mortality (Fig. 7).

The variation between plots, such as the slightly higher number of larger-diameter trees in plots 9 and 10, indicates localized differences in stand dynamics, management interventions, or site-specific ecological conditions. Overall, the forest appears to be in a healthy regenerating state, with a balanced structure that ensures sustainability if protected from further disturbances. For long-term stability, conservation measures should focus on protecting larger trees for seed production and maintaining the ecological balance of these forests.

3.2 Discussion

The average height of the trees across different vegetation types in the Yellapur forest division is presented in Table 1. The results showed that the higher average tree height was recorded in the moist deciduous forest (15.25 m) followed by semi evergreen (12.39 m) and the least was found in dry deciduous forest (11.76 m). The dry deciduous forests experience lower rainfall and prolonged dry periods. This limited water availability restricts the growth of trees, resulting in shorter and less dense forests. The intense competition for sunlight within dense vegetation often compels trees to grow taller. This adaptive strategy, driven by the plant's photosynthetic capacity, allows for optimal light interception (Kumar et al., 2011). The maximum basal area (31.44 m^2/ha) was found in semi evergreen forest due to a greater number of buttressed trees and larger trees. The volume was also found maximum in semi evergreen forest (342.35 m^3/ha). The Semi-evergreen forests often have a higher proportion of larger, mature trees compared to other forest types. These larger trees contribute more to the basal area and volume. Wood specific gravity plays a vital role in the conversion of forest volume data into biomass and is known to be significantly influenced by factors such as location, climate and potentially management practices (Ketterings et al., 2001).

The findings of this study align with earlier research that emphasizes the importance of tree diameter distribution as a critical indicator of forest structure, dynamics and regeneration. The observed reverse J-shaped distribution in the Yellapur Forest Division, with the majority of trees in smaller diameter classes, reflects a regenerating forest, consistent with findings by Rubin et al. (2006), who highlighted that such a pattern signifies active recruitment in forests with minimal disturbances. The dominance of trees in the 5–15 cm and 15–25 cm classes underscore the forest's ability to sustain a healthy recruitment cycle, ensuring long-term structural stability.

The lower representation of larger-diameter trees (>45 cm) could be attributed to factors such as selective logging, as suggested by Singh et al. (2018), or natural mortality due to competition and ageing. This imbalance may affect the forest's ecological functionality, as larger trees are known to play a vital role in carbon sequestration and biodiversity conservation (Pond & Froese, 2015). Furthermore, localized variations observed between plots, such as higher numbers of medium to large-diameter trees in plots 9 and 10, might be explained by differences in site conditions or past management interventions, as discussed by Hunter et al. (2013). Addressing these challenges will require focused management strategies, including the protection of mature trees and minimizing human interference, to preserve the forest's ecological balance and ensure its sustainable use for future generations.

The differences observed between plots emphasize the need for more targeted forest management practices. Some areas of the forest, particularly those with higher numbers of larger trees, might benefit from better protection or less disturbance, while others may be experiencing more pressure from human activities or natural factors. To address the challenges of regenerating forests with a lack of mature trees, it is essential to focus on long-term conservation strategies that include the protection of existing large trees, controlling human-induced disturbances and promoting the growth of young trees into larger diameter classes. Sustainable management practices that balance regeneration with the preservation of older trees are crucial for ensuring the continued ecological health and resilience of the Yellapur Forest Division. The volume was also found maximum in semi evergreen forest (342.35 m^3/ha) and minimum was found in moist deciduous forest due to less basal area. The Semi-evergreen forests often have a higher proportion of larger, mature trees compared to other forest types. These larger trees contribute more to the basal area and volume. The results are in line with Rachana and Koppad (2024) and also highest volume in semi evergreen forest is due to higher moisture content availability in trees of semi evergreen forest (Rachana and Koppad, 2023).

4. CONCLUSION

The study of the Yellapur forest division reveals a highly diverse and heterogeneous forest ecosystem, with 4,680 individual trees belonging to 82 species recorded across 10 permanent plots. Tectona grandis, Terminalia paniculata and Myristica malabarica were the most dominant species, with considerable variation in their distribution across plots. Forest structure analysis showed a predominance of medium-sized trees in the 12–15 m height class and the 10–20 cm diameter class, reflecting a regenerating forest with active recruitment and growth. Differences in forest types highlighted the superior basal area and volume in semi-evergreen forests, while moist deciduous forests exhibited greater tree height. The overall findings suggest that the forest is in a healthy state of regeneration, with younger trees dominating most plots and limited representation of mature trees. Conservation efforts should focus on preserving larger trees and reducing disturbances to ensure long-term ecological sustainability.

The height and diameter class distributions indicate that the forest is in an intermediate growth phase, characterized by a substantial proportion of medium-sized trees and active natural regeneration. However, the limited presence of older, larger trees points to possible past disturbances, such as selective logging or natural mortality. Variations between plots, such as the higher number of mature trees in plots 9 and 10, underscore localized differences in ecological conditions and management histories. These findings emphasize the importance of site-specific conservation strategies to maintain biodiversity and promote sustainable forest dynamics. Protecting existing mature trees while encouraging regeneration will be crucial for maintaining ecological balance and ensuring the forest's role in carbon sequestration and habitat conservation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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