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Evaluating Annual Growth Dynamics Across Forest Types Using Permanent Sample Plots in Yellapur Forest Division, Karnataka, 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

Annual tree increment requires repeated assessments on permanent sample plots, which are crucial for evaluating changes in tree size and stem volume. These plots enable long-term monitoring to estimate timber production and analyse growth dynamics. This study examines the current annual increment of growth parameters like tree height, GBH, basal area, and volume in dry, moist deciduous, and semi-evergreen forests within the Yellapur Forest Division, Uttara

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Kannada, Karnataka. The Permanent sample plots were utilized to assess growth patterns across various forest types. Total of nine one-hectare permanent plots were established across the forest types with three plots laid in each forest type and divided into subplots of size 33.33m× 33.33m and data were collected for tree parameters including girth at breast height and tree height using digital laser hypsometer. Measurements were conducted over two consecutive years i.e., in 2022 and repeated in 2023 to calculate CAI. The results revealed significant variation among forest types. Moist deciduous forests exhibited the highest CAI in height (0.45 m/year) and GBH (1.84 cm/year), while dry deciduous forests showed lower increments due to water stress and leafless periods. Semi-evergreen forests, although with dense canopy competition, demonstrated moderate growth rates. The basal area increment was highest in moist deciduous forests (0.93 m^2/ha/year), reflecting favourable moisture and nutrient conditions. The tree volume increased significantly in moist deciduous forests (22.80 m^3/ha/year). Variations in basal area and volume suggest that environmental conditions and anthropogenic activities, such as litter collection, impacted growth across forest types. These insights are critical for developing sustainable forest management practices and mitigating the impact of anthropogenic activities on forest ecosystems. This research underscores the importance of monitoring permanent plots to understand forest dynamics and supports sustainable forest management strategies.

Keywords: Annual increment; forest inventory; growth patterns; permanent plot.

1. INTRODUCTION

Forest resources play a vital role in sustaining life on Earth, providing essential ecosystem services that support human well-being and quality of life. As self-regenerating ecological units, forests are crucial for maintaining ecological balance, making it essential to study their growth patterns to ensure effective conservation (Rachana and Koppad, 2023). Conducting long-term studies to understand patterns of plant growth is a fundamental objective of ecological research in the dynamic ecosystems of tropical forests. In the recent times tropical forests of Asia, especially Western and Eastern ghats of India are vanishing at a faster rate due to various anthropogenic activities and these forests are replaced by secondary species (Parthasarathy, 1999). The main goal of ecological studies in tropical forest is to understand the pattern of plant growth which is dynamic. Over the past few decades, there has been a discernible increase in the growth rates of tropical forests (Vivek *et al*., 2016). Forest inventories are conducted to evaluate the growing stock and other key parameters of forests, including standing volume, biomass, carbon stock, regeneration status, population dynamics, and structural characteristics (Rachana and Koppad, 2024). The term "increment" in forest management typically only relates to growth in volume and that too of crops rather than individual trees. The term "increment" refers to the growth that a tree or crop experiences as it becomes older. It could be expressed in terms of a physical growth in the amount of wood present or it could refer to any of the dimensions, basal area, volume, quality, price or value that rise with age. By measuring or evaluating these parameters at the start and end of any given period the increment can be calculated (Girish and Hanumantha, 2020). It was indicated by Tomter *et al*. (2016) that the ability to estimate increment in an accurate manner is more important and necessary. The various components of annual increment can only be accurately and completely measured repeatedly on permanent sample plots. In order to estimate timber production data, permanent sample plots are typically adopted to evaluate changes in tree size and stem volume. Identifying the primary constraint on tree growth remains a complex challenge due to the interplay of multiple factors in the ecosystem (Eitzel *et al*., 2013). Therefore, implementing regular measurement of permanent monitoring plots at defined time interval over an extended durations is essential for comprehensively investigating variations occurring at the individual, species and community levels (Tamilselvan *et al*., 2021). Through repeated measurements of permanent plots across tropical regions have indicated a notable upsurge in tree growth over the past few decades in numerous cases (Lewis *et al.,* 2004; Pandian and Parthasarathy, 2017). By employing permanent sample plots for annual growth increment assessments, the study contributes to the long-term monitoring of forest ecosystems, a key aspect of sustainable forest management. The findings, which highlight variations in growth parameters across forest types, offer valuable information for understanding the impact of environmental factors and anthropogenic activities on forest productivity. This research supports the development of evidence-based conservation strategies and informs policy decisions aimed at enhancing forest health and resilience. But there are few studies on growth pattern and annual increment studies across different forest types in Uttara Kannada district, Karnataka. In this context the present study was conducted in dry, moist deciduous and semi evergreen forests of Yellapur forest division with the aim to assess the current annual increment of various growth parameters of trees in different forests.

2. MATERIALS AND METHODS

The study was conducted across various forest types within the Yellapur Forest Division of Uttara Kannada district, Karnataka. This division encompasses dry deciduous forests in the eastern region, moist deciduous forests in the central part and semi-evergreen forests in the western region. A reconnaissance survey was undertaken to identify specific sample site locations for ground inventory data collection.

To facilitate data collection, permanent plots of 1 hectare (100 m × 100 m) were established across the forest types, with three plots laid in each forest type *viz.,* dry deciduous, moist deciduous, and semi-evergreen forest resulting in a total of nine plots. Each hectare plot was further divided into nine subplots, each measuring 33.33 m × 33.33 m, delineated using nylon ropes. From these, seven subplots were randomly selected for enumeration across the three permanent plots within each forest type (Plate 1).

All trees within the selected subplots with a girth at breast height (GBH) of ≥30 cm was marked with unique numbers and permanent paint (Plate 2), following the method described by Tamilselvan *et al.* (2021). The point of measurement in tree was marked using permanent paint for the repeated measurement of tree for the incremental study of different growth parameters over the years (Plate 3). Measurements for GBH and tree height were recorded for each tree within the subplots. Tree height was measured using a digital laser hypsometer, while GBH was measured using a measuring tape.

To assess the increment, the initial enumeration was carried out in the year 2022 and to determine the increment in different forest types the re-inventory process was carried out in the year 2023 for various quantitative parameters like height and GBH.

Current annual increment in various growth parameters namely tree height(m), GBH (cm), basal area, tree volume was computed using the formula. The current annual increment in volume was calculated using following formula:

Current Annual Increment = $V_{(n+1)} - V_n$ (Girish and Hanumantha, 2020)

Where,

$V_{(n+1)}$- The volume produced in the year 2023
V_n -The volume produced in the year 2022

Based on the initial observations on respective parameter, the observations were recorded twice during the experiment *i.e.,* at the initial year (2022) and after 12-month period (in the year 2023).

Plate 1. Establishment of permanent plot

Plate 2. Marking by permanent paint

Plate 3. Marking the point of measurement

Table 1. Current annual increment in height and GBH of different forest types in Yellapur forest division of Uttara Kannada district from the year 2022 to 2023

Forest type	Average height(m)			Average GBH (cm)		
	2022	2023	CAI (m yr^{-1})	2022	2023	CAI (cm yr^{-1})
Dry deciduous	11.93	12.26	0.33	80.34	81.04	0.70
Moist deciduous	13.61	14.06	0.45	86.48	88.33	1.84
Semi evergreen	12.05	12.35	0.30	84.27	85.0	0.72
SEm (±)	0.6	0.64	0.10	5.65	5.81	0.38
CD @5%	NS	NS	NS	NS	NS	NS

**Figures in column are GBH- Girth at breast height, CAI- Current Annual Increment, NS = non-significant, CD = Critical difference, SEm-Standard error of mean*

Table 2. Current annual increment in basal area and volume in different forest types of Yellapur forest division of Uttara Kannada district from the year 2022 to 2023

Forest type	Basal area (m^2 ha^{-1})			Volume (m^3 ha^{-1})		
	2022	2023	CAI m^2 ha^{-1} yr^{-1}	2022	2023	CAI m^3 ha^{-1} yr^{-1}
Dry deciduous	27.25	27.66	0.41	269.86	280.41	10.55
Moist deciduous	32.14	33.07	0.93	400.36	423.16	22.80
Semi evergreen	47.21	47.73	0.52	612.33	626.82	14.48
SEm (±)	2.13	2.2	0.22	27.32	29.53	4.73
CD @5%	6.66	6.87	NS	85.13	92.01	NS

** Figures in column are CAI- Current Annual Increment, NS = Non-Significant, CD = Critical difference, SEm-Standard error of mean*

3. RESULTS AND DISCUSSION

The overall tree height which is crucial factor in calculating volume. The maximum height was observed in moist deciduous forest (13.61m) and the lowest was recorded from dry deciduous forest (11.93 m) during the year 2022. After a year *i.e.,* in 2023 the highest (14.06 m) and lowest (12.26 m) was noticed from same forest type as in the year 2022. Moist deciduous forests have higher moisture levels due to their proximity to areas with greater rainfall, unlike dry deciduous forests, which face more water stress. The highest net change in the height measurement after one year is observed in moist deciduous forest with CAI of 0.45 m yr^{-1} followed by dry deciduous forest i.e., 0.33 cm yr^{-1} (Table 1). The change in height measurements across vegetation types primarily depends on favorable growing conditions. The average height in semi evergreen forest is higher than dry deciduous forest but the net change in height measurement is more in dry deciduous than in semi evergreen, it can be due to closure canopy cover and crown competition in the semi evergreen forest type. Overall height increment is more in moist deciduous forest. It could be due to the higher photosynthetic structure of plant.

There was no significant variation in GBH measurement across different vegetation type in both the year. The maximum net change in GBH was observed in moist deciduous forest (1.84 cm yr^{-1}) followed by semi evergreen forest (0.72 cm yr^{-1}). The minimum change was seen in dry deciduous forest (0.70 cm yr^{-1}) which could be due to moisture stress and short-term leaf less period. The present results are in comparable with Tamilselvan *et al.* (2021) who conducted a study in permanent plots of moist evergreen forest in Eastern Ghats, reported that the growth in terms of girth increment of tree species ranged from 0.67 cm $yr^{-1}$to 1.25 cm yr^{-1}, where GBH increment of 0.7 cm yr^{-1} was observed in dry deciduous forest and increment of 0.72 cm yr^{-1} in semi evergreen forest of current study. And also, study is in line with the Pandian and Parthasarathy (2017) who reported a mean annual girth increment of tree species ranging from 0.05 ± 0.18 to 3.53 ± 1.17 cm yr^{-1} across the four study sites in tropical dry evergreen forest along the coromandel coast of India, where the present study showed CAI of 1.84 cm yr^{-1} in moist deciduous forest. The type of tree species prevalent in these forests can be credited for the rise in girth. When compared to other forests, the reported values of current annual girth increment in different forest types of Yellapur forest division which range from 0.70 to 18.4 cm yr^{-1} exceed than those observed in various other regions. For instance, in central Brazil, the mean annual girth increment was found to be 0.25 cm yr^{-1} (Felfili, 1995), in Puerto Rico, it ranged from 0.11 to 0.65 cm yr^{-1} (Schmidt and Weaver 1981), in northwestern Costa Rica, it ranged from 0.26 to 0.78 cm yr^{-1} (Chapman and Chapman 1990) and in Uganda, it was recorded as 0.44 cm yr^{-1} (Taylor *et al.,*1996). An important factor contributing to increased tree growth is the elevation in atmospheric CO_2 concentration. This rise in CO_2 levels can lead to higher plant photosynthetic rates and improved water use efficiency, thereby promoting enhanced tree growth (Holtum and Winter, 2010; Clark *et al*., 2010). The higher girth increment values observed in the different forest type of Yellapur forest division suggest potentially faster growth rates for tree species in this particular region.

Basal area per hectare across forest types differed significantly over different years. The basal area values in the year 2022 varied from 27.25 m^2 ha^{-1} in dry deciduous forest to 47.21 m^2 ha^{-1} in semi evergreen forest type of Yellapur forest division. During the year 2023 highest basal area per hectare was recorded in semi evergreen forest (47.73 m^2 ha^{-1}) and lowest in dry deciduous forest (27.66 m^2 ha^{-1}). The moist deciduous forest showed highest net change in basal area (0.93 m^2 ha^{-1} yr^{-1}) followed by semi evergreen forest (0.52 m^2 ha^{-1} yr^{-1}) and lowest CAI was given by dry deciduous forest (0.41 m^2 ha^{-1} yr^{-1}). The increment in the girth of tree species in different forest types influence on increase in basal area of trees in different forest types. Bhat *et al*. (2000) reported that the basal area ranged from 21.59 to 32.62 m^2 ha^{-1} in moist deciduous forest and 7.69 to 32.13 m^2 ha^{-1} in evergreen forest which is higher than the current study. The basal area found to have high growth of 76.23 per cent in evergreen forest zone and also found to be decreased with the increasing human disturbance as revealed by Bhat *et al*. (2000) who conducted decadal changes evergreen and moist deciduous forest zones of tropical rain forests of Uttara Kannada district. The basal area increment in the current study was influenced by anthropogenic activities such as collection of litter from the dry deciduous forest types which leads to less organic matter accumulation in the soil which might be reason for the minimum increment of basal area in dry deciduous forest. The basal area has been increased by 1.6 per cent in tropical dry evergreen forest (Pandian and Parthasarathy, 2017). Basal area of evergreen forest of Western Ghats of India was found to be 33.7 to 48.7 m^2 ha^{-1} (Pascal, 1992) and these results are found to be lesser than the current study which reported 47.21 m^2 ha^{-1} in semi evergreen forest. The net change in the basal area across different forest types may be due to availability of maximum nutrients and moisture in semi evergreen forests and moist deciduous forest types, which influence on basal area increment. The basal area of teak plantation ranged from 29.02 to 41.78 m^2 ha^{-1} was reported by Swamy *et al*. (2010) which is higher than the present study indicating 27.25 m^2 ha^{-1} basal area in dry deciduous forest.

The volume in the year 2022 ranged from 269.86 m^3 ha^{-1} in the dry deciduous forest to 612.33 m^3 ha^{-1} in the semi-evergreen forest of the Yellapur forest division. During the year 2023 highest volume was recorded in semi evergreen forest (626.82 m^3 ha^{-1}) and lowest in dry deciduous forest (280.41 m^3 ha^{-1}). Among the different forest types, the moist deciduous forest exhibited the highest net change in volume (22.80 m^3 ha^{-1}), followed by the semi-evergreen forest (14.48 m^3 ha^{-1}), while the dry deciduous forest showed the lowest net change (10.55m^3 ha^{-1} yr^{-1}). The net maximum change in the volume was observed in moist deciduous forest (22.80 m^3 ha^{-1} yr^{-1}) followed by semi evergreen (14.48 m^3 ha^{-1} yr^{-1}) which was attributed to increase in girth and basal area in respective forest types. The maximum volume in the semi evergreen is due to increased productivity of soil and more accumulation of litter. The higher basal area, tree height and tapering of the trees influence on volume production in the trees across different vegetation.

4. CONCLUSION

The study on annual growth increments in the forests of Yellapur Forest Division highlights the significant variations in growth dynamics across different forest types. Moist deciduous forests demonstrated the highest increments in tree height, girth at breast height (GBH), basal area, and volume, indicating favorable moisture and nutrient conditions. Semi-evergreen forests exhibited moderate growth due to canopy competition, while dry deciduous forests recorded lower increments, largely attributed to water stress and leafless periods. The results emphasize the critical role of environmental factors and anthropogenic activities, such as litter collection, in influencing forest growth. This research underscores the importance of permanent sample plots for long-term monitoring to better understand forest dynamics and support sustainable forest management. These findings provide valuable insights for policymakers and forest managers aiming to enhance productivity and conservation efforts across diverse forest ecosystems.

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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