

# Diversity and Population Structure of Tree Species in a Protected Area on the Southeastern Coast of Bangladesh

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## Research Article

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# Diversity and Population Structure of Tree Species in a Protected Area on the Southeastern Coast of Bangladesh

## Abstract

Inani National Park (INP) is a protected area and hosts a variety of threatened and endangered species. A wide array of anthropogenic issues, including the influx of Rohingya refugees into the Cox's Bazar region, has placed enormous pressure on the forests of INP. This study aimed to assess the composition, structure and diversity of the forest to provide a scientific basis for conservation and sustainable forest management, adopting stratified random sampling where four distinct strata were defined as- Shrub with Scattered trees, Hill Forest, Forest Plantation, and 'Others' category. Results of the study show that INP hosts a diverse tree community, comprising 455 individual trees from 66 species and 33 families, documented across 131 sampling plots (each 1,134.57 m<sup>2</sup>). The overall tree density was 160.813 trees per hectare. *Areca catechu* emerged as the most dominant species, with a relative density of 28.35%.

Diversity indices revealed a moderately diverse ecosystem with varying species distribution. The Shannon Diversity Index (H) was 3.137, with the 'Shrub with Scattered trees' stratum exhibiting the highest diversity (H = 3.572). Simpson's Diversity Index (D = 0.108) indicated high species diversity, while canopy cover varied significantly across sites, averaging 45.19%.

Despite its ecological significance, INP faces increasing threats from large-scale disturbances that have resulted in the loss of approximately 6,000 acres of forest. The presence of invasive species, particularly *Acacia auriculiformis*, suggests ongoing ecological imbalance and the need for active restoration efforts. These findings provide critical insights for biodiversity conservation and long-term ecosystem resilience in INP.

**Keywords:** Biodiversity, Species richness, Important value index, National Park, Tree density, Conservation.

## 1.Introduction

Biodiversity is a cornerstone of ecosystem health, productivity, and resilience, particularly under growing pressures from global climate change and natural disasters. Greater biological diversity increases the probability that certain species will possess adaptive traits necessary to endure environmental perturbations (Li & Wei, 2024; Sharashy, 2022). However, human activities continue to profoundly reshape ecological communities, accelerating species invasions and extinctions across scales—from local landscapes to global biomes (Butchart et al., 2010; Hooper et al., 2005; Meyer et al., 2016).

Beyond ethical and aesthetic dimensions, biodiversity loss has far-reaching implications for ecosystem functions and the provisioning of essential services upon which human societies depend (Hooper et al., 2005; IPBES, 2019). The Convention on Biological Diversity (CBD) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) emphasize biodiversity not only as a collection of species but also in terms of genetic and functional variation that ensures ecosystem resilience. The IPBES conceptual framework highlights "nature's contributions to people" and the necessity of safeguarding biodiversity for future generations (Bocchi, 2024; Díaz et al., 2018)

Ecological diversity plays a critical role in maintaining ecosystem stability (Daly et al., 2018), and its continued erosion threatens the delivery of services such as nutrient cycling, climate regulation, and pollination (Cardinale et al., 2012; Naeem et al., 2012). Since the 1992 Earth Summit, a growing body of research has demonstrated the cascading effects of biodiversity loss on ecosystem functionality and societal wellbeing.

Natural reserve forests are particularly important for biodiversity conservation, as they harbor a high richness of endemic and threatened flora and fauna (Chen & Tang, 2016; Hawkins, 2017; John et al., 2020; Kutnar et al., 2019; Lacerda & Kellermann, 2019). Defined as complex biotic communities, forests comprise diverse plant and animal assemblages interacting with abiotic factors like soil, topography, and climate (Young & Giese, 2003). These ecosystems provide critical habitats while delivering essential ecological services to human populations (Brockerhoff et al., 2017; Li & Wei, 2024).

However, various anthropogenic pressures—including illegal logging, overgrazing, agricultural expansion, and urbanization—pose significant threats to forest biodiversity and structural integrity (Usman et al., 2022). The distribution and composition of tree species in these environments are further shaped by environmental gradients such as moisture, temperature, nutrient availability, and geological characteristics (M. A. Hossain et al., 2019).

Preserving biodiversity in forested landscapes is not only a conservation priority but also a prerequisite for sustaining the ecological processes that support life on Earth.

Tropical regions support an extraordinary range of biodiversity, harboring a significant proportion of the world's plant and animal species. However, widespread deforestation and land-use transformation are causing severe losses in genetic, species, and ecosystem diversity, particularly in biodiversity hotspots. Recent global studies underscore that

even degraded forests retain substantial ecological value and biodiversity potential and therefore should be prioritized for protection rather than conversion to plantations (Ewers et al., 2024; University of Oxford, 2025). To mitigate biodiversity loss, accurate assessment of plant diversity is essential for maintaining ecosystem functionality and informing sustainable resource management. In this context, non-parametric estimators have proven useful for evaluating species richness and diversity, contributing to conservation planning (K. Burnham & Overton, 1979; K. P. Burnham & Overton, 1978; Chao, 1984, 1987).

Bangladesh, situated within the Indo-Myanmar biodiversity hotspot, is home to approximately 7,000 endemic plant species, making it one of the most biologically diverse regions globally (Mittermeier et al., 1998). Yet its forest ecosystems are increasingly vulnerable to biotic pressures and unsustainable land-use practices, leading to the degradation of native species and habitats (M. K. Hossain, 2001; Muhammed et al., 2008; M. H. Rahman et al., 2011). The country's forest cover has declined to approximately 2.53 million hectares—just 17.5% of its total land area—alongside an estimated growing stock of 30 million m<sup>3</sup> and total biomass of 63 million tons (Altrell et al., 2007). These figures highlight the need for urgent and science-based conservation measures.

Further compounding these challenges, the displacement of Rohingya refugees into the Cox's Bazar region has exerted acute environmental pressures on forested areas, particularly within Inani National Park (INP). The conversion of forestland for settlement infrastructure and fuelwood collection has escalated deforestation and habitat fragmentation, a trend verified by satellite-based assessments of forest degradation in the Cox's Bazar–Teknaf Peninsula (Hasan et al., 2021; Hassan et al., 2023; Sarkar et al., 2023). These developments underscore the critical need to monitor ecological change in this region and to formulate targeted conservation interventions.

Understanding plant biodiversity is central to evaluating forest dynamics, species interactions, and processes such as nutrient cycling and carbon sequestration (M. A. Hossain et al., 2013). Global research has consistently affirmed biodiversity's role in sustaining ecosystem functions and enhancing ecological resilience (Hooper et al., 2005). Vegetation structure and composition are key determinants of ecosystem stability and are vital for guiding sustainable management (Nath et al., 2000), while functional diversity offers an important dimension of ecological assessment (Pakeman, 2011).

Bangladesh has established several protected areas to conserve its biological resources, and numerous studies have investigated plant diversity within these zones (Motaleb & Hossain, 2011; S. M. M. Uddin & Misbahuzzaman, 2007). However, ecologically critical areas such as INP remain underexplored in terms of tree species diversity, regeneration status, and population structure. Inani National Park is particularly significant not only for its plant richness but also as habitat for numerous threatened mammals, including Asian elephants (*Elephas maximus*), leopards (*Panthera pardus*), and Western hoolock gibbons (*Hoolock hoolock*), the latter recently documented with declining population trends in this park (Dampha et al., 2022; Kabir et al., 2017; M. M. H. Khan, 2018).

Trees serve as structural pillars in tropical ecosystems, supporting wildlife, regulating ecological processes, and offering key ecosystem services (Cannon et al., 1998; Huston, 1994). Yet deforestation, resource overexploitation, and habitat fragmentation continue to drive a decline in tree populations across Bangladesh (M. K. Hossain, 2001; M.

M. Rahman & Ahmad, 2000). The greater Chittagong region, encompassing INP, is a floristically rich area containing 2,260 of Bangladesh's 3,611 known flowering plant species (S. Khan et al., 2008; M. A. Rahman et al., 2019). However, a lack of detailed data on species composition and regeneration dynamics restricts effective conservation planning.

Biodiversity assessment provides a scientific foundation for monitoring and managing ecosystems by quantifying species richness, evenness, and heterogeneity (Cardinale et al., 2012). These indices are crucial in identifying extinction risk, assessing the health of ecological communities, and informing policy. Commonly applied diversity measures such as the Shannon-Wiener index and Simpson index offer critical insights into forest viability and ecosystem resilience (Backéus et al., 2006; Banda et al., 2006; Stanisci et al., 2005), particularly when analyzed in conjunction with regeneration and population structure (Verma et al., 1999; Wyatt-Smith, 1987).

Species diversity in tropical forests is shaped by environmental heterogeneity, species interactions, topography, and soil conditions (Ram et al., 2004). Understanding these patterns is imperative for restoring degraded landscapes and curbing biodiversity loss. Recent studies emphasize the importance of assessing the current status of tree species diversity, composition, and abundance to improve management strategies and prioritize conservation actions (Jeje et al., 2021; University of Oxford, 2025).

The present study aims to assess tree species diversity, population structure, and regeneration status in Inani National Park, located in southeastern Bangladesh. By addressing existing knowledge gaps, this research seeks to provide an empirical basis for long-term biodiversity conservation, sustainable forest management, and ecosystem restoration in the Indo-Myanmar biodiversity hotspot.

## **2. Materials and Methods**

### ***2.1 Study Area***

The Cox's Bazar Forest Division, covering 940.58 sq. km (or 94,058 ha), is one of Bangladesh's most resource-rich forest regions. It was reorganized into Cox's Bazar North and South Forest Divisions on July 1, 2001, with the South Division covering areas from the Baghkhali River to the Bay of Bengal, including Teknaf (13,859.74 ha), Ukhiya (18,850.96 ha), and parts of Ramu (910,569.87 ha) and Cox's Bazar Sadar Upazila (894.34 ha). Inani National Park (INP), also known as Inani National Park, is a designated Protected Area (PA) covering around 7,085.16 hectares, located 26 kilometers south of Cox's Bazar (Sarker & Røskraft, 2011). Officially declared a national park on April 15, 2019, under Section 17 of the Bangladesh Wildlife (Conservation and Security) Act, 2012, it is home to the critically endangered Western Hoolock Gibbon (Feeroz, 2016). Geographically situated between 21°6'-21°17' North latitude and 92°3'-92°7' East longitude, INP is bordered by Himchari National Park to the north, Teknaf Wildlife Sanctuary to the south, the Bay of Bengal to the west, and the Teknaf-Cox's Bazar highway to the east (Figure 1) (M. Z. Uddin et al., 2013). The park contains degraded evergreen to semi-evergreen forests, including the Swankhali, Inani, Jalia

Palong, and Raja Palong Beats within the Inani Range, and Dochori, Thainkhali, and Musarkhola Beats in the Ukhiya Range (Feeroz, 2016). The park's topography is marked by gently sloping hills formed by various geological formations, including Pleistocene, Pliocene, Mio-Pliocene, and Miocene sediments, with distinct soil types ranging from clay and loamy soils to sandy soils (A. Hossen & Røskoft, 2021; Miah & Hossain, 2022). Its hydrology is influenced by abundant rainfall, runoff from surrounding hills, and numerous streams and wetlands that provide vital habitats for wildlife (Alam et al., 2014; Das et al., 2018). INP's forest cover is rich in epiphytes, climbers, bamboo, and a variety of flora, including species like Chapalish, Chundul, Pitraj, Uriam, and Toon. The park also hosts critically endangered species such as Asiatic elephants and Western Hoolock Gibbons (Feeroz, 2016).

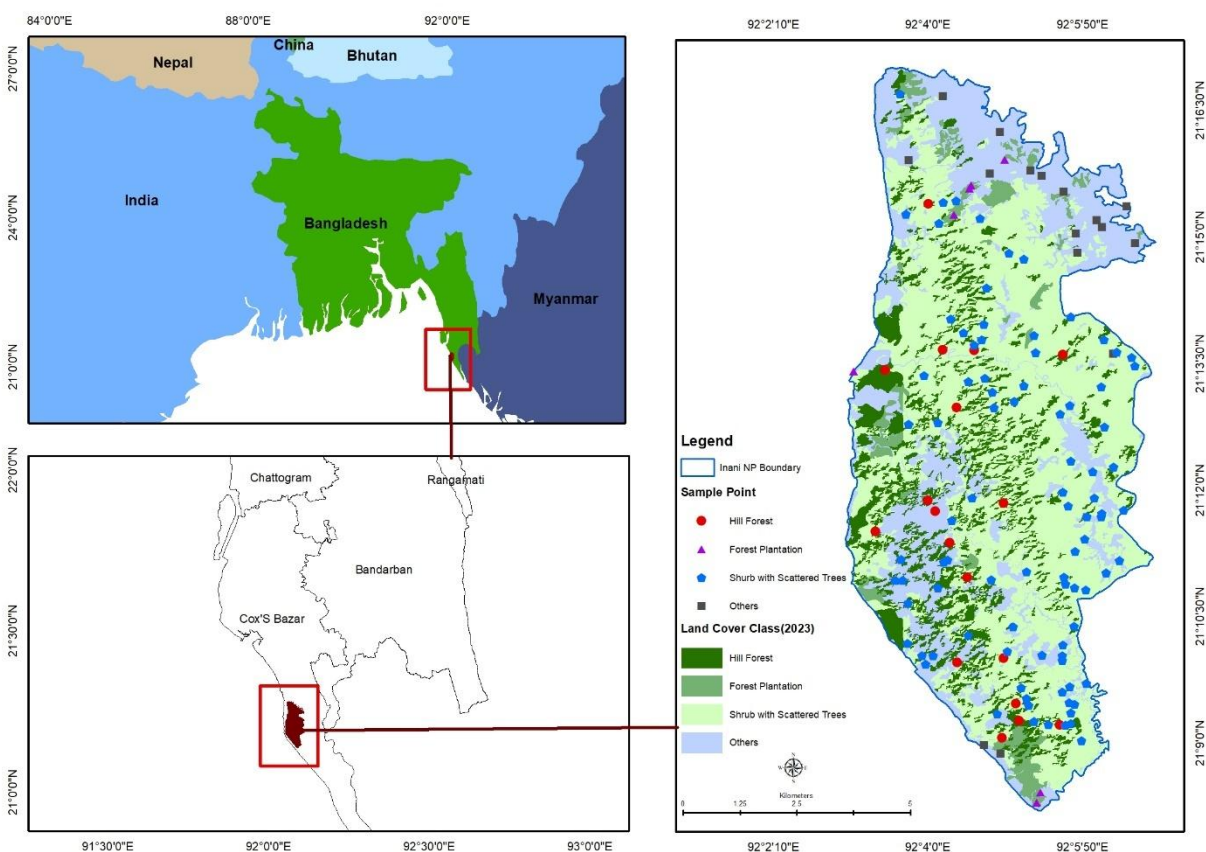


**Figure 1. Study area and Location of the study Sites.**

## ***2.2 Methodology***

In our study, we adopted stratified random sampling method for the vegetation survey. GIS and MS Excel software were used to generate sample points. The National Land Cover Map of 2023 was used for stratification to get a more representative sample clip study area land cover by using ArcGIS Software (Figure 1). There are ten land cover strata or areas found in the study area (Table 1).

**Table 1. Calculation of the strata area.**

| <b>SL No.</b> | <b>Strata/Class</b>                   | <b>Number of Polygon</b> | <b>Minimum Polygon Area (ha)</b> | <b>Maximum Polygon Area (ha)</b> | <b>Average Polygon Area (ha)</b> | <b>Total Area (ha)</b> |
|---------------|---------------------------------------|--------------------------|----------------------------------|----------------------------------|----------------------------------|------------------------|
| 1             | Hill Forest                           | 391                      | 0.50                             | 49.80                            | 2.60                             | 1015.89                |
| 2             | Forest Plantation                     | 38                       | 0.51                             | 55.05                            | 7.61                             | 289.37                 |
| 3             | Shrub with Scattered Trees            | 85                       | 0.51                             | 3325.29                          | 44.54                            | 3785.73                |
| 4             | Orchard and Other Plantations (Trees) | 11                       | 0.53                             | 3.12                             | 1.21                             | 13.29                  |
| 5             | Rural Settlement                      | 84                       | 0.54                             | 165.79                           | 9.42                             | 790.90                 |
| 6             | Rivers and Khals                      | 7                        | 0.59                             | 22.04                            | 6.29                             | 44.04                  |
| 7             | Lake                                  | 1                        | 0.94                             | 0.94                             | 0.94                             | 0.94                   |
| 8             | Fresh Water Aquaculture               | 1                        | 1.17                             | 1.17                             | 1.17                             | 1.17                   |
| 9             | Multiple Crop                         | 58                       | 0.51                             | 34.32                            | 3.31                             | 192.23                 |
| 10            | Single Crop                           | 131                      | 0.51                             | 250.81                           | 5.53                             | 724.78                 |
| <b>Total</b>  |                                       | <b>807</b>               |                                  |                                  |                                  | <b>6858.34</b>         |

The total area of Inani National Park is 6858.34 ha (GIS area) while the area of Hill Forest is 1015.89 ha, Forest Plantation is 289.37 ha, Shrubs with scattered trees is 3785.26 ha and ‘others’ is 1767.35 ha (Table 1). The following equation was used to determine sample size at 90% confidence interval, 10% standard error and coefficient of variance. The coefficient of variance was derived using National Forest Inventory data, 2018 (Government of Bangladesh, 2019) of Cox’s Bazar area.

$$n_{i+1} = \frac{1}{\frac{1}{N} + \left[ \frac{E}{(t_{n_i-1, \alpha/2}) CV} \right]^2}$$

Where,  $n_{i+1}$  is the number of plots needed, N is the population sample size (total acres/plot size in acres), E is the allowable error expressed as a percentage of the mean,  $t_{n_i-1, \alpha/2}$  is the student’s t-value at  $n_i - 1$  df,  $\alpha = 1 - P/100$  is the probability of a type I error for a stated percent confidence of P, and CV is the coefficient of variation.

The total number of sample plots was 126 distributed proportionally among the vegetation strata. The Forest Department, Bangladesh has developed several national land cover maps landsat-based maps for 2000, 2005 and 2010 including a SPOT-6-based map for 2015. Initially The SPOT-6 based land cover map, 2015 was used for stratification and sample interpretation where the plantation stratum covered 80 hectares under two sample plots. However, some afforestation and reforestation initiatives have been taken in the study area through different projects, led to the expansion plantation area up to 285 hectares till the study period. To ensure better representation, five additional plots were added to the plantation stratum. After adding 5 additional plots, the total number of plots were 131 (Table 2). Based on land cover map considering all strata for the purpose the study area had been divided into four major strata had been assigned namely, Hill Forest, Forest Plantation, Shrubs with Scattered trees and Others (Figure 2).

**Table 2. Number of plots employed for each stratum**

| SL. No. | Strata/Class                | Number of Plots |
|---------|-----------------------------|-----------------|
| 1       | Hill Forest                 | 18              |
| 2       | Forest Plantation           | 7               |
| 3       | Shrubs with Scattered trees | 90              |
| 4       | Others                      | 16              |

Additional 5 plots were added to the plantation Strata/Class based on expert opinion to make it more representative.

The following equation was used to calculate the number of plots employed for each stratum:

$$\text{Number of plots employed for 'x' strata} = \frac{\text{Total number of plot}}{\text{Total area of study area}} \times \text{area of 'x' strata}$$

Here, ‘x’= Hill Forest strata or Forest plantation strata or shrubs with scattered trees strata or other strata.

### 2.3 Sample Plot Diagram

A 19 m radius circular plot was used to collect vegetation data. The plot contained three types of circular subplots (Figure 2). Large (L) subplot of 19-meter radius, medium (M) subplot of 8-meter radius and small (S) subplot of 2.5-meter radius. Any tree dbh equal to or above 30 cm was recorded from the L subplot, tree dbh of <30 cm to greater than or equal to 10 cm was recorded from M subplot. Lastly saplings (dbh < 10 m) and seedling are recorded from S subplots (Bangladesh Forest Department (BFD), 2016).

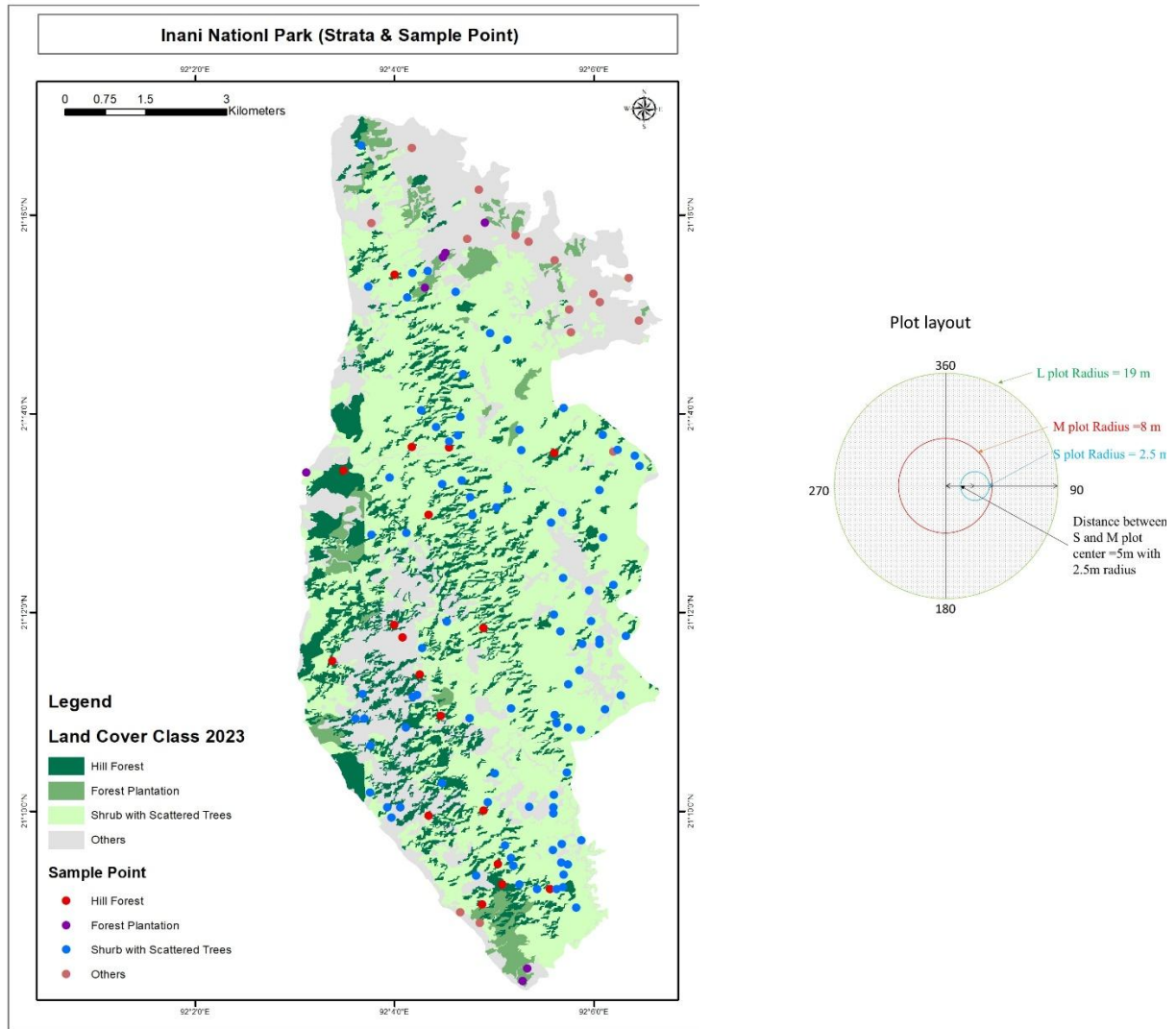


Figure 2. Distribution of Strata & Sample plots.

## 2.4 Data Analysis

For each tree, sapling and regeneration species, phytosociological attributes of species such as- relative density (RD), relative frequency (RF), relative dominance (RDo), relative abundance (RA) and importance value index (IVI) were calculated following the methodologies outlined in Shukla & Chandel (1994), Ulfah et al. (2019), Dallmeier (1992), Misra (1968), Krebs (1989), Shukla & Chandel (1994). Height and DBH were utilized to ascertain the structural composition. Tree counts and diameters were employed to determine the stem density and basal area for all species, following the method described by Shukla & Chandel (1994). In the current study, nine diversity and richness indices were examined to gain a thorough understanding of the diversity of trees, species in the study area. The acquired data was evaluated using Microsoft Excel software and R for quantitative data. The equations used for these analyses are listed below (Table 3).

**Table 3. Specification of phytosociological parameters and biodiversity indices for tree species in the INP.**

| Phytological attributes | Formula                                                                                                  | Note and References                                                                                                                                                                       |
|-------------------------|----------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Density</b>          | $x = \frac{a}{b}$                                                                                        | Where, x is the density (Shukla & Chandel, 1994),<br>a is the total number of individuals of a species in all the plots,<br>b is the total number of plots.                               |
| <b>Frequency</b>        | $y = \frac{c}{b}$                                                                                        | Where, y is the frequency (Shukla & Chandel, 1994),<br>c is the total number of plots in which the species occurs,<br>b is the total number of plots.                                     |
| <b>Abundance</b>        | $z = \frac{a}{c}$                                                                                        | Where, z is the abundance (Shukla & Chandel, 1994),<br>a is the total number of individuals of a species in all the plots,<br>c is the total number of plots in which the species occurs. |
| <b>Basal Area</b>       | $d = \frac{22}{7} * (\frac{dbh}{2})^2$                                                                   | Where, d is the basal area (Ulfah et al., 2019).                                                                                                                                          |
| <b>Basal Area/ha</b>    | $BA = \frac{\sum \frac{22}{7} * \frac{dbh^2}{4}}{\sum Area\ of\ all\ quadrates} * 10000$                 |                                                                                                                                                                                           |
| <b>No. of Trees/ha</b>  | $No.\ of\ Trees/ha = \frac{No.\ of\ individuals\ of\ a\ species}{\sum Area\ of\ all\ quadrates} * 10000$ |                                                                                                                                                                                           |
|                         | $RD = \frac{n}{N} * 100$                                                                                 | Where, RD is relative density (Dallmeier, 1992; Misra, 1968),<br>n is the number of individuals of a species,                                                                             |

|                                          |                                            |                                                                                                                                                                                                                                                           |
|------------------------------------------|--------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                          |                                            | N is the total number of individuals of all the species.                                                                                                                                                                                                  |
| <b>Relative Frequency</b>                | $RF = \frac{y_i}{\sum_{i=1}^k y_i} * 100$  | Where, RF is relative frequency (Dallmeier, 1992; Misra, 1968),<br>$y_i$ is the frequency of i species.                                                                                                                                                   |
| <b>Relative Dominance</b>                | $RDo = \frac{d_i}{\sum_{i=1}^k d_i} * 100$ | Where, RDo is relative dominance (Dallmeier, 1992; Misra, 1968),<br>$d_i$ is the basal area of i species.                                                                                                                                                 |
| <b>Important Value Index</b>             | $IVI = RD + RF + RDo$                      | Where, IVI is the important value index (Dallmeier, 1992; Krebs, 1989; Misra, 1968; Shukla & Chandel, 1994).                                                                                                                                              |
| <b>Species Diversity Index</b>           | $S_{DI} = \frac{S}{N}$                     | where, $S_{DI}$ is the species diversity index (Odum & Barrett, 1971),<br>S the total number of species,<br>N the total number of individuals of all the species.                                                                                         |
| <b>Shannon-Wiener Diversity Index</b>    | $H = - \sum_{i=1}^s P_i \ln P_i$           | where, H is the Shannon-Wiener diversity index (Michael, 1984),<br>$P_i = \frac{n_i}{N}$ , $n_i$ = Number of individuals of i species,<br>N = Total number of individuals of all species.                                                                 |
| <b>Shannon's Maximum Diversity Index</b> | $H_{max} = \ln S$                          | where, $H_{max}$ is Shannon's maximum diversity index (Kent, 2011),<br>S is the total number of species.                                                                                                                                                  |
| <b>Shannon's Equitability Index</b>      | $E_H = \frac{H}{H_{max}}$                  | where, $E_H$ is Shannon's equitability index (Kent, 2011),<br>H the Shannon-Wiener diversity index,<br>$H_{max}$ the Shannon's maximum diversity index.                                                                                                   |
| <b>Simpson's Diversity Index</b>         | $D = \sum_{i=1}^n P_i^2$                   | where, D is the Simpson's diversity index (Magurran & McGill, 2011),<br>$P_i = \frac{n_i}{N}$ , $n_i$ = Number of individuals of i species,<br>N = Total number of individuals of all species.<br>As biodiversity increases, the Simpson index decreases. |
| <b>Dominance of Simpson's Index</b>      | $D' = 1 - D$                               | where, D' is dominance of Simpson index (Magurran & McGill, 2010).                                                                                                                                                                                        |
| <b>Simpson's Reciprocal Index</b>        | $D_r = \frac{1}{D}$                        | where, $D_r$ is Simpson's reciprocal index (Keller, 2000).                                                                                                                                                                                                |

|                                                                |                              |                                                                                                                                                                                   |
|----------------------------------------------------------------|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Margalef's Diversity Index /<br/>Species Richness Index</b> | $R = \frac{(S - 1)}{\ln(N)}$ | where, R is the Margalef's diversity index or species richness index (Margalef, 1958),<br>S the total number of species,<br>N the total number of individuals of all the species. |
| Species Evenness Index                                         | $E = \frac{H}{\log(S)}$      | where is E is the species evenness index (Pielou, 1966),<br>H the Shannon-Winner diversity index,<br>S the total number of species.                                               |

### 3.Result

#### 3.1. Tree diversity

A total of 455 individual trees (dbh  $\geq$  10 cm) from 66 species belonging to 33 families were documented across 131 plots (Tables 4 & 5). Out of all the families, Fabaceae had the most species (10), followed by Moraceae (8 species), Lamiaceae (4 species), Anacardiaceae (3 species), Euphorbiaceae (3 species), Malvaceae (3 species), and so on (Table 5). The study also found a tree density of 160.813 trees per hectare in the whole study area. The tree density is found highest in the 'Forest Plantation' stratum, with 508.491 trees per hectare, while the hill forest stratum has the lowest density, with only 92.615 trees per hectare. Species richness was highest in the 'Shrub with Scattered trees' stratum (52 species belonging to 25 families) and lowest in the 'Forest Plantation' stratum (9 species belonging to 5 families). Across the entire study area, 12.24 dead trees per hectare were recorded. The 'Hill Forest' stratum had the highest number of dead trees per hectare, accounting for 25.35 trees per hectare, followed by the 'Forest Plantation' stratum making up 22.57 trees per hectare. The greatest number of stumps was found in the 'Shrub with Scattered trees' stratum, with 9.78 stumps per hectare. Overall, combining all strata, there were 6.79 stumps per hectare (Table 4).

**Table 4. Strata-wise basic tree information recorded from the study area.**

| <i>Basic information</i>                               | <i>Forest<br/>Plantation</i> | <i>Hill<br/>Forest</i> | <i>Shrub with<br/>Scattered trees</i> | <i>Others</i> | <i>Overall</i> |
|--------------------------------------------------------|------------------------------|------------------------|---------------------------------------|---------------|----------------|
| <i>Area of each plot size (r=19 m) (m<sup>2</sup>)</i> | 1134.57                      | 1134.57                | 1134.57                               | 1134.57       | 1134.57        |
| <i>No. of plots studied</i>                            | 7                            | 18                     | 90                                    | 16            | 131            |
| <i>Total no. of individuals</i>                        | 79                           | 36                     | 205                                   | 135           | 455            |
| <i>No. of families</i>                                 | 5                            | 17                     | 25                                    | 13            | 33             |
| <i>No. of total species</i>                            | 9                            | 22                     | 52                                    | 15            | 66             |
| <i>Tree density per ha.</i>                            | 508.491                      | 92.615                 | 105.061                               | 396.471       | 160.813        |
| <i>No. of dead trees per ha.</i>                       | 22.57                        | 25.35                  | 10.99                                 | 0.00          | 12.24          |
| <i>No. of stumps per ha.</i>                           | 7.10                         | 0.49                   | 9.78                                  | 0.00          | 6.79           |

### 3.2 Phytosociological Characteristics of Tree Species

Forest structure, composition, and dynamics are critical features for developing appropriate silvicultural systems for sustainable forest management (Appanah et al., 1990). The study evaluated the forest structure and composition of INP by analyzing key ecological metrics, including tree density, basal area, relative density (RD), relative frequency (RF), relative dominance (RDo), importance value index (IVI), and canopy cover. *Areca catechu* emerged as the most dominant species, having the highest density (48.957 trees per hectare), basal area (0.540 m<sup>2</sup> per hectare), relative density (28.35%), and importance value index (IVI) of 40.01, indicating its significant ecological presence in the forest. *Acacia auriculiformis* and *Mangifera indica* were also prominent. *Acacia auriculiformis* was the second most dominant cluster (IVI = 24.35) followed by *Mangifera indica* (IVI = 20.20) with the highest relative frequency of 5.79%. *Cassia fistula* had the highest relative dominance (15.61%) reflecting its strong contribution to forest biomass. In contrast, species like *Grewia asiatica* and *Artocarpus lacucha* showed the lowest IVI (0.81) with the lowest relative density (0.22%) and relative frequency (0.53%), suggesting their limited distribution within the study area (Table 5). Canopy cover, an important ecological factor influencing microclimate and biodiversity, varied widely across sites, with an average of 45.19% and a range from 0% to 100%. This variation likely results from natural disturbances, edge effects, and human activities affecting forest structure. The findings highlight the dominance of a few key species while also reflecting the presence of diverse, less abundant species, providing valuable insights for sustainable forest management and conservation strategies in INP.

1 Table 5. Phytosociological attributes of recorded tree species in Inani National Park, Bangladesh.

| Family                           | Scientific Name                                      | Density<br>(stems/ha) | Basal area<br>(m <sup>2</sup> /ha) | RD<br>(%) | RF<br>(%) | RDo<br>(%) | IVI   |
|----------------------------------|------------------------------------------------------|-----------------------|------------------------------------|-----------|-----------|------------|-------|
| 1. Achariaceae                   | 1. <i>Hydnocarpus kurzii</i>                         | 2.032                 | 0.055                              | 1.54      | 2.63      | 1.99       | 6.16  |
| 2. Anacardiaceae (3 species)     | 2. <i>Mangifera indica</i>                           | 0.759                 | 0.012                              | 6.59      | 5.79      | 7.82       | 20.20 |
|                                  | 3. <i>Lannea coromandelica</i> Houtt Merr            | 9.824                 | 0.290                              | 0.44      | 1.05      | 0.21       | 1.70  |
|                                  | 4. <i>Swintonia floribunda</i>                       | 1.139                 | 0.018                              | 0.66      | 1.58      | 0.33       | 2.56  |
| 3. Annonaceae                    | 5. <i>Annona squamosa</i> L                          | 0.759                 | 0.008                              | 0.44      | 0.53      | 0.14       | 1.11  |
| 4. Apocynaceae<br>(2 species)    | 6. <i>Alstonia scholaris</i>                         | 0.380                 | 0.014                              | 0.22      | 0.53      | 0.26       | 1.00  |
|                                  | 7. <i>Holarrhena antidysenterica</i> L Wall ex Decne | 0.380                 | 0.007                              | 0.22      | 0.53      | 0.12       | 0.86  |
| 5. Araliaceae                    | 8. <i>Trevesia palmata</i> Roxb Vis                  | 0.380                 | 0.005                              | 0.22      | 0.53      | 0.09       | 0.84  |
| 6. Arecaceae (2 species)         | 9. <i>Areca catechu</i>                              | 48.957                | 0.540                              | 28.35     | 2.11      | 9.55       | 40.01 |
|                                  | 10. <i>Cocos nucifera</i>                            | 0.514                 | 0.030                              | 0.66      | 1.58      | 1.31       | 3.55  |
| 7. Bignoniaceae                  | 11. <i>Stereospermum colais</i> Buch Ham ex Dillw    | 0.447                 | 0.039                              | 0.44      | 1.05      | 1.97       | 3.46  |
| 8. Bombacaceae                   | 12. <i>Bombax ceiba</i>                              | 0.759                 | 0.023                              | 0.44      | 1.05      | 0.41       | 1.90  |
| 9. Burseraceae                   | 13. <i>Protium serratum</i> Wall ex DC Engler        | 2.657                 | 0.041                              | 1.54      | 2.11      | 0.72       | 4.36  |
| 10. Cannabaceae                  | 14. <i>Trema orientalis</i> L Blume                  | 0.380                 | 0.012                              | 0.22      | 0.53      | 0.21       | 0.96  |
| 11. Dichapetalaceae              | 15. <i>Dichapetalum gelonioides</i> Roxb             | 1.206                 | 0.022                              | 0.88      | 2.11      | 0.81       | 3.79  |
| 12. Dilleniaceae                 | 16. <i>Dillenia pentagyna</i> King                   | 0.380                 | 0.011                              | 0.22      | 0.53      | 0.19       | 0.94  |
| 13. Dipterocarpaceae             | 17. <i>Dipterocarpus turbinatus</i>                  | 2.657                 | 0.084                              | 1.54      | 2.63      | 1.49       | 5.66  |
| 14. Elaeocarpaceae               | 18. <i>Elaeocarpus floribundus</i>                   | 0.067                 | 0.011                              | 0.22      | 0.53      | 1.15       | 1.89  |
| 15. Euphorbiaceae<br>(3 species) | 19. <i>Macaranga denticulata</i> Blume Muell Arg     | 3.416                 | 0.050                              | 1.98      | 2.63      | 0.88       | 5.49  |
|                                  | 20. <i>Mallotus nudiflorus</i>                       | 0.447                 | 0.017                              | 0.44      | 1.05      | 1.08       | 2.57  |
|                                  | 21. <i>Shirakiopsis indica</i>                       | 0.759                 | 0.005                              | 0.44      | 1.05      | 0.08       | 1.58  |
| 16. Fabaceae (10 species)        | 22. <i>Acacia auriculiformis</i>                     | 20.695                | 0.294                              | 12.53     | 5.26      | 6.56       | 24.35 |

| Family                     | Scientific Name                              | Density<br>(stems/ha) | Basal area<br>(m <sup>2</sup> /ha) | RD<br>(%) | RF<br>(%) | RDo<br>(%) | IVI   |
|----------------------------|----------------------------------------------|-----------------------|------------------------------------|-----------|-----------|------------|-------|
|                            | 23. <i>Albizia procera</i>                   | 0.581                 | 0.044                              | 0.88      | 1.58      | 3.04       | 5.49  |
|                            | 24. <i>Cassia fistula</i> L                  | 0.067                 | 0.156                              | 0.22      | 0.53      | 15.61      | 16.35 |
|                            | 25. <i>Dalbergia ovata</i> Graham ex Benth   | 0.380                 | 0.005                              | 0.22      | 0.53      | 0.09       | 0.84  |
|                            | 26. <i>Derris robusta</i> Roxb ex DC Benth   | 4.175                 | 0.091                              | 2.42      | 3.68      | 1.61       | 7.72  |
|                            | 27. <i>Erythrina ovalifolia</i>              | 1.139                 | 0.015                              | 0.66      | 0.53      | 0.26       | 1.45  |
|                            | 28. <i>Samanea saman</i>                     | 0.447                 | 0.031                              | 0.44      | 1.05      | 2.37       | 3.86  |
|                            | 29. <i>Senna siamea</i> Lamk Irwin & Barneby | 0.759                 | 0.022                              | 0.44      | 1.05      | 0.39       | 1.88  |
|                            | 30. <i>Sesbania grandiflora</i> Pers         | 6.072                 | 0.080                              | 3.52      | 2.63      | 1.42       | 7.57  |
|                            | 31. <i>Xylia xylocarpa</i> Roxb              | 0.380                 | 0.004                              | 0.22      | 0.53      | 0.07       | 0.82  |
| 17. Fagaceae (2 species)   | 32. <i>Castanopsis indica</i>                | 1.273                 | 0.040                              | 1.10      | 2.63      | 2.11       | 5.84  |
|                            | 33. <i>Quercus acuminata</i>                 | 0.759                 | 0.007                              | 0.44      | 1.05      | 0.12       | 1.61  |
| 18. Lamiaceae (4 species)  | 34. <i>Callicarpa macrophylla</i> Vahl       | 2.724                 | 0.076                              | 1.76      | 2.11      | 5.31       | 9.17  |
|                            | 35. <i>Gmelina arborea</i>                   | 2.657                 | 0.079                              | 1.54      | 2.11      | 1.40       | 5.04  |
|                            | 36. <i>Tectona grandis</i>                   | 0.894                 | 0.029                              | 0.88      | 1.58      | 1.52       | 3.98  |
|                            | 37. <i>Vitex glabrata</i> R Br               | 2.277                 | 0.056                              | 1.32      | 2.11      | 0.99       | 4.41  |
| 19. Lauraceae              | 38. <i>Phoebe lanceolata</i> Nees            | 0.067                 | 0.005                              | 0.22      | 0.53      | 0.47       | 1.22  |
| 20. Lythraceae (2 species) | 39. <i>Lagerstroemia parviflora</i>          | 2.657                 | 0.065                              | 1.54      | 1.58      | 1.14       | 4.26  |
|                            | 40. <i>Lagerstroemia speciosa</i>            | 3.103                 | 0.051                              | 1.98      | 3.68      | 1.32       | 6.98  |
| 21. Malvaceae (3 species)  | 41. <i>Brownlowia elata</i> Roxb             | 1.585                 | 0.061                              | 1.10      | 2.63      | 2.64       | 6.37  |
|                            | 42. <i>Grewia asiatica</i>                   | 0.380                 | 0.004                              | 0.22      | 0.53      | 0.06       | 0.81  |
|                            | 43. <i>Grewia nervosa</i> Lour Panigr        | 2.657                 | 0.055                              | 1.54      | 2.63      | 0.97       | 5.14  |
| 22. Meliaceae (2 species)  | 44. <i>Aphanamixis polystachya</i>           | 0.380                 | 0.004                              | 0.22      | 0.53      | 0.07       | 0.82  |
|                            | 45. <i>Walsura robusta</i> Roxb              | 0.826                 | 0.045                              | 0.66      | 1.05      | 1.96       | 3.68  |
| 23. Moraceae (8 species)   | 46. <i>Artocarpus chama</i>                  | 0.067                 | 0.005                              | 0.22      | 0.53      | 0.48       | 1.22  |

| Family                        | Scientific Name                                | Density<br>(stems/ha) | Basal area<br>(m <sup>2</sup> /ha) | RD<br>(%) | RF<br>(%) | RDo<br>(%) | IVI  |
|-------------------------------|------------------------------------------------|-----------------------|------------------------------------|-----------|-----------|------------|------|
|                               | 47. <i>Artocarpus heterophyllus</i> Lam        | 2.724                 | 0.069                              | 1.76      | 1.58      | 1.62       | 4.95 |
|                               | 48. <i>Artocarpus lacucha</i> Buch Ham         | 0.380                 | 0.004                              | 0.22      | 0.53      | 0.07       | 0.81 |
|                               | 49. <i>Broussonetia papyrifera</i>             | 0.380                 | 0.013                              | 0.22      | 0.53      | 0.23       | 0.98 |
|                               | 50. <i>Ficus benghalensis</i> L                | 0.514                 | 0.035                              | 0.66      | 1.58      | 3.15       | 5.39 |
|                               | 51. <i>Ficus benjamina</i> L                   | 0.067                 | 0.019                              | 0.22      | 0.53      | 1.90       | 2.65 |
|                               | 52. <i>Ficus carica</i> L                      | 2.277                 | 0.039                              | 1.32      | 1.05      | 0.69       | 3.06 |
|                               | 53. <i>Ficus semicordata</i> Buch Ham ex Smith | 4.934                 | 0.129                              | 2.86      | 3.16      | 2.28       | 8.29 |
| 24. Myristicaceae             | 54. <i>Knema bengalensis</i>                   | 2.344                 | 0.038                              | 1.54      | 2.63      | 1.06       | 5.23 |
| 25. Myrsinaceae               | 55. <i>Maesa indica</i> Roxb A DC              | 1.139                 | 0.011                              | 0.66      | 0.53      | 0.19       | 1.38 |
| 26. Myrtaceae (2 species)     | 56. <i>Syzygium claviflorum</i>                | 0.380                 | 0.005                              | 0.22      | 0.53      | 0.08       | 0.83 |
|                               | 57. <i>Syzygium cumini</i> L Skeels            | 1.206                 | 0.035                              | 0.88      | 2.11      | 1.01       | 4.00 |
| 27. Phyllanthaceae            | 58. <i>Glochidion arborescens</i> Blume        | 0.380                 | 0.005                              | 0.22      | 0.53      | 0.08       | 0.83 |
| 28. Rhizophoraceae            | 59. <i>Carallia brachiata</i>                  | 0.380                 | 0.009                              | 0.22      | 0.53      | 0.16       | 0.90 |
| 29. Rubiaceae (2 species)     | 60. <i>Mitragyna rotundifolia</i>              | 3.416                 | 0.061                              | 1.98      | 4.21      | 1.09       | 7.27 |
|                               | 61. <i>Neolamarckia cadamba</i>                | 0.447                 | 0.044                              | 0.44      | 1.05      | 2.37       | 3.87 |
| 30. Salicaceae                | 62. <i>Flacourtia indica</i> Burm f Merr       | 1.518                 | 0.019                              | 0.88      | 2.11      | 0.34       | 3.33 |
| 31. Sterculiaceae (2 species) | 63. <i>Abroma augusta</i>                      | 0.380                 | 0.006                              | 0.22      | 0.53      | 0.10       | 0.85 |
|                               | 64. <i>Pterospermum acerifolium</i>            | 0.380                 | 0.023                              | 0.22      | 0.53      | 0.41       | 1.16 |
| 32. Verbenaceae               | 65. <i>Phyla nodiflora</i> L Greene            | 0.759                 | 0.011                              | 0.44      | 0.53      | 0.19       | 1.16 |
| 33. Vitaceae                  | 66. <i>Leea indica</i> Burm f Merr             | 1.518                 | 0.010                              | 0.88      | 0.53      | 0.18       | 1.58 |
| Total                         |                                                | 160.813               | 3.201                              | 100       | 100       | 100        | 300  |

### 3.3 Hierarchical cluster of the species based on the dominance of the tree species in the INP

To determine the optimal number of clusters, we generated a scree plot, which clearly indicates that the recorded tree species can be categorized into five hierarchical clusters based on their Importance Value Index (IVI) (Figure 3). The hierarchical clustering results (Figure 4) highlight that *Areca catechu* emerges as the most dominant species, forming the first cluster. The second cluster consists of other dominant species, including *Acacia auriculiformis*, *Mangifera indica*, and *Cassia fistula*. Meanwhile, the remaining tree species are distributed among the third, fourth, and fifth clusters, representing varying degrees of ecological significance within the study area.

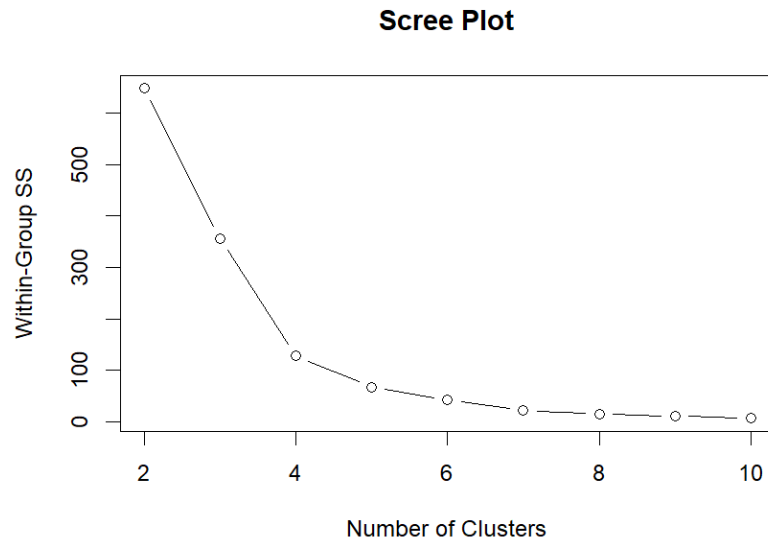


**Figure 3. Scree plot to determine the number of clusters for tree species.**

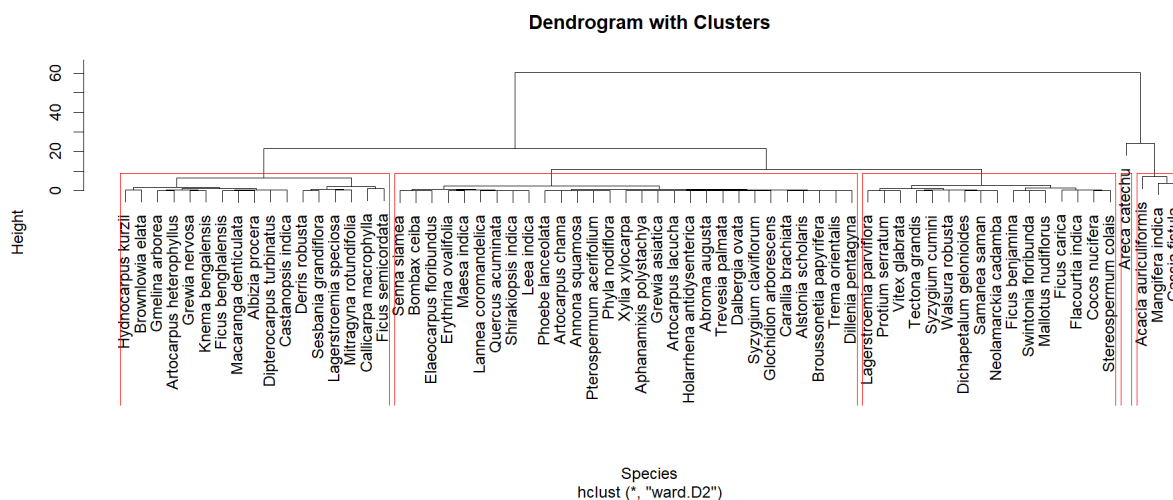


**Figure 4. Hierarchical cluster of the tree species in the INP.**

### 3.4 Tree diversity indices

The species diversity indices analysis in INP revealed significant variations across forest strata (Table 6). The Species Diversity Index ( $S_{DI}$ ) was found highest in the ‘Hill Forest’ stratum (0.611) and lowest in the ‘Others’ stratum (0.111) with an overall value of 0.145. Among the four strata, the ‘Shrub with Scattered trees’ stratum had the highest Shannon Diversity Index (3.572), whereas the ‘Others’ stratum had the lowest (1.229) (Table 6). The Shannon Maximum Diversity ( $H_{max}$ ) was 4.190, with the ‘Shrub with Scattered trees’ having the highest (3.951) and the ‘Forest Plantation’ the lowest (2.197) (Table 6). Simpson’s Diversity Index ( $D$ ) for INP was 0.108, indicating high diversity and low dominance, with the ‘Others’ stratum having the highest  $D$  value (0.485), reflecting species dominance, while the ‘Shrub with Scattered trees’ had the lowest (0.038), indicating high diversity. The Species Evenness Index ( $E$ ) was highest in the shrub with scattered trees (2.082) and lowest in the ‘Others’ stratum (1.045). A radar plot analysis confirmed that the ‘Shrub with Scattered trees’ had the highest biodiversity and evenness, while ‘Hill Forests’, despite high richness, showed lower evenness due to species dominance (Figure 5). The forest plantation showed moderate diversity, and the ‘others’ stratum exhibited the lowest biodiversity and highest dominance.

Key observations highlight the ecological status of different forest types. Hill forests showed the highest species richness ( $S_{DI}$ : 0.611,  $R$ : 5.860,  $D_r$ : 15.805) but had a low Shannon Diversity Index (0.244) and very low evenness ( $E_h$ : 0.079,  $E$ : 0.182), suggesting the dominance of a few species (Table 6). Radar plot analysis confirmed this uneven distribution (Figure 5). The ‘Shrub with scattered trees’ had the highest Shannon Diversity Index (3.572), Shannon Equitability Index (0.904), and lowest Simpson’s Index (0.038), indicating a well-balanced ecosystem with minimal species dominance, making it a prime candidate for conservation. The radar plot also highlighted this as the most balanced and biodiverse stratum (Figure 5). The ‘Forest Plantation’ displayed moderate diversity ( $H$ : 1.251,  $E$ : 1.311), indicating a structured but limited species variety, which could be improved by introducing native species. The ‘Others’ category exhibited the lowest biodiversity ( $S_{DI}$ : 0.111,  $H$ : 1.229) and the highest Simpson’s Index (0.485), reflecting severe biodiversity loss and species dominance. The radar plot confirmed it as the most degraded ecosystem (Figure 5). Conservation strategies should focus on protecting hill forests while improving species evenness, preserving the biodiversity of shrubland ecosystems, diversifying plantations with native species, and restoring degraded areas. These findings provide essential guidance for conservation planning, afforestation, and biodiversity management to enhance ecosystem resilience in INP.

**Table 6. Strata-wise biological diversity indices for the recorded tree species in Inani National Park, Bangladesh.**

| Diversity indices                       | Forest Plantation | Hill Forest | Shrub with scattered trees | Others | Overall |
|-----------------------------------------|-------------------|-------------|----------------------------|--------|---------|
| Species Diversity Index (SDI)           | 0.114             | 0.611       | 0.254                      | 0.111  | 0.145   |
| Shannon Diversity Index (H)             | 1.251             | 0.244       | 3.572                      | 1.229  | 3.137   |
| Shannon Maximum Diversity ( $H_{max}$ ) | 2.197             | 3.091       | 3.951                      | 2.708  | 4.190   |
| Shannon Equitability Index ( $E_h$ )    | 0.569             | 0.079       | 0.904                      | 0.454  | 0.749   |

|                                              |       |        |        |       |        |
|----------------------------------------------|-------|--------|--------|-------|--------|
| Simpson's Diversity Index (D)                | 0.379 | 0.063  | 0.038  | 0.485 | 0.108  |
| Dominance of Simpson's Index (D')            | 0.621 | 0.937  | 0.962  | 0.515 | 0.892  |
| Simpson's Reciprocal Index (D <sub>r</sub> ) | 2.639 | 15.805 | 26.151 | 2.063 | 9.248  |
| Margalef's Diversity Index (R)               | 1.831 | 5.860  | 9.581  | 2.854 | 10.620 |
| Species Evenness Index (E)                   | 1.311 | 0.182  | 2.082  | 1.045 | 1.724  |

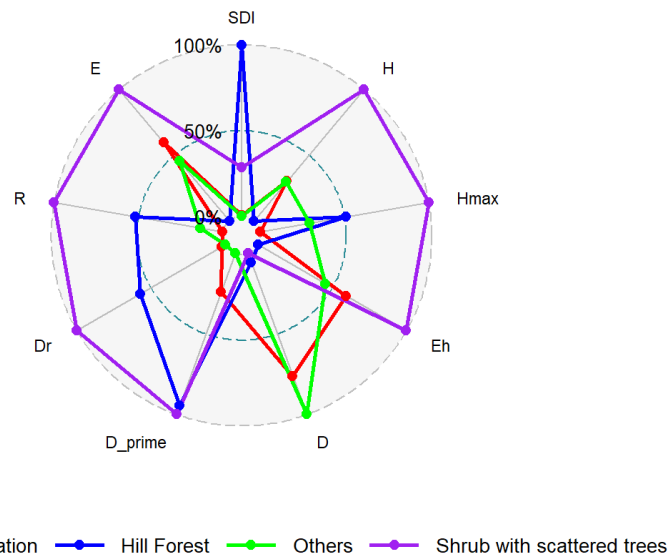


**Figure 5. Diversity indices across forest types in INP.**

Note: Species Diversity Index (S<sub>DI</sub>); Shannon Diversity Index (H); Shannon Maximum Diversity (H<sub>max</sub>); Shannon Equitability Index (E<sub>h</sub>); Simpson's Diversity Index (D); Dominance of Simpson's Index (D'); Simpson's Reciprocal Index (D<sub>r</sub>); Margalef's Diversity Index (R); Species Evenness Index (E).

## 4. Discussion

Ecological experiments, observations, and theoretical developments show that ecosystem properties depend greatly on biodiversity in terms of the functional characteristics of organisms present in the ecosystem and the distribution and abundance of those organisms over space and time (Hooper et al., 2005). The floral composition of Inani National Park (INP) is relatively diverse, with 66 species, making it richer compared to forests like Fashiakhali Wildlife Sanctuary (FWS) (32 species) (Das et al., 2018) and Medha Kachhapia National Park (MKNP) (10 species) (M. Uddin et al., 2020). However, it is still less diverse than Himchori National Park (HNP) (88 species) (S. Hossen et al., 2020) and Kamalachari Natural Forest (KNP) (107 species) (M. A. Hossain et al., 2015).

The IVI analysis revealed that four species—*Areca catechu*, *Acacia auriculiformis*, *Mangifera indica*, and *Cassia fistula* L.—dominate the forest, accounting for 48% of the density and 40% of the basal area per hectare (Table 5). These species, particularly *Acacia auriculiformis*, an invasive alien species, reflect the consequences of anthropogenic disturbances, such as land encroachment and forest degradation. The ecological dominance of *A.*

65 *auriculiformis*, a fast-growing nitrogen-fixing species, may alter soil nutrient cycles, suppress native seedling  
66 regeneration, and reduce understory plant diversity. Its presence, alongside species like *Mangifera indica* and  
67 *Areca catechu*, reflects a landscape increasingly shaped by human intervention rather than natural succession.

68 The dominance of *Cassia fistula* can be considered a good indicator of naturally grown native tree species showing  
69 strong resilience to grow under relatively harsher conditions. The presence of other species with low IVI values  
70 indicates that most species in the forest are rare and possibly at risk of local extinction.

71 The Species Diversity Index ( $S_{DI}$ ) for INP (0.145) generally indicates low biodiversity, representing a community  
72 where a few species are dominant, with most species being relatively rare. However, the  $S_{DI}$  for the ‘Hill Forest’  
73 stratum (0.611) was higher than that of HNP (0.092) (S. Hossen et al., 2020) and Bangabandhu Sheikh Mujib  
74 Safari Park (BSMSP) (0.067) (M. Uddin et al., 2020), indicating a more diverse ecosystem in that particular  
75 stratum. The Shannon Diversity Index (H) for INP (3.137) was lower than HNP (3.733) but higher than FWS  
76 (2.06) and MKNP (1.16) (Das et al., 2018; M. Uddin et al., 2020), showing significant floristic diversity. The  
77 Shannon Equitability Index ( $E_h$ ) was 0.749, lower than HNP (0.834) but higher than MKNP (0.21066), showing  
78 moderate species uniformity.

79 However, the coexistence of a relatively high Shannon Index with a low Simpson’s Reciprocal Index ( $D_r = 9.248$ )  
80 suggests a discrepancy in species evenness. While Shannon Index values are more sensitive to rare species,  
81 Simpson’s index gives greater weight to the most abundant species. This discrepancy indicates a floristic structure  
82 where richness exists, but a few species disproportionately dominate the landscape, limiting ecological balance.  
83 The  $D_r$  value is much lower than that of HNP (25.641), reflecting reduced evenness and the potential vulnerability  
84 of the ecosystem.

85 Margalef’s Diversity Index (R) for INP (10.620) was slightly lower than HNP (12.667). Bohn & Huth, 2017)  
86 showed that forest structures are the dominant drivers of forest productivity. Forest structural complexity, defined  
87 by attributes such as physiognomies, growth forms, and ages, appears to have a close link to forest biodiversity  
88 (Pan et al., 2013). In terms of biodiversity, the Shannon Diversity Index (H) of 3.596 for INP, compared to 3.440  
89 in BSMSP, also supports the higher diversity in INP, although its Shannon Equitability Index ( $E_h$ ) of 0.844 is  
90 slightly lower than that of BSMSP (0.855), suggesting a slightly uneven distribution of species.

91 Despite these positive diversity indices, this study offers new insights by quantifying the floristic structure of INP  
92 in the post-2017 period, following large-scale anthropogenic disruptions due to refugee influx. INP faces  
93 significant threats, including land encroachment, fuelwood collection, illegal timber cutting, and habitat  
94 destruction. The establishment of Rohingya refugee camps in 2017 alone led to the loss of ~6,000 acres of forest,  
95 drastically impacting biodiversity and ecosystem functions.

96 The dominance of invasive species like *Acacia auriculiformis*, planted horticultural species like *Areca catechu*  
97 and *Mangifera indica* on encroached lands, alongside the impacts of human disturbances, has led to a  
98 compromised ecosystem. These disturbances have reduced the abundance and frequency of many native species,  
99 further contributing to forest degradation. Although the forest still hosts a variety of species, their low abundance  
100 underscores the urgent need for conservation efforts to restore ecological balance.

This study contributes to the growing body of literature on anthropogenic impacts on tropical forest diversity by offering a multi-index comparison across similar ecosystems in Bangladesh. INP's biodiversity is still richer than that of Fashiakhali Wildlife Sanctuary and Medha Kachhapia National Park but faces significant challenges. A focused conservation strategy—including, but not limited to, halting further encroachment, enforcing legal protection of forest lands, strengthening co-management activities, and promoting the planting of native tree species—is essential to preserve biodiversity and ensure the long-term sustainability of INP's ecosystems.

## 5. Conclusion

Inani National Park (INP) demonstrates a remarkable diversity of plant species, despite the significant anthropogenic pressures it faces. Our study revealed that the 'Shrub with Scattered trees' stands out with the highest species diversity, as reflected in various diversity indices. While 'Hill Forests' are vital for preserving this diversity, expanding and protecting 'Forest Plantations' is crucial for restoring ecosystem functionality. The process of ecosystem restoration, through natural regeneration or planting efforts, is key to reversing forest degradation and enhancing ecological resilience (UNEP, 2019).

The conservation of native tree species in INP can be approached through a three-phase strategy: identification of at-risk species, immediate protection measures, and long-term recovery initiatives (M. K. Hossain et al., 2020). These strategies will be instrumental in safeguarding the park's biodiversity, with particular attention given to the ongoing impacts of human activities, such as land encroachment, fuelwood collection, and deforestation caused by the establishment of refugee camps.

The findings from this study provide critical insights into the density, diversity, dominance, and composition of tree species in INP, which will inform the development of a sustainable management plan. By focusing on both natural regeneration and artificial interventions, this study underscores the gradual progress made in restoring the park's ecosystems. Ultimately, the data gathered can guide effective conservation efforts aimed at ensuring the long-term ecological health and resilience of Inani National Park.

**Study Implications:** This study provides a scientific baseline for conservation planning by identifying species richness and ecological trends within the Inani National Park. It supports policy decisions aimed at biodiversity conservation and sustainable forest management in INP at Cox's Bazar.

**Data Availability:** The datasets generated during and /or analysed during the current study are available from the corresponding author on reasonable request.

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136

### 137 **Author contributions**

138 BKD conceptualization; data curation; fund acquisition; investigation; methodology; project

139 administration; writing— original draft. MFJ conceptualization; methodology; supervision;

140 writing—review & editing. MJ conceptualization; methodology; supervision; writing—review &

141 editing. MD formal analysis; methodology; writing—review & editing. BM writing—review & editing.

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