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RESEARCH ARTICLE

Tree diversity and regeneration dynamics toward forest conservation and environmental sustainability: A case study from Nawabganj Sal Forest, Bangladesh

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Abstract
The objective of this study was to examine the regeneration dynamics and population structure of the most prevalent tree species, *Shorea robusta* (Sal), alongside four other dominant tree species (*Tectona grandis*, *Syzygium cumini*, *Trema orientale*, and *Cassia fistula*) in the Nawabganj Sal Forest in Bangladesh. The regeneration status and tree diversity of all documented tree species were assessed using a simple random sampling technique. Among the 30 species, 5 species (*Shorea robusta*, *Tectona grandis*, *Trema orientale*, *Gmelina arborea*, and *Artocarpus heterophyllus*) exhibited favorable regeneration state, whereas 15 species had moderate regeneration status. However, the absence of the condition 'no regeneration' was due to the absence of the adult stage, which resulted in the absence of seedlings and saplings. The quantity of seedlings was greater during the rainy season compared to the dry season. The girth class distribution of *Shorea robusta* and all other studied tree species combined exhibited a reverse J-shaped population curve. There was a decline in tree density as the girth class increased, and trees with a larger girth class accounted for 34 individuals per hectare, indicating a strong ongoing regeneration capability. The Shannon-Wiener diversity index, Simpson's dominance index, Pielou's evenness index, and Margalaf's species richness index had values of 0.223, 0.937, 0.077, and 2.249, respectively. These values imply a limited diversity of tree species in the examined forest. *Shorea robusta* has the highest dominance (m^2/ha), followed by *Tectona grandis* (0.091), *Syzygium cumini* (0.087), *Trema orientale* (0.022), and *Cassia fistula* (0.008). The cumulative basal area of the tree species examined amounted to 40.04 m^2/ha, with Shorea robusta accounting for 39.81 m^2/ha. This indicates that Sal is the prevailing tree species in the forest. Nevertheless, this study offers fundamental data regarding the current condition of the tropical Sal Forest toward forest conservation and environmental sustainability.

Keywords: Regeneration; Tree diversity; Population structure; *Shorea robusta*; Forest conservation; Environmental sustainability

Introduction

Deforestation is the second most significant contributor to the increase in human-caused carbon emissions, which in turn leads to global warming and climate change (Abdallah et al., 2023;). Tropical forests are more vulnerable, and biodiversity is being threatened due to deforestation and forest degradation (Lapola et al., 2023;). Therefore, the significance of preserving forests for the purpose of maintaining environmental sustainability is on the rise because of the expanding global consciousness regarding the environment (Koulelis et al., 2023). The process of natural regeneration is crucial for the maintenance and growth of plant populations in a forest ecosystem (Latterini et al., 2023). Both natural regeneration and artificial regeneration are essential for forest conservation because of the unpredictability of multiple causes (Li & Xu, 2023). Tree regeneration is a crucial aspect of forest dynamics and has a significant impact on the structure, composition, and variety of forest ecosystems (Ma et al., 2023). The process is intricate and comprises a sequence of processes, commencing with pollination and culminating in the successful establishment of a single plant (Bullones et al., 2023). Regeneration refers to the process of renewal by which forest trees and other organisms are able to survive and perpetuate themselves (Calvia et al., 2023). Natural regeneration is a vital process in tropical forest dynamics that is necessary for the preservation and maintenance of biodiversity (Elliott et al., 2023). The reclamation behavior of tree species in a forest can be inferred from the population structure and growth (Bergsagel & Heisel, 202). Population structure refers to the distribution of individuals within different size classes of tree species (Jamloki et al., 2023) as well as the classification of a species based on many characteristics such as diameter, girth, height, and age. Biological diversity refers to the assortment of different life forms found on Earth, encompassing animals, plants, and even microorganisms (Hald-Mortensen, 2023). Tree diversity is a crucial component of plant diversity as it enhances the variety of other organisms by providing them with food and shelter (Haq et al., 2023).

A tropical moist deciduous forest, often known as a Sal Forest, is characterized by the dominance of a single plant species, specifically the Sal tree (*Shorea robusta* Gaertn.), along with other associated plants (Kumar & Saikia, 2021). Sal is a type of tree that is native to the Indian subcontinent (Sharma et al., 2022). It can be classified as deciduous, semi-deciduous, or evergreen. Sal trees are found in the southern region of the Himalayas, extending from Myanmar in the east to Nepal, India, and Bangladesh (Mishra et al., 2021). Sal is a versatile tree species that is categorized as endangered by the International Union for Conservation of Nature (IUCN). It has significant socio-economic potential and is primarily utilized for lumber, medicinal uses, animal feed, fuelwood, dried leaves for cooking and heating, fresh leaves for producing plates, edible seeds, and religious practices (Kumar & Saikia, 2021). Seedlings and saplings play a vital role in the forest ecosystem as they are essential for the regeneration, diversity, and future population structure (Maletha et al., 2023). The productivity and regeneration of the Sal Forest are contingent upon the optimal abundance of seedlings, saplings, and mature trees (Iskandar et al., 2023). Successful regeneration is shown by the presence of a sufficient quantity of seedlings, saplings, and young trees within a particular population (Gonçalves & Fonseca, 2023).

The regeneration of tree species is influenced by a range of biotic and abiotic variables (Ibáñez et al., 2022). Biotic variables encompass the living organisms present within the ecosystem (Costas-Selas et al., 2023). Human beings, insects, and animals are all biotic components. Nevertheless, it is humans who bear the primary responsibility for the disruptions in a forest. Unmanaged animals have an impact on both the decrease and increase of forest regeneration. However, in most situations, people living near the forest allow their livestock to graze in the forest to meet their livestock's feed requirements. Human-induced disruptions impact the ability of Sal Forest to regenerate and alter the composition of its population (Behera et al., 2023). The regeneration of the Sal Forest is influenced by the presence or absence of termite mounds, as well as the impact of the Sal borer on Sal regeneration (Kumar & Saikia, 2021). In addition, abiotic variables, which are nonliving components, also impact the reclamation status, population structure, diversity, and species composition of the Sal Forest in Bangladesh, Nepal, and India. Slope and aspect are abiotic elements that influence the regeneration, diversity, and growth of Sal trees in the Pragatisil community forest in Nepal (Bhatta & Devkota, 2020). The regeneration of Sal Forest is influenced by the nature of the site and the availability of sunshine (Behera et al., 2023). The composition of Sal forests is influenced by the gradient of light, as light plays a crucial role in the germination, growth, and survival of seedlings in the lower layers of tropical forests (Sharma et al., 2019). The presence of sunlight, a crucial factor for the optimal development of plants, is contingent upon the extent of crown cover and the degree of tree canopy opening (Liu et al., 2023). The regeneration of Sal is influenced by the opening in the tree canopy and the cover of the crown (Baral & Ghimire, 2020). The reverse J-shaped girth class distribution in the case of population structure signifies a healthy regeneration of the forest (Kumar & Saikia, 2021).

The Sal Forest in Bangladesh spans over 0.12 million hectares of land, accounting for approximately 4.7% of the country's total forest area (Roshni et al., 2023). The distribution of Sal forests in Bangladesh is primarily concentrated in the central and northern regions of the country. The Sal Forest ecosystem in northern Bangladesh spans an area of 26.5 thousand acres, primarily located in three districts: Dinajpur (69.42%), Thakurgaon (9.28%), and Panchagar (21.30%). The Sal Forest is located in three forest ranges within the Dinajpur district, including the Madhdhapara, Chorkai, and Sadar Dinajpur ranges. Deforestation is a significant environmental issue in Bangladesh (Ullah et al., 2022). The presence of cut stumps serves as evidence of forest disturbances. Although the government of Bangladesh has taken appropriate measures to mitigate this issue, it has not been completely eradicated. The disturbance index has a positive or negative correlation with the density and basal area of trees inside the forest (Liu et al., 2022). Forest-dependent people in Bangladesh have a significant impact on the regeneration of Sal forests since they rely on them to meet their diverse needs (Ray et al., 2023). Additionally, they also engage in livestock grazing within the forest regions. This woodland habitat has suffered extensive degradation due to both human activities and natural events (Saha et al., 2021).

Currently, there is a need for regeneration research to restore and conserve forests. The forest area of Bangladesh is decreasing steadily. Therefore, it is imperative to implement appropriate measures for the preservation and safeguarding of forests in order to enhance environmental sustainability. Prior to engaging in conservation efforts, it is necessary to possess knowledge regarding the diversity, regeneration state, and population structure of the forest. Additionally, understanding the variables that contribute to forest regeneration is crucial. Prior to implementing effective measures for the conservation of the Sal Forest, it is imperative to ascertain the current state of regeneration of the forest. Previous studies focusing on tree diversity, population structure, and regeneration dynamics of the Sal Forest were carried out in the center portion of Bangladesh (Roshni et al., 2023). However, there is a research gap exploring the tree diversity and regeneration dynamics in the Sal Forest in the northern region of Bangladesh, specifically the Nawabganj Sal Forest, Dinajpur. The climate, altitude, and edaphic elements in the northern region of Bangladesh differ not only from the central part of the country but also from the Sal Forest area in India and Nepal. Given the aforementioned considerations, the current investigation was undertaken to fill up the existing research gap. The study aims to assess the population structure and regeneration status of *Shorea robusta*, focusing on four dominant tree species (*Tectona grandis*, *Syzygium cumini*, *Trema orientale*, and *Cassia fistula*). This assessment was based on both density and dominance. Furthermore, this study seeks to ascertain the current state of regeneration and the level of biodiversity among all documented tree species inside this forest. This study offers fundamental data on the current condition and prospective sustainability of the tropical Sal Forest in the northern region of Bangladesh. The findings of the study would help take necessary actions for improving the Sal Forest conservation and management toward environmental sustainability.

Methodology

Study area

The research was carried out in the Nawabgonj Sal forest located in the Dinajpur district of Bangladesh. Figure 1 displays the map of the research area. The Nawabgonj Sal forest, also known as Nawabgonj National Park, is located at coordinates 25.4517524°N and 89.0534941°E. It spans a total area of 517.61 hectares. The declaration of the national park took place on October 24, 2010, and it was subsequently renamed Sheikh Rasel National Park in 2016. Dinajpur is located approximately 37 meters above sea level in Bangladesh. The district is defined by a level plain formed by the deposition of sediment carried by rivers, and it is interrupted by the slightly elevated. This region is covered with a type of forest known as tropical moist deciduous forest or Sal Forest, which is primarily composed of a single species of tree called Sal tree (*Shorea robusta*). The soil of Dinajpur is characterized as sandy clay loam, with medium-high elevation, 51-60% soil porosity, medium organic matter content, severely acidic pH levels, no salinity, and non-calcareous brown floodplain with black terai soils. Dinajpur has a tropical climate characterized by high temperatures, abundant rainfall, and high humidity. Dinajpur is classified under the Köppen climate classification as having a tropical wet and dry climate. The mean temperature recorded in Dinajpur district from 2019 to 2022 was 28.38˚C. Figure 2 displays the annual rainfall, duration of sunlight, number of rainy days, and number of sunny days in the study area from 2019 to 2022.

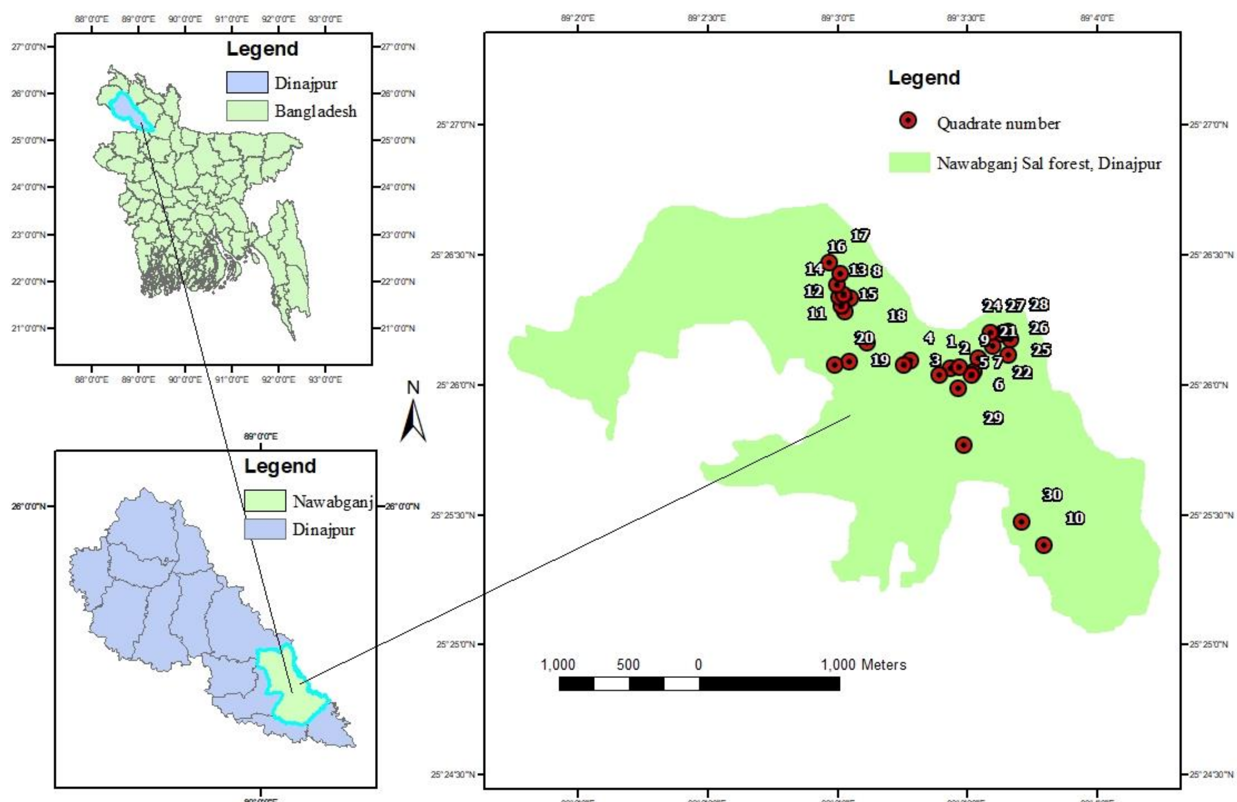

Figure 1. Map of the study area (The sampling site is indicated by a round red icon).

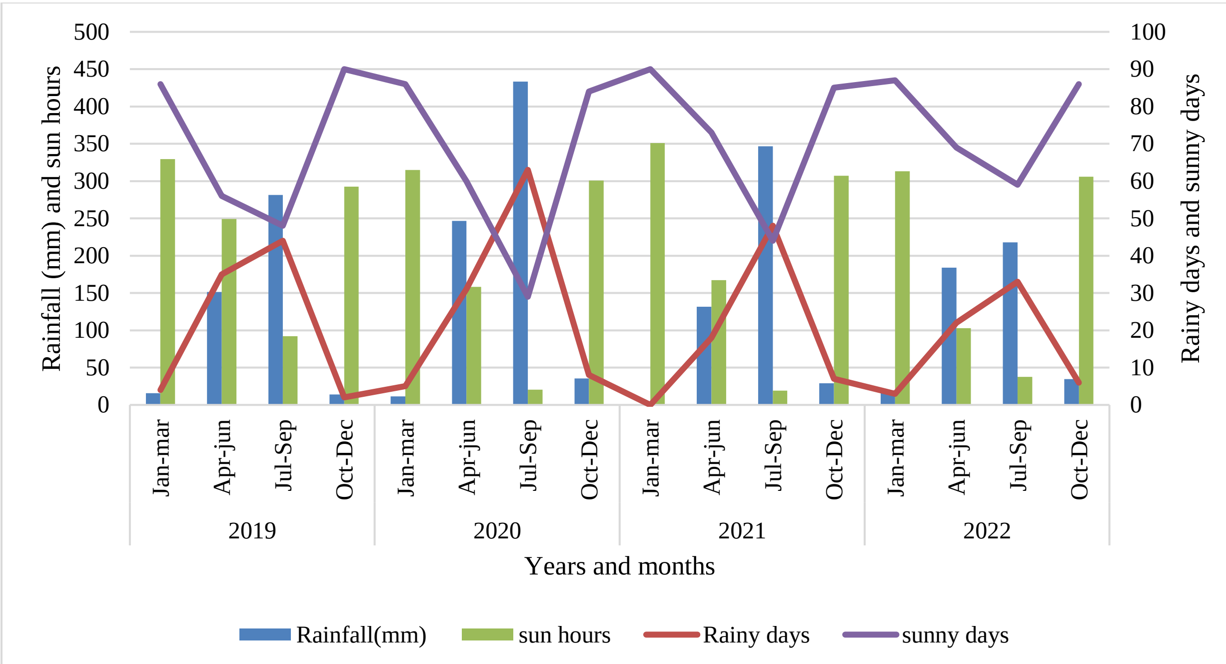

Figure 2. The annual rainfall, duration of sunlight, number of rainy days, and number of sunny days in Dinajpur, Bangladesh.

Sampling and data collection

Field sampling was conducted in Nawabganj Sal Forest from July 2021 to December 2022 using the quadrat method by Mishra (1968). 30 quadrats were randomly sampled from Nawabganj National Park using a simple random sampling procedure. Random sampling is a sampling technique where any population within a given area has an equal chance of being selected as part of the sample. The determination of the number and size of the quadrats was based on the species-area curve method (Mishra, 1968; Scheiner, 2003). Plants with a girth at breast height (GBH) greater than 10 cm were classified as trees. Plants with a GBH less than or equal to 10 cm and a height greater than 30 cm were classified as saplings. Individuals with a height less than or equal to 30 cm were classified as seedlings (Kumar & Saikia, 2020). A 20 m × 20 m square was used to count the number of adult plants. Additionally, a smaller 5 m × 5 m square was nested within the larger square to count the number of saplings and seedlings. Within the 20 m × 20 m square, four diagonally opposed 1 m × 1 m squares were nested to collect data. The dimensions of each square were measured using a 30-meter-long measuring tape. The GBH of trees, measured 1.37 meters above the ground, and the height of all adult individuals was determined in each quadrate. The GBH was measured using a thin measuring tape with a length of 1.5 meters, while the Haga-Altimeter was used to measure the height.

The assessment of the regeneration status of tree species was conducted by evaluating the population sizes of seedlings, saplings, and mature trees (Sarkar & Devi, 2014; Pokhriyal et al., 2010). If the population hierarchy is such that seedlings have a greater number than saplings, and saplings have a greater number than adults, then the regeneration status of tree species can be classified as "good regeneration". If the population consists of seedlings that are either greater than or equal to saplings, and saplings that are less than or equal to adults, with the additional condition that seedlings are less than or equal to saplings and saplings are greater than adults, and if there are no adults present, then the regeneration status of the tree species is classified as "fair regeneration". If a tree species only survives in the sapling stage and not as seedlings (with saplings potentially being larger, smaller, or equal in

size to adults), then the regeneration status of that tree species is considered to be "poor regeneration". If a species is exclusively found in its mature form, it is classified as "non-regenerating". A species is classified as "new" or a "new arrival" if it is exclusively found in the seedling or sapling stage without any adult individuals present.
The individual trees were categorized into seedlings, saplings, and mature trees based on their girth and height. This research followed the proposed method by Kumar and Saikia (2020) for studying the population structure of Sal and other allied tree species by categorizing individuals into different age groups based on their girth at breast height (GBH in cm) and height (in meters). This classification into five separate classes (Table 1) was done to facilitate a more thorough investigation and understanding of the population structure. Figure 3 illustrates the sampling methodology employed in the study.

Table 1. Different age groups based on tree GBH and height for population structure study.

GBH (cm) / Height (cm)	Age group on GBH	Height (m)	Age based on mean height
Height ≤30	Seedling	<1	Seedling
GBH ≤10 and Height >30	Sapling	1-5	Sapling
GBH >11-30	Pole	>5-10	Understory
GBH >31-60	Young	>10-20	Canopy
GBH >61-90	Adult	>20	Emergent
GBH >91-120	Mature		
GBH >121	Old		

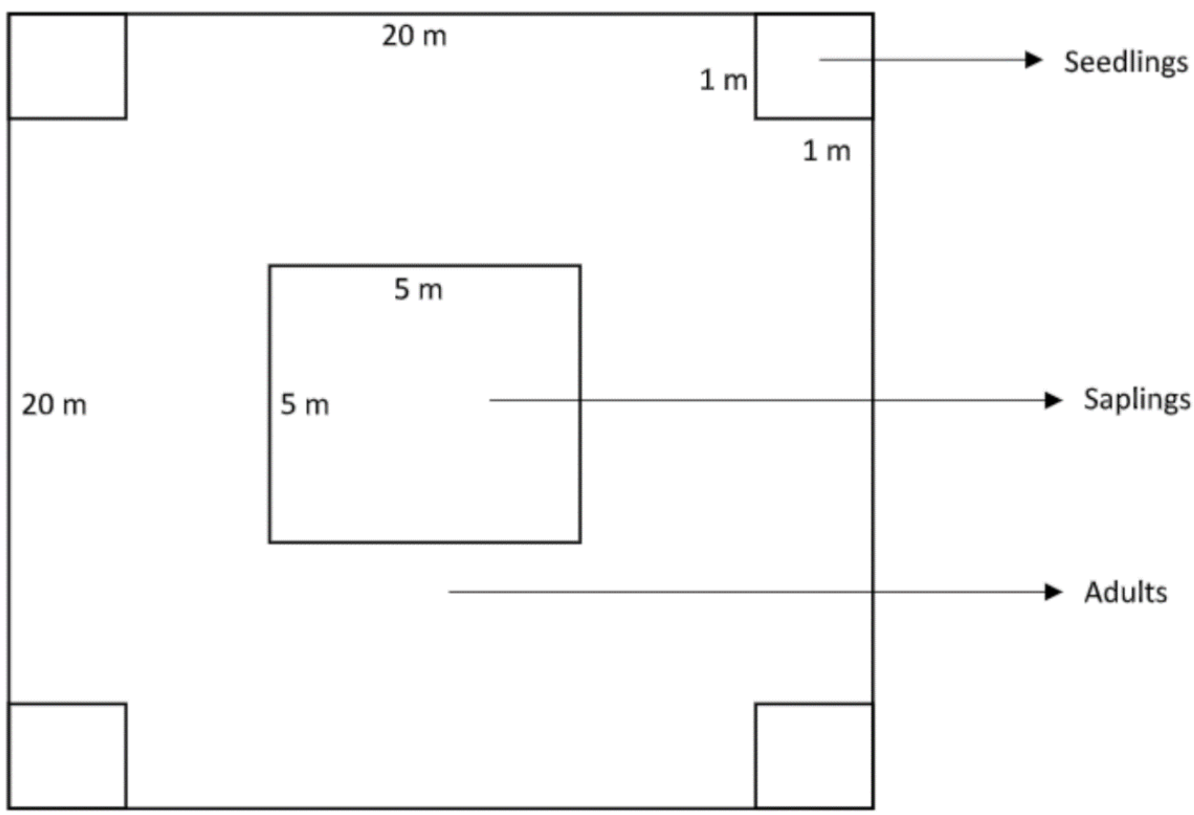

Figure 3. The sampling design of the study.

Data analysis

The data recorded were quantitatively analyzed for frequency, density, dominance, abundance and the relative values of these parameters were calculated and summed up for the Importance Value Index (IVI) (Mishra, 1968; Chhetri et al., 2019; Kunwar et al., 2020). The number of plants were converted into individuals/ha. The equations for the data analysis are presented below:

$$\text{Frequency (\%)} = \frac{\text{Number of quadrates of species occurrence}}{\text{Total number of quadrates studied}} \times 100 \quad (1)$$

$$\text{Density} = \frac{\text{Total number of individuals of a species present in all quadrates}}{\text{Total number of quadrates studied}} \times 100 \quad (2)$$

$$\text{Density} = \frac{\text{Total number of species present in all quadrates}}{\text{Total number of quadrates studied}} \times 100 \quad (3)$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species present in all quadrates}}{\text{Total number of quadrates studied}} \times 100 \quad (4)$$

$$\text{Dominance} = \sum \text{Basal area of all individuals of a species in all the studied quadrates} \quad (5)$$

$$\text{Relative frequency} = \frac{\text{Frequency of a species}}{\text{Sum of the frequency of all specie}} \times 100 \quad (6)$$

$$\text{Relative density} = \frac{\text{Density of a species}}{\text{Sum of the density of all specie}} \times 100 \quad (7)$$

$$\text{Relative abundance} = \frac{\text{Abundance of a species}}{\text{Sum of the abundance of all specie}} \times 100 \quad (8)$$

$$\text{Relative dominance} = \frac{\text{Dominance of a species}}{\text{Sum of the dominance of all specie}} \times 100 \quad (9)$$

$$\text{Importance Value Index (IVI)} = \text{Relative frequency} + \text{Relative density} + \text{Relative abundance} \quad (10)$$

Also, the index was calculated using dominance in place of abundance.

$$\text{Importance Value Index (IVI)} = \text{Relative frequency} + \text{Relative density} + \text{Relative dominance} \quad (11)$$

Margalef's index was used as a simple measure of species richness (Margalef, 1958) using the formula Margalef's index of richness (R).

$$R = \frac{S-1}{\ln N} \quad (12)$$

where S is the total number of species and N is the total number of individuals. A value of zero indicates a very low diversity of species. A value Greater than 8 indicates very high diversity of species.

Moreover, the study used the Shannon–Wiener diversity index (Shannon & Wiener, 1963) presented in the equation below:

$$H' = -\sum(p_i \ln p_i) \tag{13}$$

where, p_i is the proportion of individuals of one particular species (n) found divided by the total number of individuals (N) found. The higher index indicates more diversity of species in the habitat. If the index is zero, only one species is present in the forest.
The concentration of dominance CD was assessed using Simpson's index (Simpson, 1949) presented in the equation below:

$$CD = \sum_{i=1}^{s} P_i^2 \tag{14}$$

The value of Simpson's dominance index ranges from 0 to 1 in which 1 represents no diversity but 0 represents infinite diversity.
For calculating the evenness of species E, Pielou's evenness index was used (Pielou, 1966).

$$E = \frac{H'}{Hmax'} \tag{15}$$

where H' is the Shannon–Wiener diversity index and Hmax' is ln of total number of species. The calculated value of Pielou's evenness index ranges from 0 (No evenness) to 1 (Complete evenness).
Basal area of standing trees was calculated using following formula:

$$\text{Basal area} = \pi \times \left(\frac{DBH}{2}\right)^2 \tag{16}$$

where, DBH is the diameter at breast height.
This research performed the data analysis by using Microsoft Excel and Statistical Package for the Social Sciences (SPSS, Version 22.0) software. The maps of the study area were generated with the help of ArcGIS (Version 10.3) and Google Earth.

Results

The present study recorded a total of 1918 individuals of trees (of 30 species) in Nawabganj Sal Forest of Dinajpur in which 944 (49.22%) individuals were pole, 361 (18.82%) individuals were young, 397 (20.70%) adult, 175 (9.12%) mature and 41 (2.14%) old. Small-sized trees (poles and young) had dominated the tree population, while the maximum density (787 individuals/ha) recorded of pole individuals (> 10-30cm girth class). In terms of density (Individuals/ha), *Shorea robusta* was the most dominant tree 1548 individuals/ha followed by *Tectona grandis* (9 individuals/ha), *Syzygium cumini* (8 individuals/ha), *Trema orientale* (7 individuals/ha), *Cassia fistula* (6 individuals/ha). The density of seedlings was the highest, followed by the density of saplings in case of *Shorea robusta*, *Tectona grandis*, *Trema orientale* and *Cassia fistula*, while the density of saplings was highest, followed by seedlings in case of *Syzygium cumini*. This study found that the number of *Shorea robusta* seedlings per hectare (28923) is higher than sapling (4267) and adult trees (1548). Figure 4 presents the seedlings, saplings, and adult density of *Shorea robusta* in Nawabganj Sal Forest.

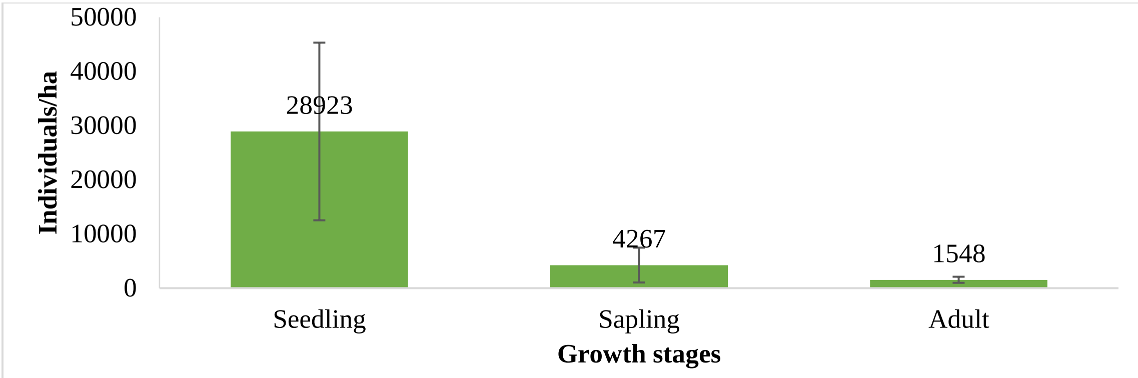

Figure 4. Seedlings, saplings, and adult density of *Shorea robusta*.

Figure 5 presents the density of tree species in different girth classes recorded in Nawabganj Sal Forest. There was a minimization in tree density with an increase in girth class in *Shorea robusta* indicating a reverse J-shaped pattern. A reverse J-shaped pattern signifies good natural regeneration. The girth class distribution of all the trees of Nawabganj Sal Forest also had a reverse J-shaped curve. A reverse J-shaped curve is a mathematical model that represents the capacity of a forest site to regenerate. This phenomenon is marked by a substantial population of seedlings, which is then followed by a decline at the subsequent stage. The reverse J-shaped morphology is also regarded as a reliable sign of old-growth woods in a state of balance. The requirement is upheld by the presence of equal death rates among all diameter classes. In undisturbed natural forests, regenerating species that are considered to be of high quality generally have an inverted J-shaped curve. The majority of studies on the population structure of tree species in tropical forests have indicated that most of these species exhibit an inverted J-shaped curve.

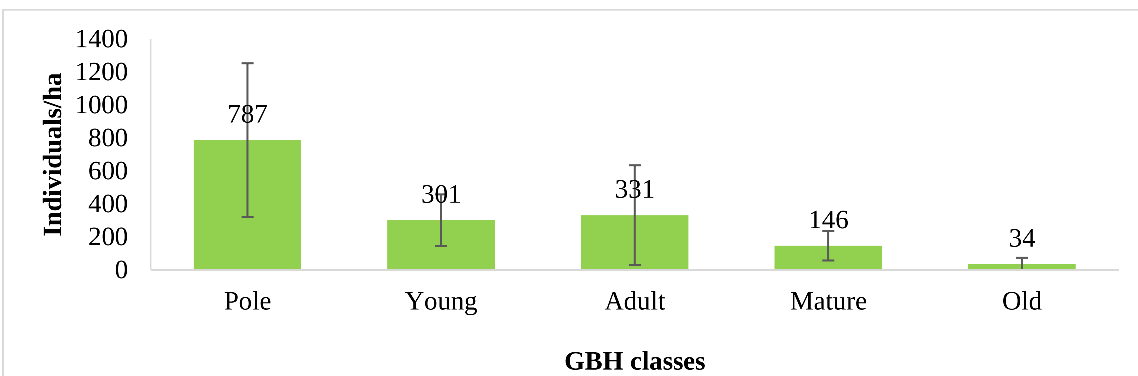

Figure 5. Density of tree species in different girth classes.

In addition, Figure 6 presents the population structure of the most dominant tree species *Shorea robusta* in Nawabganj Sal Forest. Furthermore, Figure 7 presents the population structure of four dominant tree species recorded, which are *Tectona grandis*, *Syzygium Cumini*, *Trema orientale*, and *Cassia fistula*. For *Syzygium Cumini*, the number of saplings was higher than the number of seedlings. Within a tropical forest, the population structure is expected to have an inverted J shape as it reaches its climax. This indicates that there is a higher number of seedlings compared to juveniles, and a higher number of juveniles compared to adults. A population characterized by the absence of seedlings and an abundance of adults is indicative of a population in decline. An insufficient quantity of seedlings, saplings, and young trees within a population signifies a deficiency in regeneration. The lack of young plants and trees suggests a lack of new growth.

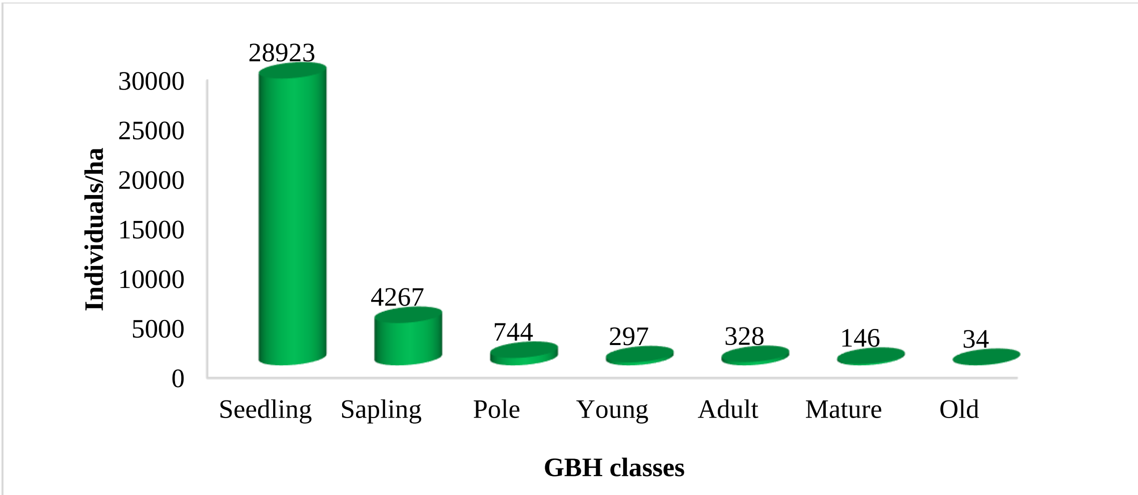

Figure 6. The population structure of the most dominant tree species *Shorea robusta*.

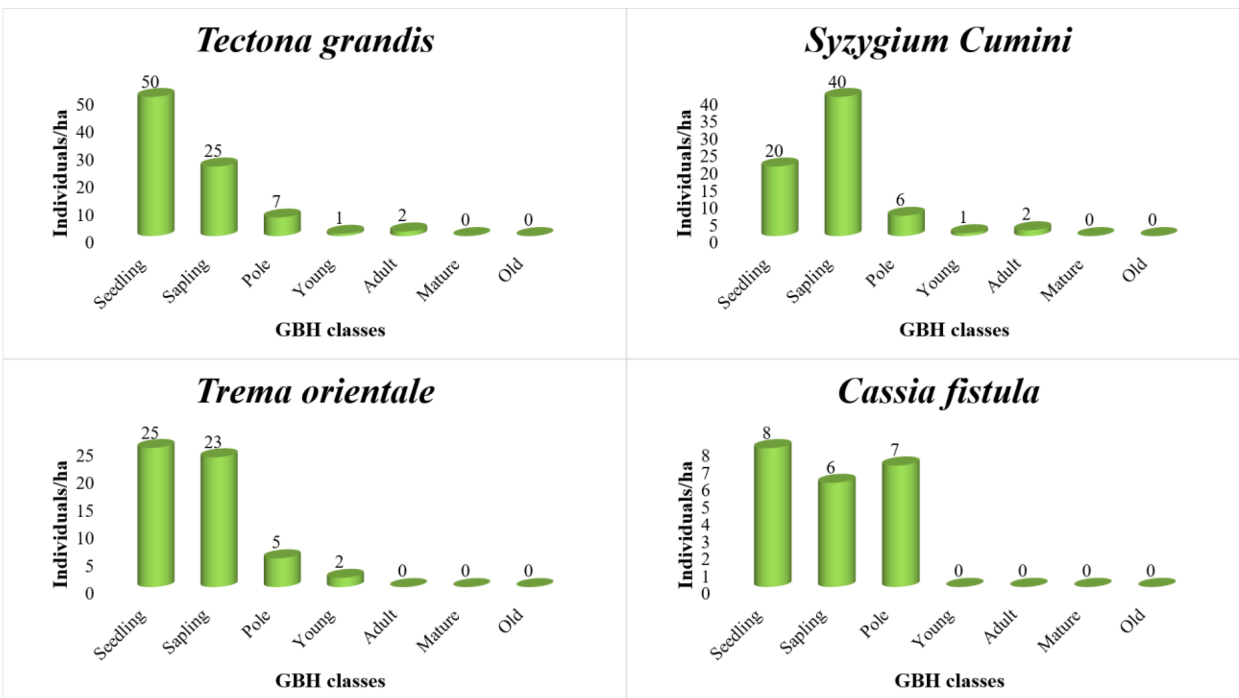

Figure 7. The population structure of four dominant tree species.

The density of trees varies significantly based on their height position. Figure 8 presents the density and percentage of tree species in different height classes in Nawabganj Sal Forest. The height of tree species ranged from 1 to 23 m (mean 5.38 ± 4.52), and the distribution of individuals was not uniform among five different height class. On the contrary, maximum percentage of species (96%) and the second highest density (1902.5/ha individuals) were found in 1–5-meter height class (saplings). The density 438 individuals/ha (13.33%) and 468 individuals/ha (6.67%) were respectively recorded in > 5-10 m (understorey) and > 10-20 m (canopy) height class. The lowest percentage (3.33%) of species was recorded in the top height class (>20 m) with a density of 21 individuals/ha. In addition, the highest density (134130 individuals/ha) and maximum percentage of species (51.61%) were recorded in < 1m height class.

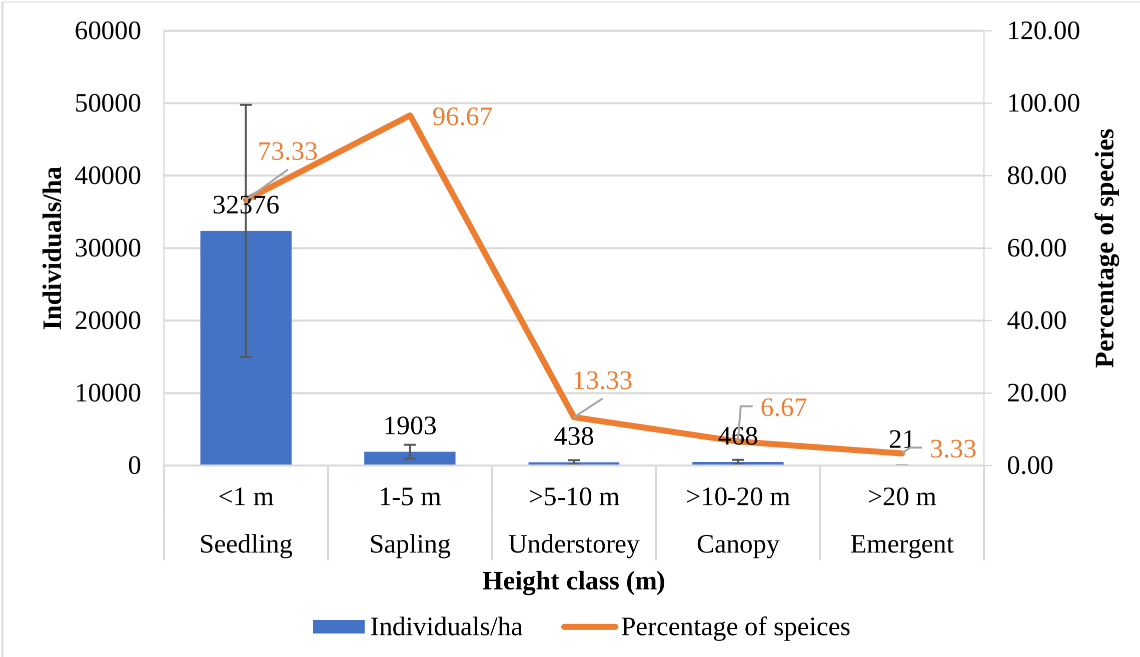

Figure 8. Density and percentage of tree species in different height classes.

The regeneration state of a tree species is assessed by the population sizes of its seedlings, saplings, and adult trees. Table 2 presents the seedling, sapling and adult density of tree species density and its regeneration status in Nawabganj Sal Forest. Among the 30 tree species, 5 species (16.67% species of total), 15 species (50% species of total), 2 species (6.67% species of total), and 8 species (26.67% species of total) respectively showed good, fair, poor, and new regeneration (Figure 9). Only adult stage was not found in all the species, so status "no regeneration " was not shown in the present study. However, the maximum species (50%) was under 'fair' status. Besides, *Shorea robusta* showed good regeneration status.

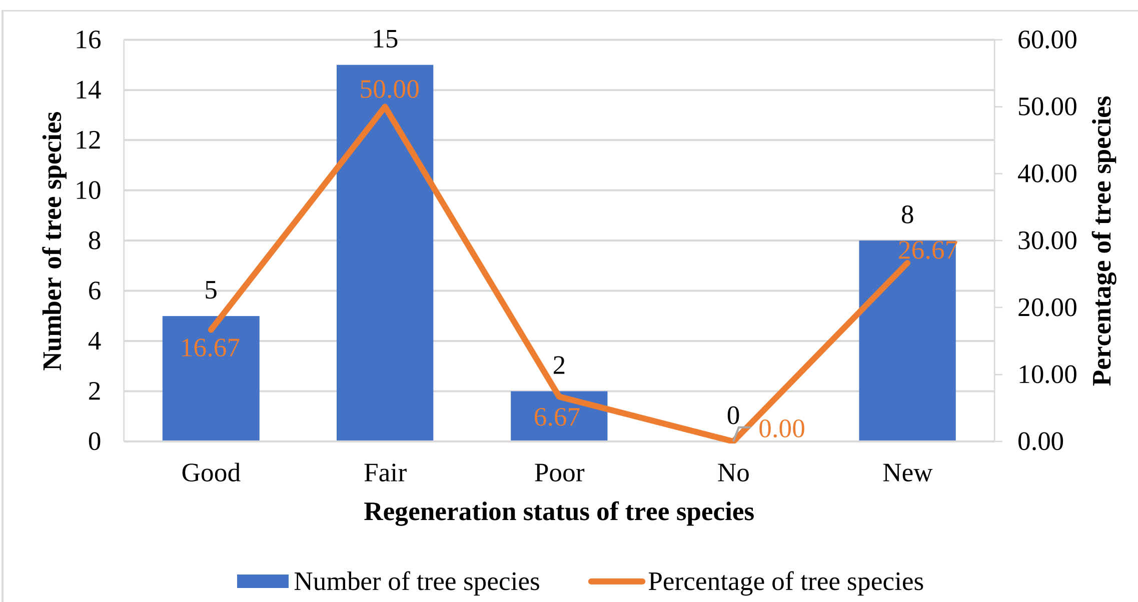

Figure 9. Regeneration status of all recorded tree species.

Table 2. The tree species density and their regeneration status.

Sl no	Common name	Species	Density (Individuals/ha)			Regeneration status
			Seedlings	Saplings	Adults	
1	Sal	*Shorea robusta*	28923	4266.67	1548.33	Good
2	Segun	*Tectona grandis*	50	25	9.17	Good
3	Jam	*Syzygium Cumini*	20	40	8.33	Fair
4	Jhingon	*Trema orientale*	25	23.33	6.67	Good
5	Sonalu	*Cassia fistula*	6.67	5.00	5.83	Fair
6	Akashmoni	*Acacia auriculiformis*	8.33	8.33	4.17	Fair
7	Pitali	*Trewia nudiflora*	8.33	20.83	3.33	Fair
8	Amloki	*Phyllanthus emblica*	0.00	3.33	2.50	Poor
9	Palash	*Butea monosperma*	8.33	13.33	1.67	Fair
10	Gamari	*Gmelina arborea*	8.33	5.00	1.67	Good
11	Kadam	*Neolamarckia cadamba*	0.00	15.00	1.67	Poor
12	Raj Koroi	*Albizia richardiana*	2.50	3.33	1.67	Fair
13	Garjon	*Dipterocarpus turbinatus*	5.83	6.67	0.83	Fair
14	Kanchan	*Bauhinia acuminata*	4.17	10.00	0.83	Fair
15	Bohera	*Terminalia bellirica*	4.17	8.33	0.83	Fair
16	Chalta	*Dillenia indica*	3.33	0.83	0.83	Fair
17	Deoa	*Artocarpus lacucha*	2.50	21.67	0.83	Fair
18	Kanthal	*Artocarpus heterophyllus*	6.67	2.50	0.83	good
19	Am	*Mangifera indica*	8.33	2.50	0.00	Fair
20	Peyara	*Psidium guajava*	0.00	1.67	0.00	New
21	Shimul	*Bombax ceiba*	0.00	1.67	0.00	New
22	Misti Amra	*Spondias pinnata*	0.00	1.67	0.00	New
23	Boroi	*Ziziphus mauritiana*	0.00	4.17	0.00	New
24	Arjun	*Terminalia arjuna*	7.50	7.50	0.00	Fair
25	Jarul	*Lagerstroemia speciosa*	0.00	0.83	0.00	New
26	Jalpai	*Elaeocarpus serratus*	0.00	0.83	0.00	New
27	Pakur	*Ficus rumphii (Pakur)*	0.00	6.67	0.00	New
28	Horitoki	*Terminalia chebula*	8.33	4.17	0.00	Fair
29	Khude Jam	*Syzygium jambos*	4.17	3.33	0.00	Fair
30	Eucalyptus	*Eucalyptus globulus*	0.00	0.83	0.00	New

Moreover, Table 3 presents a comparison of Sal seedlings regeneration in the rainy season and dry season. The p-value is greater than 0.05 which indicates the relation is not significant. Seedling shoots die back repeatedly during the long drought that follows the monsoon rain.

Table 3. Comparison of Sal seedlings regeneration in the rainy season and dry season.

Variable	Seedling numbers (Ind./ha)		Calculated value	Tabulated value	p-value
	Rainy season	Dry season			
The seedling density of Sal (Individuals/ha)	35000 ± 16583	27708 ± 16420	0.91	2.05	0.37

Table 4 presents the relative frequency, relative density, relative abundance, and IVI of the regenerating tree species. The IVI of a species is the sum of its relative frequency, relative density, and relative dominance. It's a measure of how dominant a species is in a given forest area. In terms of frequency, density and abundance, the *Shorea robusta* is completely dominated among 30 tree species by comprising highest IVI (206.83) compares to others. The other subdominant species of the site are *Tectona grandis* (13.36), *Trema orientale* (11.15), *Syzygium Cumini* (9.32), and *Cassia fistula* (8.40). In contrast, *Artocarpus heterophyllus*, *Terminalia bellirica*, *Dillenia indica*, *Artocarpus lacucha*, *Dipterocarpus turbinatus* and *Bauhinia acuminata* showed lowest IVI (2.635) values of the regenerating tree species.

Table 4. Regenerating tree species with relative frequency, relative density, relative abundance, and IVI.

Species	Relative frequency	Relative density	Relative abundance	IVI
Shorea robusta	46.875	96.771	63.186	206.832
Tectona grandis	1.563	0.573	11.223	13.358
Trema orientale	9.375	0.417	1.360	11.152
Syzygium Cumini	6.250	0.521	2.551	9.321
Cassia fistula	6.250	0.365	1.785	8.400
Trewia nudiflora	6.250	0.208	1.020	7.479
Acacia auriculiformis	1.563	0.260	5.101	6.924
Phyllanthus emblica	3.125	0.156	1.530	4.812
Gmelina arborea	3.125	0.104	1.020	4.249
Neolamarckia cadamba	3.125	0.104	1.020	4.249
Butea monosperma	1.563	0.104	2.040	3.707
Albizia richardiana	1.563	0.104	2.040	3.707
Artocarpus heterophyllus	1.563	0.052	1.020	2.635
Terminalia bellirica	1.563	0.052	1.020	2.635
Dillenia indica	1.563	0.052	1.020	2.635
Artocarpus lacucha	1.563	0.052	1.020	2.635
Dipterocarpus turbinatus	1.563	0.052	1.020	2.635
Bauhinia acuminata	1.563	0.052	1.020	2.635

Table 5 presents the regenerating tree species with frequency, density, basal area (m^2/ha) and IVI of Nawabganj Sal Forest. In case of frequency, density and basal area or dominance, maximum IVI value was also found for *Shorea robusta* (243.05) followed by *Trema orientale* (9.85), *Syzygium Cumini* (6.99), *Cassia fistula* (6.64) and *Trewia nudiflora* (6.47). On the other hand, *Terminalia bellirica*, *Dillenia indica*, *Artocarpus lacucha*, *Dipterocarpus turbinatus* and *Bauhinia acuminata* showed lowest IVI (1.62) values of the regenerating tree species. Furthermore, the Shannon-Wiener index score is positively correlated with biodiversity. Conversely, the Simpson index quantifies the proportional prevalence of species, where a greater value signifies greater dominance and lower biodiversity. The calculated value of Shannon-Weiner Index (H') and Simpson's Index in the study site were 0.223 and 0.937 respectively.

Table 5. Regenerating tree species with frequency, density, basal area (m²/ha), and IVI.

Species	Family	Frequency	Density (individuals/ha)	Basal area (m²/ha)	IVI
Shorea robusta	Dipterocarpaceae	100.000	1548.333	39.8080	243.048
Trema orientale	Cannabaceae	20.000	6.667	0.0220	9.847
Syzygium Cumini	Myrtaceae	13.333	8.333	0.0874	6.989
Cassia fistula	Fabaceae	13.333	5.833	0.0083	6.635
Trewia nudiflora	Euphorbiaceae	13.333	3.333	0.0041	6.468
Phyllanthus emblica	Phyllanthaceae	6.667	2.500	0.0016	3.285
Gmelina arborea	Lamiaceae	6.667	1.667	0.0018	3.234
Neolamarckia cadamba	Rubiaceae	6.667	1.667	0.0018	3.234
Tectona grandis	Lamiaceae	3.333	9.167	0.0913	2.364
Acacia auriculiformis	Fabaceae	3.333	4.167	0.0045	1.834
Butea monosperma	Fabaceae	3.333	1.667	0.0072	1.685
Albizia richardiana	Leguminosae	3.333	1.667	0.0016	1.671
Artocarpus heterophyllus	Moraceae	3.333	0.833	0.0035	1.623
Terminalia bellirica	Combretaceae	3.333	0.833	0.0010	1.617
Dillenia indica	Dilleniaceae	3.333	0.833	0.0010	1.617
Artocarpus lacucha	Moraceae	3.333	0.833	0.0010	1.617
Dipterocarpus turbinatus	Dipterocarpaceae	3.333	0.833	0.0008	1.617
Bauhinia acuminata	Fabaceae	3.333	0.833	0.0008	1.617

Discussion

The present study investigated the seedling, sapling and adult density of Shorea robusta in Nawabgonj Sal forest, Bangladesh. This study found that pole and young trees are dominated in the study are. Similarly, pole and young trees had also dominated in Ranchi Sal forests, Jharkhand, India as well as the young individuals were recorded in maximum density in this forest (Kumar & Saikia, 2020). Moreover, this research found that, in terms of density *Shorea robusta* was the most dominant tree followed by *Tectona grandis*, *Syzygium cumini*, *Trema orientale*, and *Cassia fistula*. Kumar and Saikia (2020) reported that, in case of density, *Shorea robusta* was the most dominant tree followed by *Diospyros melanoxylon*, *Buchanania cochinchinensis*, *Madhuka longifolia*, and *Butea monosperma* in Ranchi Sal forests, Jharkhand, India.

However, the seedling density (28923±16392) of individuals/ha of *Shorea robusta* in the present study was higher than the seedling density (22071 individuals/ha) of Ranchi Sal forests, Jharkhand, India (Kumar & Saikia, 2021), Madhupur National Park, Bangladesh (18046 seedlings/ha) (Rahman et al., 2020), Lalgarh forest range of west Bengal, India (16550 seedlings/ha) (Manna & Mishra, 2017), Sal forests of Satpura Tiger reserve, Madhya province, India (6372 seedlings/ha) (Chaubey & Sharma, 2013) and Sal forests of West Bengal, India (670 seedlings/ha) (Nag & Gupta 2014). But lower than the managed Sal Forest area (35834 individuals/ha) of Terai Sal Forest, Western Nepal (Baral & Ghimire, 2020). On the contrary, the adult density of *Shorea robusta* (1548 individuals/ha) in the present study was lower than the adult density (2431 individuals/ha) of the Sal forests of Assam, India (Deka et al., 2012), Ballavpur Wildlife Sanctuary of west Bengal, India (1414 to 2233 individuals/ha) (Nag & Gupta, 2014) but higher than the Ranchi Sal forests, Jharkhand, India (416 individuals/ha) (Kuamr and Saikia, 2021), Lalgarh forest range of west Bengal, India (318 individuals/ha) (Manna & Mishra, 2017).

There was a minimization in tree density with an increase in girth class in *Shorea robusta* indicating a reverse J-shaped pattern. A Reverse J-shaped pattern signifies good natural regeneration. A reverse J-shaped pattern in the case of *Shorea robusta* was also found by Kumar and Saikia (2021). Moreover, the girth class distribution of all the trees of Nawabganj Sal Forest also had a reverse J-shaped curve. A reverse J-shaped curve also found in Ranchi Sal forests, Eastern India (Kumar & Saikia, 2021) Madhupur and Bhawal National Park (Rahman & Vacik, 2010). The average height of tree species in Nawabganj Sal Forest is 5.38 meter, which is lower than the height (14.2 meter) of the tree species of Ranchi Sal Forest, Eastern India (Kumar & Saikia, 2021). The lowest percentage of species was recorded in the top height class and a similar result was also found in Ranchi Sal Forest (Kumar & Saikia, 2021). In accordance with Kumar and Saikia (2021) the highest density and maximum percentage of species were recorded in < 1m height class.

This study found good, fair, poor, and new regeneration of 17%, 50%, 7%, and 27% of the total species, respectively. Maximum species (50%) was under 'fair' status and the same result was also found by Manna and Mishra (2017) in Lalgarh forest range of West Bengal, India. In the present study *Shorea robusta* showed good regeneration status which is similar to the status of *Shorea robusta* found in tropical moist deciduous forest in Northern India (Mishra et al., 2023) and Ranchi Sal Forest in Eastern India (Kumar & Saikia, 2020), whereas the fair regeneration status of Sal was found in Lalgarh forest range of west Bengal, India (Manna & Mishra, 2017). In the current investigation, the adult stage was absent in all species, so the condition of "no regeneration" was not observed. Nonetheless, Kumar and Saikia (2021) conducted a study on the regeneration of Sal Forest in Ranchi Forest, India. Their findings revealed that 50 species had a "no regeneration" status.

Moreover, this research presents a comparison of Sal seedlings regeneration in the rainy season and dry season. The finding indicates that the relation is not significant. However, the result is different from the Troup (1921) as he stated that drought is a major cause of poor seedling survival of *Shorea robusta* and germination of freshly dispersed seeds used to be high during June and July and recruitment is high during August as well as seedling population minimizes after the rainy season with increased mortality in the dry winter although the death and dying back disease of Sal seedlings were high in the rainy season. According to Rao and Singh (1985), most shoots die during the dry season, and shoots establish merely if rainfall starts.

This study found that *Shorea robusta* is completely dominated among 30 tree species by comprising highest IVI (206.83) compares to others. The other subdominant species of the site are *Tectona grandis* (13.36), *Trema orientale* (11.15), *Syzygium Cumini* (9.32), and *Cassia fistula* (8.40). In contrast, *Artocarpus heterophyllus*, *Terminalia bellirica*, *Dillenia indica*, *Artocarpus lacucha*, *Dipterocarpus turbinatus* and *Bauhinia acuminata* showed lowest IVI (2.635) values of the regenerating tree species. However, Rahman et al. (2020) studied regeneration of Madhupur National Park, where they recorded the IVI values of regenerating tree species. The highest IVI values was for *Shorea robusta* (66.25 out of 300) followed by *Mallotus philippensis* (27.33), *Aporosa* sp. (17.82), *Terminalia bellirica* (14.75), *Grewia nervosa*, *Bridelia tomentosa* (14.10). On the contrast, *Grewia asiatica*, *Derris robusta*, *Lagerstroemia glutinosa* showed the lowest regeneration IVI (0.93) of the regenerating tree species.

In case of frequency, density and basal area or dominance, maximum IVI value was also found for *Shorea robusta* (243.05) followed by *Trema orientale* (9.85), *Syzygium Cumini* (6.99), *Cassia fistula* (6.64) and *Trewia nudiflora* (6.47). Conversely, *Terminalia bellirica*, *Dillenia indica*, *Artocarpus lacucha*, *Dipterocarpus turbinatus* and *Bauhinia acuminata* showed lowest IVI (1.62) values of the regenerating tree species. Manna and Mishra (2017) found that *Shorea robusta* was completely dominated among the 52 tree species by comprising highest IVI (119.32) compared to others and followed by *Diospyros melanoxylon* (27.49), *Madhuca longifolia* (18.85), *Terminalia bellirica* (13.9), *Terminalia tomentosa* (13.67) and *Terminalia tomentosa* (10.67), while *Glochidon ferdinandii* showed lowest IVI (0.02). Moreover, Kumar and Saikia (2020) also found the maximum IVI for *shorea robusta* (167.29) followed by *Diospyrus melanoxylon* Roxb. (13.04), *Buchanania cochinchinensis* (11.04), *Madhuca* *longifolia* (10.05), *Lagerstroemia parviflora* (8.50) and so on. The calculated value of Shannon-Weiner Index (H') and Simpson's Index in the study site were 0.223 and 0.937 respectively. Table 6 presents a comparison of vegetation characteristics of the studied Sal Forest with Bangladeshi Sal Forest and Indian Sal Forest.

Table 6. Comparison of vegetation characteristics of the studied Sal Forest with other Sal forests in Bangladesh and India.

Forest type and location	Plot size (ha)	Size class (cm)	Species richness	Stand density (Individuals/ha)	Basal area (m^2/ha)	Sources
Nawabganj Sal forest, Dinajpur, Bangladesh (Tropical moist deciduous forest)	1.200	≥ 10 GBH	30	1600	44.11	Present study
Madupur National Park, Tangail, Bangladesh	3.600	> 10 DBH	52	331	19.2	Rahman and Vacik (2010)
Bhawal National Park, Gazipur, Bangladesh	3.600	> 10 DBH	13	742	16.5	Rahman and Vacik (2010)
Tropical moist deciduous forests of Ranchi District, Jharkhand, India	23.500	≥ 10 GBH	137	397	262.5	Kumar and Saikia (2020)
Shorea robusta -Schima wallichii, South district, Tripura, India	4.000	≥ 10 GBH	152	872	38.6	Majumdar et al. (2014)
Moist Sal Forest (Eastern Himalayan Terai Sal) West Bengal, India	3.200	≥ 30 GBH	134	438	56.5	Kushwaha and Nandy (2012)
Sal forest of Gorakhpur Division, India	24.000	≥ 30 GBH	93	404	22.23	Pandey and Shukla (2003)
Sal forest of Gorakhpur Division, India	24.000	< 30 GBH	115	20413	0.83	Pandey and Shukla (2003)
Sal forest of Eastern Himalayas, India	2.000	≥ 10 GBH	87	484	263	Shankar (2001)
Sal forest of central Himalayas doon Valley, India	0.020	≥ 10 GBH	13.00-21.00	1150-1920	22.3-37.8	Pande (1999)
Corbett National Park, India	2.900	≥ 31.5 GBH	3.00-20.00	180-860	14.5-71.8	Singh et al. (1995)
Sal forest in Central India dry tropical, Vindhya region, India		≥ 30 GBH		294-559	7.00-23.00	Jha and Singh (1990)

The range of the Shonon-Wiener diversity index (H') was 0.83-4.10 for Indian tropical forest (Jha & Singh, 1990; Ayyappan & Parthasarathy, 1999; Pandey, 2000). Shannon-Weiner Index (H') value of the present study is higher than the Shannon-Weiner Index (H') value (0.09) of Bhawal National Park but lower than the value (1.99) of Madhupur National Park studied by Rahman and Vacik (2010). The range of Simpson's index value for a tropical forest of India was 0.21-0.92 (Visalakshi, 1995). Simpson's index value in the present study is higher than the value

(0.36) of Madhupur National Park (Rahman & Vacik, 2010), Ranchi Sal Forest, Jharkhand, India (Kumar & Saikia, 2020). In contrast, the value is lower than the Simpson's index value (0.98) of Bhawal National Park (Rahman & Vacik, 2010). Species (Pielou's) evenness index found by the current study is 0.077 whereas Margalaf's species richness index is 2.25. Species (Pielou's) evenness index of the current study is lower than the Ranchi Sal Forest, Jharkhand, Eastern India (Kumar & Saikia, 2020) as well as the index (0.50) in Madhupur National Park (Rahman & Vacik, 2010). In contrast, the value is higher than the value (0.03) found for the Bhawal National Park (Rahman & Vacik, 2010). According to Kumar and Saikia (2020), the Margalaf's species richness index was 10.28 but, in this study, it is 2.25 which is much lower than Ranchi Sal Forest, Jharkhand, Eastern India.

Global warming and climate change is a burning issue due to the increasing carbon emissions from deforestation and energy use. Nevertheless, the Sal forests in Bangladesh have seen significant degradation and currently the tree density is decreasing (Ray er al., 2023). At this critical juncture, it is imperative to enhance the existing management practices of the Sal Forest ecosystem for the future advantage of all parties involved. The viability of this ecosystem hinges upon the successful and efficient execution of a sustainable forest management strategy. To effectively manage and safeguard the current Sal Forest regions from the existing dangers, it is necessary to develop and execute a forest management plan that adheres to sustainable forest management principles. In order to safeguard and preserve the Sal forests of Bangladesh, it is imperative to contemplate a number of steps. Enhancements to silvicultural systems are necessary to facilitate successful regeneration. Simultaneously, it is worth considering sustainable alternatives to livelihoods that rely on forests, such as engaging in activities like home gardening, establishing small cottage industries that utilize forest products, engaging in beekeeping, and chicken farming. Technical and institutional education and training might also generate alternate employment prospects. In order to develop effective management strategies, it is necessary to have access to growth and yield data obtained from a suitable forest inventory. This data will enable the calculation of an annual allowable harvest that can be extracted from the Sal forests, while ensuring the long-term sustainability of their ecological, economic, and social values.

Moreover, it is necessary to conduct a precise assessment of the invaded Sal woodland in order to formulate an effective strategy for reclaiming the land. Furthermore, it is imperative to establish comprehensive safeguards to address the unlawful practices of converting forest land for agriculture, engaging in unauthorized tree cutting, smuggling timber, and hunting protected wildlife. It is imperative to enhance the management of the Sal Forest by hiring highly skilled and motivated forestry experts, allocating adequate funding, and improving infrastructure. The Sal woods should be designated as community reserves, allowing local residents to actively participate in the conservation and management efforts. At present, there is a lack of a structured framework for the extraction of timber or the collection of wild medicinal and aromatic plants. Unregulated logging frequently leads to the deterioration of forests and the decline in habitat quality. The preservation and conservation of the Sal Forest in Bangladesh hinges on the formulation and effective execution of a sustainable management strategy to safeguard these vital forest resources. The government has implemented several attempts to safeguard these crucial ecosystems, but the long-term viability of these resources has not been attained due to a dearth of effective management strategies. An inclusive and efficient sustainable management strategy should be formulated, engaging all beneficiaries and stakeholders, to effectively preserve these significant ecosystems for both current and future generations. Besides, strict law enforcement is necessary for the protection and conservation of the Sal Forest which would enhance the natural regeneration as well as the environmental sustainability.

Conclusion

The Sal forests in Bangladesh are very diverse ecosystems with significant forest biodiversity. Nevertheless, the scientific community, policymakers, and local residents have limited knowledge about the extent of diversity, resulting in inadequate documentation. The forests are under significant threat from human activities, as individuals who rely on forest resources for their social well-being directly or indirectly disrupt the forest ecosystems. Due to the lack of recognition of the value of these forests, the growing human population in the surrounding areas is expected to pose a significant threat to their survival. Large areas of forest have been cut down for the purpose of establishing human settlements, engaging in agricultural activities, constructing roads, and establishing industrial facilities. Despite being legally protected, the remaining patches are still not secure. Illegal logging and harvesting of fuelwood, gathering of non-timber products, grazing, and hunting also present a significant hazard. Nevertheless, the Sal Forest is a highly significant ecosystem due to its exceptional species richness and diversity. Therefore, this study aims to examine the regeneration dynamics and population structure of Nawabganj Sal Forest in Bangladesh toward forest conservation and environmental sustainability. The result indicates that overall regeneration status of *Shorea robusta* is good in the studied Sal Forest and the regeneration of seedlings is almost same in the rainy and the dry season. Reverse J-shaped girth class distribution shows good regeneration capacity of the forest. The Shonnon-Winner diversity index and Simpson's dominance index reveal the very low diversity of tree species as well as the basal area of tree species. The finding indicates that the Sal is the most dominant tree species followed by *Tectona grandis*, *Syzygium Cumini*, *Trema orientale* and *Cassia fistula* in Nawabganj Sal Forest, Bangladesh.

Human-caused disruptions have a substantial effect on the social and environmental welfare of society. The present study documents the population structure and regeneration status of tree species in the Nawabganj Sal Forest, which can offer essential insights for designing effective protection and management measures for these diversified forests that contain several tree species of significant ecological and economic importance. Forest management methods should prioritize fulfilling the growing demands for various wood and non-timber forest products, while simultaneously preserving the plant diversity found in these natural forests. Additionally, the results can offer administrators valuable insights into the significance of maintaining a harmonious distribution of undisturbed Sal forests for the purpose of developing biodiversity conservation strategies. Gaining a more profound comprehension of the variety of plants in Sal Forest ecosystems can also assist the country in implementing international legal agreements, such as the Convention on Biological Diversity.

However, stopping anthropogenic disturbances is needed to augment the regeneration and diversity of the forest. The diversity of shrubs, herbs, and factors that influence the regeneration of forest species have not been studied by this research, which can be explored by future studies. Moreover, it is important to prioritize minimizing disturbance, as extensive disturbance has been shown to have negative effects on the regeneration of Sal trees and the overall diversity of the forest. There is a deficiency in assessing the impact of disturbances and identifying the specific life stages of trees that are most vulnerable to disturbances. Conducting in-depth research on these inquiries would yield crucial data for holistic forest management and enhance our understanding of ecological responses to disturbances in Sal forests.

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References

Abdallah, S., Akayim, A. R., Amedor, E. N., & Afetsu, J. Y. (2023). Climate Change, Who Is Responsible?. Open Journal of Applied Sciences, 13(12), 2431-2446.

Ayyappan, N., & Parthasarathy, N. (1999). Biodiversity inventory of trees in a large-scale permanent plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats, India. Biodiversity & Conservation, 8, 1533-1554.

Baral, S., & Ghimire, P. (2020). Effect of tree canopy opening in the regeneration layer of Terai Sal (Shorea robusta Gaertn.) forest in Western Nepal: A case study. Tropical Plant Research, 7(2), 502-507.

Behera, M. C., Sahoo, U. K., Mohanty, T. L., Prus, P., Smuleac, L., & Pascalau, R. (2023). Species composition and diversity of plants along human-induced disturbances in tropical moist Sal forests of Eastern Ghats, India. Forests, 14(10), 1931.

Bergsagel, D., & Heisel, F. (2023). Structural design using reclaimed wood–A case study and proposed design procedure. Journal of Cleaner Production, 420, 138316.

Bhatta, S. P., & Devkota, A. (2020). Community structure and regeneration status of Sal (Shorea robusta Gaertn.) forests of Dadeldhura district, Western Nepal. Community Ecology, 21(2), 191-201.

Bullones, A., Castro, A. J., Lima-Cabello, E., Fernandez-Pozo, N., Bautista, R., Alché, J. D. D., & Claros, M. G. (2023). Transcriptomic Insight into the Pollen Tube Growth of Olea europaea L. subsp. europaea Reveals Reprogramming and Pollen-Specific Genes Including New Transcription Factors. Plants, 12(16), 2894.

Calvia, G., Casula, P., Farris, E., Fenu, G., Fantini, S., & Bacchetta, G. (2023). Shrub cover and soil moisture affect Taxus baccata L. regeneration at its southern range. Plants, 12(9), 1819.

Chaubey, O. P., & Sharma, A. (2013). Population structure and regeneration potential of sal (Shorea robusta Gaertn. f.) and its associates in sal bearing forests of Satpura Tiger Reserve. International Journal of Bio-Science and Bio-Technology, 5(6), 63-70.

Chhetri, N. B. K., & Shrestha, K. K. (2019). Floristic diversity and important value indices of tree species in lower Kanchenjunga Singhalila ridge Eastern Nepal. American Journal of Plant Sciences, 10(1), 248-263.

Costas-Selas, C., Martínez-García, S., Logares, R., Hernández-Ruiz, M., & Teira, E. (2023). Role of bacterial community composition as a driver of the small-sized phytoplankton community structure in a productive coastal system. Microbial Ecology, 86(2), 777-794.

Deka, J., Tripathi, O. P., & Khan, M. L. (2012). High dominance of Shorea robusta Gaertn. in alluvial plain Kamrup sal forest of Assam, NE India. International Journal of Ecosystem, 2(4), 67-73.

Elliott, S., Tucker, N. I., Shannon, D. P., & Tiansawat, P. (2023). The framework species method: harnessing natural regeneration to restore tropical forest ecosystems. Philosophical Transactions of the Royal Society B, 378(1867), 20210073.

Gonçalves, A. C., & Fonseca, T. F. (2023). Influence management and disturbances on the regeneration of forest stands. Frontiers in Forests and Global Change, 6, 1123215.

Hald-Mortensen, C. (2023). The Main Drivers of Biodiversity Loss: A Brief Overview. Journal of Ecology and Natural Resources, 7(3), 000346.

Haq, S. M., Pieroni, A., Bussmann, R. W., Abd-ElGawad, A. M., & El-Ansary, H. O. (2023). Integrating traditional ecological knowledge into habitat restoration: implications for meeting forest restoration challenges. Journal of Ethnobiology and Ethnomedicine, 19(1), 33.

Ibáñez, T. S., Wardle, D. A., Gundale, M. J., & Nilsson, M. C. (2022). Effects of soil abiotic and biotic factors on tree seedling regeneration following a boreal forest wildfire. Ecosystems, 25(2), 471-487.

Iskandar, M., Siregar, I. Z., & Krisnawati, H. (2023). Potential of carbon sequestration enhancement through intensive silvicultural techniques using Shorea leprosula plantation in Central Kalimantan, Indonesia. Biodiversitas Journal of Biological Diversity, 24(8), 4699-4513.

Jamloki, A., Singh, A., Chandra, S., Shukla, V., Nautiyal, M. C., & Malik, Z. A. (2023). Population structure, regeneration potential and leaf morphological traits of Rhododendron campanulatum D. Don along an altitudinal gradient in Western Himalaya. Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology, 157(1), 159-174.

Jha, C. S., & Singh, J. S. (1990). Composition and dynamics of dry tropical forest in relation to soil texture. Journal of Vegetation Science, 1(5), 609-614.

Koulelis, P. P., Proutsos, N., Solomou, A. D., Avramidou, E. V., Malliarou, E., Athanasiou, M., ... & Petrakis, P. V. (2023). Effects of climate change on greek forests: A review. Atmosphere, 14(7), 1155.

Kumar, R., & Saikia, P. (2020). Floristic analysis and dominance pattern of sal (Shorea robusta) forests in Ranchi, Jharkhand, eastern India. Journal of Forestry Research, 31(2), 415-427.

Kumar, R., & Saikia, P. (2021). Population structure and regeneration status of Shorea robusta and associated trees in Sal forests of Ranchi, Eastern India. Tropical Ecology, 62(1), 34-51.

Kunwar, R. M., Fadiman, M., Thapa, S., Acharya, R. P., Cameron, M., & Bussmann, R. W. (2020). Plant use values and phytosociological indicators: Implications for conservation in the Kailash Sacred Landscape, Nepal. Ecological Indicators, 108, 105679.

Kushwaha, S. P. S., & Nandy, S. (2012). Species diversity and community structure in sal (Shorea robusta) forests of two different rainfall regimes in West Bengal, India. Biodiversity and Conservation, 21, 1215-1228.

Lapola, D. M., Pinho, P., Barlow, J., Aragão, L. E., Berenguer, E., Carmenta, R., ... & Walker, W. S. (2023). The drivers and impacts of Amazon forest degradation. Science, 379(6630), eabp8622.

Latterini, F., Mederski, P. S., Jaeger, D., Venanzi, R., Tavankar, F., & Picchio, R. (2023). The Influence of Various Silvicultural Treatments and Forest Operations on Tree Species Biodiversity. Current Forestry Reports, 9(2), 59-71.

Li, K., & Xu, E. (2023). Differentiating effects of salvage logging and recovery patterns on post-fire boreal forests in Northeast China using a modified forest disturbance index. GIScience & Remote Sensing, 60(1), 2188674.

Liu, D., Zhou, C., He, X., Lei, X., Zhang, H., & Liu, X. (2023). Exploring the role of canopy triangular units in analysing canopy effects on saplings. Forest Ecology and Management, 552, 121572.

Liu, D., Zhou, C., He, X., Zhang, X., Feng, L., & Zhang, H. (2022). The effect of stand density, biodiversity, and spatial structure on stand basal area increment in natural spruce-fir-broadleaf mixed forests. Forests, 13(2), 162.

Ma, L., Du, W., Shu, H., Cao, H., & Shen, C. (2023). Spatial Pattern of Deadwood Biomass and Its Drivers in a Subtropical Forest. Forests, 14(4), 773.

Majumdar, K., Shankar, U., & Datta, B. K. (2014). Trends in tree diversity and stand structure during restoration: a case study in fragmented moist deciduous forest ecosystems of Northeast India. Journal of Ecosystems, 2014.

Maletha, A., Maikhuri, R. K., & Bargali, S. S. (2023). Population structure and regeneration pattern of Himalayan birch (Betula utilis D. Don) in the timberline zone of Nanda Devi Biosphere Reserve, Western Himalaya, India. Geology, Ecology, and Landscapes, 7(3), 248-257.

Manna, S. S., & Mishra, S. P. (2017). Diversity, population structure and regeneration of tree species in Lalgarh forest range of West Bengal, India. International Journal of Botany Studies, 2(6), 191-195.

Margalef, R. (1958) Temporal succession and spatial heterogeneity in phytoplankton. In: Buzzati-Traverso A (ed) Perspectives in marine biology. University of California Press, Berkeley, (pp. 323–347).

Mishra, G., Meena, R. K., Kant, R., Pandey, S., Ginwal, H. S., & Bhandari, M. S. (2023). Genome-wide characterization leading to simple sequence repeat (SSR) markers development in Shorea robusta. Functional & Integrative Genomics, 23(1), 51.

Mishra, R. (1968). Ecology Work Book. Oxford and IBH Publications, Co. New Delhi.

Mishra, S. N., Gupta, H. S., & Kulkarni, N. (2021). Impact of climate change on the distribution of Sal species. Ecological Informatics, 61, 101244.

Nag, A., & Gupta, H. (2014). Population structure and natural regeneration of sal (Shorea Robusta Gaertn. F.) in dry deciduous forests of West Bengal. International Journal of Scientific Research in Environmental Sciences, 2(11), 421.

Pande, P. K. (1999). Comparative vegetation analysis and sal (Shorea robusta) regeneration in relation to their disturbance magnitude in some Sal forests. Tropical Ecology, 40(1), 51-61.

Pandey, S. K. (2000). Population status and regeneration strategy of some perennial legumes in plantation forests of North-Eastern Uttar Pradesh (Doctoral dissertation, Ph. D. Thesis, DDU Gorakhpur University, Gorakhpur, India).

Pandey, S. K., & Shukla, R. P. (2003). Plant diversity in managed sal (Shorea robusta Gaertn.) forests of Gorakhpur, India: species composition, regeneration and conservation. Biodiversity & Conservation, 12(11), 2295-2319.

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. Journal of theoretical biology, 13, 131-144.

Pokhriyal, P., Uniyal, P., Chauhan, D. S., & Todaria, N. P. (2010). Regeneration status of tree species in forest of Phakot and Pathri Rao watersheds in Garhwal Himalaya. Current science, 171-175.

Rahman, M. M., & Vacik, H. (2010). Vegetation analysis and tree population structure of Sal (Shorea robusta CF Gaertn) forests: A case study from the Madhupur and Bhawal National Park in Bangladesh. In National parks: vegetation, wildlife and threats (pp. 193-206). Nova Science Publishers New York.

Rahman, M. R., Hossain, M. K., Hossain, M. A., & Hasan, M. E. (2020). Natural regeneration potential of Madhupur National Park, Bangladesh. Bangladesh Journal of Botany, 49(4), 989-996.

Rao, P. B., & Singh, S. P. (1985). Population dynamics of a foot-hill Sal (Shorea robusta Gaertn. f.) forest in Kumaun Himalaya. Acta Oecologica Oecologia Plantarum (France).

Ray, P. C., Hasan, M. F., Hossan, M. S., & Hanif, M. A. (2023). Forest co-management for improvement of livelihood and forest cover: Experience from Sal Forest of Bangladesh. Trees, Forests and People, 14, 100450.

Roshni, N. A., Hasan, M. K., Wadud, M. A., Hasan, A. K., Akter, R., Khan, R. N. A., & Hemel, S. A. K. (2023). Toxic Metal Levels in Forest Soils Caused by Industrialization and Impacts on Tree Biomass Carbon Stock. Environmental Processes, 10(3), 45.

Saha, S., Hasan, S. S., Haque, M. E., & Ahamed, T. (2021). Perception based assessment of ecosystem services of Madhupur Sal Forest in Bangladesh. European Journal of Agriculture and Food Sciences, 3(1), 39-44.

Sarkar, M., & Devi, A. (2014). Assessment of diversity, population structure and regeneration status of tree species in Hollongapar Gibbon Wildlife Sanctuary, Assam, Northeast India. Tropical plant research, 1(2), 26-36.

Scheiner, S. M. (2003). Six types of species-area curves. Global ecology and biogeography, 12(6), 441-447.

Shankar, U. (2001). A case of high tree diversity in a sal (Shorea robusta)-dominated lowland forest of Eastern Himalaya: Floristic composition, regeneration and conservation. Current Science, 776-786.

Shannon, C. E., & Wiener, W. (1963). The mathematical theory of Communication University. Urbana: Illinois Press, 125.

Sharma, L. N., Adhikari, B., Watson, M. F., Shrestha, B. B., Paudel, E., Karna, B., & Rijal, D. P. (2022). Forest canopy resists plant invasions: a case study of Chromolaena odorata in Sal (Shorea robusta) forests of Nepal. Journal of Tropical Ecology, 38(2), 49-57.

Sharma, L. N., Shrestha, K. B., & Måren, I. E. (2019). Tree regeneration in gap-understory mosaics in a subtropical Shorea robusta (Sal) forest. Journal of Forestry Research, 30, 2061-2068.

Simpson, E. H. (1949). Measurement of diversity. nature, 163(4148), 688-688.

Singh, A., Reddy, V. S., & Singh, J. S. (1995). Analysis of woody vegetation of Corbett National park, India. Vegetatio, 120, 69-79.

Troup, R.S. (1921). The silviculture of Indian trees. Claredon press, Oxford, 1-3.

Ullah, S. A., Tsuchiya, J., Asahiro, K., & Tani, M. (2022). Exploring the socioeconomic drivers of deforestation in Bangladesh: The case of Teknaf Wildlife Sanctuary and its surrounding community. Trees, Forests and People, 7, 100167.