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Tree species diversity, composition and structure in the tropical moist deciduous forest of Kadigarh National Park, Mymensingh, Bangladesh

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Abstract. *Das N. 2024. Tree species diversity, composition and structure in the tropical moist deciduous forest of Kadigarh National Park, Mymensingh, Bangladesh. Asian J For 8: 41-49.* The species diversity, floristic composition, and structural characteristics of tree species in Kadigarh National Park, Mymensingh, Bangladesh, where the forest is of the tropical moist deciduous type, were explored. The study was carried out by randomly sampling 20 m × 20 m plots to record and identify trees in the area, resulting in 87 species belonging to 70 genera and 34 families. Additionally, the stem density, Basal area, diversity indices, and importance value index of tree species with a Diameter at Breast Height (DBH) of ≥5 cm were assessed in this protected area. The basal area of tree species and stem density were 18.105±1.06 m^2 ha^{-1} and 1373.07±44.83 stems ha^{-1}, respectively. The diversity indices, such as the Shannon-Wiener diversity, Simpson diversity, Margalef's richness, and Pielou's evenness index, showed poor diversity compared to other protected areas in Bangladesh. The structural composition based on DBH and height indicated higher regeneration and recruitment, but the trees of large-growth classes were removed. *Sal* (*Shorea robusta* Gaertn.) was identified as the most dominant and native tree species, accounting for 72% of the tree individuals. However, some rare tree species, such as *Sidha* (*Lagerstroemia parviflora* Roxb.), *Mahua* (*Madhuca longifolia* (J.Koenig ex L.) J.F.Macbr.), and *Thona* (*Oroxylum indicum* (L.) Kurz), showed the presence of *Sal*. Therefore, this research will support future policymakers in formulating a forest resource management plan for Kadigarh National Park.

Keywords: Diversity indices, Kadigarh National Park, structural composition

INTRODUCTION

The natural forest structure of Bangladesh has been negatively changed by biotic and abiotic disturbances, which have ultimately affected the regeneration and population dynamics during the last few decades (Shaforth et al. 2002; Kwit and Platt 2003). The size distribution of trees in natural forests is a fundamental characteristic of forest structure (Lai et al. 2013). Understanding forest stand parameters, such as DBH class distribution, height class distribution, and stocking, is important for modeling future forest wood production (Das et al. 2018a). Describing the number of species, tree density, Basal area, and stock (volume) per hectare in a forest stand is important for comparing it with a desired level for balanced forest health and growth. However, the rapid loss and degradation of forests have led to an alarming rate of forest biodiversity depletion in Bangladesh (Rahman et al. 2000; Hossain 2001). The conservation of biological diversity to ensure their sustainable use, the fair and equitable sharing of benefits arising from using genetic resources, and complex ecosystem functions are major aims of the convention of biological diversity. Moreover, information on floristic composition, their quantitative structure, and diversity is vital for understanding the functioning and dynamics of forest ecosystems (Reddy et al. 2008).

Floristic and ecological studies are essential for understanding the distribution and composition of plant communities in natural forests (Haq et al. 2023). Assessing the levels, distribution, and dynamics of native tree species is crucial for a better understanding of a particular forest's distribution and species diversity dynamics. The flora of forest regeneration plays a key role in preserving biodiversity and informing conservation plans. Additionally, understanding the status and structure of biological resources is vital for achieving effective conservation and management, particularly for native tree species. Bangladesh consists of 3611 angiosperm species belonging to 198 families, of which 988 species under 41 families belong to monocotyledons and 2623 species under 158 families belong to dicotyledones (Ahmed et al. 2008).

The *Sal* (*Shorea robusta* Gaertn.) forest is a tropical, moist deciduous forest located in the Districts of Tangail, Mymensingh, Gazipur, and Dinajpur in Bangladesh (Rahman et al. 2010). *Sal* is gregarious and dominant in its stand (Troup 1986). *Sal* regenerates from seed origin or by coppicing, sprouting from root suckers, and there is no difference in the vigor of the seedlings from coppice or seed origin (Gautam and Devoe 2006; Das 2015a). The biodiversity of *Sal* forests is very wide and interesting from ecological and conservation perspectives (Alam 1995). The composition of tree species is considered a biodiversity indicator and an important attribute of forest ecosystems (Malaker et al. 2010). Furthermore, non-timber forest products of *Sal* forests are important to rural people in terms of food, fodder, medicines, and domestic requirements (Das 2014a). These forests are composed of many medicinal plants like *Arjune* (*Terminalia arjuna*

(Roxb.) Wight & Arn.), *Haritaki* (*Terminalia chebula* Retz.), *Bohera* (*Terminalia bellirica* (Gaertn.) Roxb.), and *Kurchi* (*Holarrhena antidysenterica* (L.) Wall. ex A.DC.) (Khan et al. 2001). At present, devastating anthropogenic and natural impacts, along with overexploitation of forest resources, have caused severe damage to the *Sal* forest ecosystem (Hossain et al. 2013a).

Forest biodiversity conservation is essential in Bangladesh as the forests are undergoing severe degradation countrywide due to anthropogenic disturbances inside the forest, over-extraction of forest resources, inappropriate forest management systems, and lack of proper conservation initiatives (Hassan 1995; Dutta et al. 2015). Many researchers have investigated plant species diversity and forest stand structure in Bangladesh (Rahman et al. 2011; Hossain et al. 2012; Hossain et al. 2013b; Feeroz and Uddin 2015; Hossain et al. 2015; Sarker et al. 2015; Chowdhury et al. 2018; Das et al. 2018b). The sustainability and resiliency of a forest ecosystem can be ensured if the floristic composition, structure, and diversity are known for managerial decision-making and development planning. However, the Kadigarh National Park lacks information regarding structural composition, stocking, and conservation issues. Hence, the present study was conducted in Bangladesh's Kadigarh National Park (KNP) to assess tree species composition, diversity, and structural composition based on DBH and height class distribution.

MATERIALS AND METHODS

Study area

Kadigarh National Park (KNP) is a tropical, moist deciduous forest under the jurisdiction of the Mymensingh Forest Division, Bangladesh. It is located between 24°19' to 24°21'N latitude and 90°18' to 90°20'E longitude, situated on the western side of the Dhaka-Mymensingh main road, covering an area of 344.13 ha (Figure 1). The soil is highly oxidized, reddish-brown clay containing ferruginous nodules and manganese spots, belonging to the bio-ecological zone of the Madhupur Sal Tract (Nishat et al. 2002, Das and Sarker 2015). The soils have a moderate to strong acidic reaction (Richards and Hassan 1988) and are characterized by low organic matter and fertility (Alam 1995). According to the Bangladesh Meteorological Department (BMD 2008) studies, the annual rainfall ranges from 2110 to 2310 mm, temperatures range from 11 to 35°C, and humidity falls between 61 and 87%.

Field data collection

The study was conducted from November 2021 to March 2022. Approximately 62 random sample plots, each measuring 20 m × 20 m, covered a sample intensity of 0.72% of the total area based on the QGIS geoprocessing tool in and around the KNP for the present study (Figure 1). The geographical locations of each sample plot were recorded using a Ground Positioning System (GPS) device (Transight Systems Private Limited & ICOMPASS). If randomly generated plots were unavailable, the nearest available plots were selected instead. Plants with a Diameter at Breast Height (DBH) ≥5 cm (Hossen et al. 2021) were enumerated from the quadrats. The total height (m) and DBH (in cm) of all trees inside the demarcated plots were measured using a Santo Clinometer (SUUNTO & Suunto PM-5 Clinometer) and diameter tape, respectively. For multi-stemmed trees, the bole DBH (cm) was measured below the forking if the height was 1.37 m from the ground (Sarker et al. 2013; Das 2014b, c; Das 2015b). Samples of unknown tree species were collected for the preparation of herbarium.

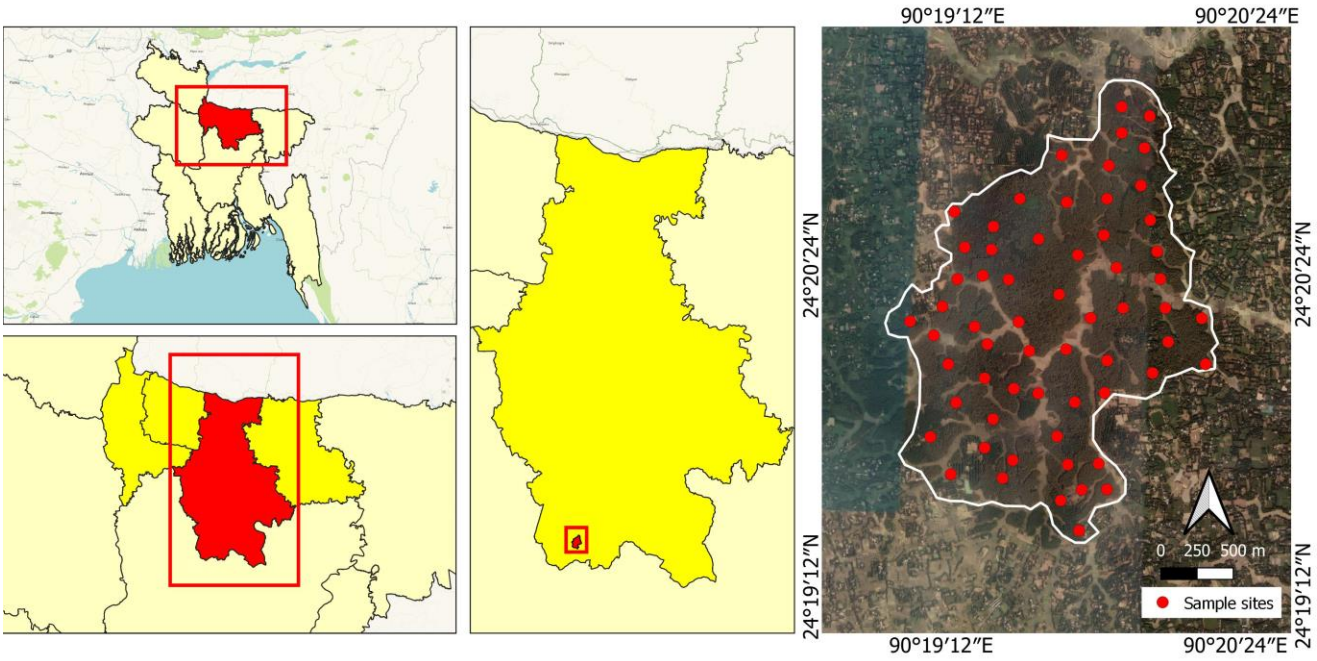

Figure 1. Location map of Kadigarh National Park in Bangladesh

Table 1. The list of phytosociological characters of the vegetation

Phytosociological Features	Formula	References
Basal Area/ha (BA)	$BA=\frac{\sum \Pi \times D2/4}{\sum \text{Area of all quadrate}} \times 10000$	Shukla and Chandel (2000), Chowdhury et al. (2019)
Density (D)	$D=\frac{a}{b}$	Shukla and Chandel (2000)
Relative Density (RD)	$RD=\frac{n}{N} \times 100$	Dallmeier et al. (1992)
Frequency (F)	$F=\frac{c}{b}$	Shukla and Chandel (2000)
Relative Frequency (RF)	$RF=\frac{Fi}{\sum_{i=1}^{s}(Fi)}$	Dallmeier et al. (1992)
Abundance (A)	$A=\frac{n}{c}$	Shukla and Chandel (2000)
Relative Abundance (RA)	$RA=\frac{Ai}{\sum_{i=1}^{s}(Ai)}$	Shukla and Chandel (2000)
Relative dominance (D)	$RD=\frac{\text{Basal area of one specis}}{\text{Total basal area}} \times 100$	Hossain et al. (2013a), Chowdhury et al. (2019)
Importance Value Index (IVI)	IVI=RD+RF+RA	Dallmeier et al. (1992), Shukla and Chandel (2000)

Table 2. The list of biodiversity indices of the vegetation

Biodiversity Indices	Formula	References
Shannon-Weiner's diversity index (H)	$H=-\sum_{i=1}^{n} P_i \ln P_i$	Shannon and Weaver (1963)
Simpson's diversity index (D)	$D=\sum_{i=1}^{n} P_i^2$	Simpson (1949)
Margalef's richness index (R)	$R=\frac{(S-1)}{LN(N)}$	Margalef (1958)
Pielou's evenness index (E)	$E=\frac{H}{Ln(S)}$	Pielou (1966)

Data analysis

The field data were analyzed to determine density, Relative Density (RD %), frequency, relative frequency (RF %), abundance, Relative Abundance (RA %), and Importance Value Index (IVI) (Table 1). Moreover, biodiversity indices such as Shannon's diversity index (Shannon and Weaver 1963), Simpson's diversity index (Simpson 1949), Pielou species evenness index (Pielou 1966), and Margalef species richness index (Margalef 1958) are listed in Table 2.

RESULTS AND DISCUSSION

Tree species composition

The study reveals 87 species belonging to 70 genera and 34 families in Kadigarh National Park (Table 3). Moraceae and Euphorbiaceae are represented by the highest number of species (eight species each), followed by Caesalpiniaceae, Mimosaceae, and Myrtaceae, each having five species. Some common species of the natural forest, such as *Sal* (*S. robusta*), *Bohera* (*T. bellirica*), *Haritaki* (*T. chebula*), *Neol* (*Protium serratum* (Wall. ex Colebr.) Engl.), *Sinduri* (*Mallotus philippensis* (Lam.) Müll.Arg.), and *Bheola* (*Semecarpus anacardium* L.fil.), are growing within the natural forest patch.

Diversity indices

A total of 1,373 individual stems are recorded from this park. The vacant area of the forest is now covered with more or less mixed plantations, resulting in a high stem density of 878 stems per hectare. The Shannon-Wiener diversity index (0.791±0.06), Simpson diversity index (0.583±0.04), Margalef species richness index (1.278±0.10), and Pielou species evenness index (0.429±0.01) were calculated for the study area (Table 4). The values of the Shannon-Wiener diversity, Simpson diversity, Margalef's richness, and Pielou's evenness index indicate a poor diversity of tree species in this area.

Quantitative structure of tree species

Sal (*S. robusta*) is represented by maximum stem density (1,193.72 stem ha^{-1}) followed by *T. chebula* (32.56 stem ha^{-1}). *S. robusta* is the single plant species represented by maximum (57.84%) relative density, maximum (40.76%) relative frequency, maximum (28.62%) relative abundance, and maximum (81.34%) relative dominance (Table 5). The highest relative density of this plant species was comprised of all the tree individuals, followed by *T. chebula* (3.30%), *T. bellirica* (2.89%), and *H. orixensis* (2.82%). The importance value index (IVI) of the species revealed that *S. robusta* has a maximum IVI of 185.12 out of 300, followed by *T. chebula* (8.59) and *T. bellirica* (6.42) (Table 5).

Table 3. List of tree species recorded from Kadigarh National Park, Bangladesh

Family	Scientific Name	Local Name	Use
Anacardiaceae	*Mangifera indica* L.	*Aam*	F, Fd, T
Anacardiaceae	*Semecarpus anacardium* L.fil.	*Bheula, Bhela*	Fd, N, T
Annonaceae	*Miliusa velutina* (Dunal) Hook. f. & Thom.	*Gandhi gajari*	Fd
Apocynaceae	*Alstonia scholaris* (L.) R. Br.	*Chatian*	M, N
Apocynaceae	*Holarrhena antidysenterica* (L.) Wall. ex A.DC.	*Kurchi*	M
Arecaceae	*Phoenix acaulis* Buch. –Ham. ex Roxb.	*Khudi khejur*	Fd
Bignoniaceae	*Oroxylum indicum* (L.) Kurz	*Thona*	M
Bixaceae	*Bixa orellana* L.	*Ranggula*	M, N
Bombacaceae	*Bombax ceiba* L.	*Shimul*	M, T
Burseraceae	*Garuga pinnata* Roxb.	*Sada Jiga*	Fd, M, T
Burseraceae	*Lannea coromandelica* (Houtt.) Merr.	*Jiga*	Fd, M, N, T
Burseraceae	*Protium serratum* (Wall. ex Colebr.) Engl.	*Neul, Neur*	Fd, T
Caesalpiniaceae	*Bauhinia malabarica* Roxb.	*Chokakola*	F, N
Caesalpiniaceae	*Cassia fistula* L.	*Sonalu, Banor noli*	Fd, M, N, T
Caesalpiniaceae	*Delonix regia* Rafin.	*Krisnachura*	N
Caesalpiniaceae	*Peltophorum pterocarpum* (DC.) K. Heyne	*Halud krisnachura*	Fd, N, T
Caesalpiniaceae	*Tamarindus indica* L.	*Tentul*	Fd, T
Clusiaceae	*Garcinia cowa* Roxb. ex DC.	*Cao*	Fd, M
Combretaceae	*Terminalia arjuna* (Roxb.) Wight & Arn.	*Arjun*	M, T
Combretaceae	*Terminalia bellirica* (Gaertn.) Roxb.	*Bohera*	Fd, M, T
Combretaceae	*Terminalia chebula* Retz.	*Haritaki*	Fd, M, N, T
Dilleniaceae	*Dillenia indica* L.	*Chalta*	Fd, M, T
Dilleniaceae	*Dillenia scabrella* Roxb. ex Wall.	*Ajuli, Ajugi*	Fd, T
Dipterocarpaceae	*Dipterocarpus costatus* Gaertn.	*Sada garjan*	F, N, T
Dipterocarpaceae	*Dipterocarpus turbinatus* Gaertn.	*Telia garjan*	N, T
Dipterocarpaceae	*Hopea odorata* Roxb.	*Telsur*	M, N, T
Dipterocarpaceae	*Shorea robusta* Gaertn.	*Sal*	T
Euphorbiaceae	*Antidesma acuminatum* Wall. in Wight.	*Chokoi*	Fd
Euphorbiaceae	*Aporosa* sp.	*Kharjon*	F, Fd
Euphorbiaceae	*Bischofia javanica* Bl.	*Kanjal bhadi*	M, T
Euphorbiaceae	*Bridelia tomentosa* Bl.	*Sitki*	M
Euphorbiaceae	*Croton tiglium* L.	*Bish khagor, Jamai gota*	M, N
Euphorbiaceae	*Mallotus philippensis* (Lam.) Müll.Arg.	*Sinduri*	T
Euphorbiaceae	*Phyllanthus emblica* L.	*Amloki*	Fd, M, N
Euphorbiaceae	*Ricinus communis* L.	*Varenda*	M
Fabaceae	*Gliricidia sepium* (Jacq.) Kunth ex Walp.	*Gliricidia*	M, N
Lauraceae	*Cryptocarya amygdalina* Nees.	*Ojha*	Fd, T
Lauraceae	*Litsea glutinosa* (Lour.) Robinson	*Kharajora, Menda*	M
Lecythidaceae	*Careya arborea* Roxb.	*Gadila, Kumbi*	N, T
Lythraceae	*Lagerstroemia parviflora* Roxb.	*Sidha*	N, T
Lythraceae	*Lagerstroemia speciosa* (L.) Pers.	*Jarul*	N, T
Meliaceae	*Azadirachta indica* A. Juss.	*Neem*	M, N
Meliaceae	*Melia azedarach* L.	*Ghoranim, Bokhain*	M, T
Meliaceae	*Swietenia mahagoni* Jacq.	*Mahagoni*	T
Meliaceae	*Toona ciliata* M. Roem.	*Toon, Rongi*	T
Mimosaceae	*Acacia auriculiformis* A. Cunn. ex Benth.	*Akashmoni*	F, N, T
Mimosaceae	*Albizia lebbeck* (L.) Benth.	*Kala Koroi*	Fd, M, N, T
Mimosaceae	*Albizia procera* (Roxb.) Benth.	*Shil koroi, Sada koroi*	F, M, T
Mimosaceae	*Albizia richardiana* (Voigt.) King & Prain	*Raj koroi*	N, T
Mimosaceae	*Aphanamixis polystachya* (Wall.) R.N. Parker.	*Ptiraj*	Fd, M, T
Moraceae	*Artocarpus heterophyllus* Lam.	*Kanthal*	Fd, N, T
Moraceae	*Artocarpus lacucha* Buch.-Ham.	*Borta*	Fd, M, T
Moraceae	*Ficus benghalensis* L.	*Bot*	Fd, M, N
Moraceae	*Ficus hispida* L.f.	*Dumor, Kodora*	Fd, T
Moraceae	*Ficus racemosa* L.	*Jagya dumur*	Fd, M, N
Moraceae	*Ficus religiosa* L.	*Bot*	Fd, M
Moraceae	*Ficus virens* Ait.	*Pakur, Pakar, Paikur*	Fd
Moraceae	*Streblus asper* Lour.	*Sheora*	F, Fd, M
Myrsinaceae	*Ardisia colorata* Roxb.	*Vet*	M
Myrtaceae	*Cleistocalyx nervosum* (DC.) Kosterm.	*Ludijam, Dephajam,*	M
Myrtaceae	*Psidium guajava* L.	*Payara*	F, Fd, M, N
Myrtaceae	*Syzygium cumini* (L.) Skeels	*Kalojam*	Fd, T
Myrtaceae	*Syzygium firmum* Thw.	*Dhakijam*	Fd, N

Myrtaceae	*Syzygium fruticosum* DC.	*Putijam, Titijam*	Fd, T
Oxalidaceae	*Averrhoa carambola* L.	*Kamranga*	Fd, M, N
Rhamnaceae	*Ziziphus mauritiana* Lam.	*Boroi*	Fd
Rhamnaceae	*Ziziphus rugosa* Lam.	*Anoi, Anai gota*	Fd, M
Rubiaceae	*Haldina cordifolia* (Roxb.) Ridsdale	*Kaika, haldu*	T
Rubiaceae	*Hymenodictyon orixensis* (Roxb.) Mabb.	*Bhutum*	N, M
Rubiaceae	*Neolamarckia cadamba* (Roxb.) Bosser	*Kadom*	M, N, T
Rubiaceae	*Tamilnadia uliginosa* (Retz.) Tirveng. & Sastre	*Pirilagota, Piralo*	M
Rutaceae	*Aegle marmelos* (L.) Corr.	*Bel*	Fd, M, T
Rutaceae	*Limonia acidissima* L.	*Kodbel, Koethbel*	Fd, M, T
Rutaceae	*Murraya paniculata* (L.) Jack	*Kamini*	M, T
Rutaceae	*Zanthoxylum rhetsa* (Roxb.) DC.	*Bajna*	M, N, T
Sapindaceae	*Lepisanthes rubiginosa* (Roxb.) Leenh.	*Harinagola*	Fd
Sapindaceae	*Schleichera oleosa* (Lour.) Oken.	*Joyna, Kusum*	Fd, M, N, T
Sapotaceae	*Madhuca longifolia* (J.Koenig ex L.) J.F.Macbr.	*Mahua*	M, T
Sterculiaceae	*Abroma augustum* (L.) L.f.	*Ulotkombol*	M
Sterculiaceae	*Sterculia villosa* Roxb. ex Smith	*Udal*	M, N
Thymeliaceae	*Aquilaria agallocha* Roxb.	*Agar*	N
Tiliaceae	*Grewia asiatica* L.	*Kapaia*	Fd, N
Ulmaceae	*Trema orientalis* (L.) Bl.	*Jigni*	F, Fd, N
Verbenaceae	*Callicarpa arborea* Roxb.	*Bormala*	F, Fd, M
Verbenaceae	*Gmelina arborea* Roxb.	*Gamar, Jogi*	M, T
Verbenaceae	*Tectona grandis* L.f.	*Shegun*	M, T
Verbenaceae	*Vitex glabrata* R.Br.	*Hakuni gach, Baskura*	Fd, M, T

Note: F: Fuelwood, Fd: Food and fodder, M: Medicinal, N: Miscellaneous non-timber uses (other than food, fuel, fodder and medicinal), T: Timber, Nk: Not known

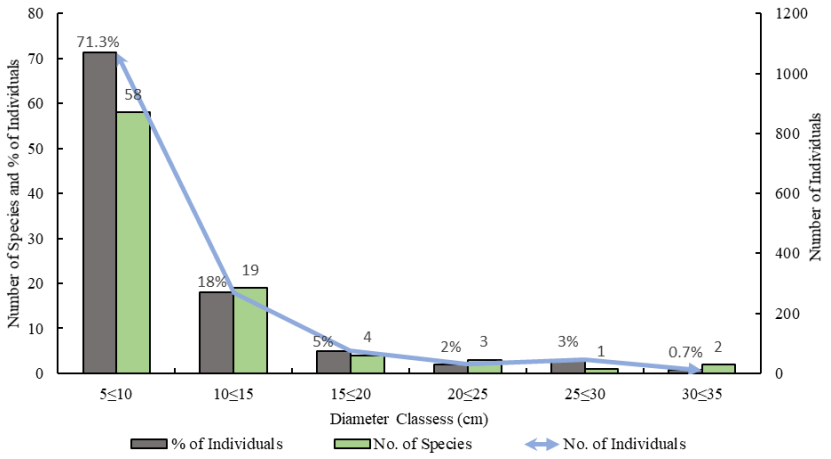

Figure 2. Tree species distribution and tree individuals into different diameter classes

Table 4. Diversity indices and Quantitative status of tree species for Kadigarh National Park, Bangladesh

Category	Value
Shannon-Wiener diversity index	0.791±0.06
Simpson diversity index	0.583±0.04
Margalef species richness index	1.278±0.10
Pielou species evenness index	0.429±0.01
Basal area (m^2) per hectare	18.105±1.06
Number of stems per hectare	1,373.07±44.83

Structural composition based on DBH class distribution

The structural composition of the tree species is assessed by dividing them into six diameter classes based on their diameter at breast height (1.37 m from the base). The diameter (cm) ranges are 5≤10, 10≤15, 15≤20, 20≤25, 25≤30, and ≥35. The lowest diameter range of 5≤10 cm is represented by the maximum (71.30%) tree individuals belonging to 58 tree species (Figure 2). Tree individuals of almost all the tree species are found in this diameter range. The *S. robusta* is the flagship plant species of the KNP forest, dominating almost all the diameter classes except the ≥35 cm class. On the other hand, a diameter range of 30≤35 cm is represented by only two *Ficus* species and a minimum number of (0.7%) tree individuals. The graph representing the number of tree species and individuals reduces gradually in the upper diameter classes, an important feature of natural forests (Figure 2).

Table 5. Density, Relative Density (RD), Relative Frequency (RF), Relative Abundance (RA), Relative Dominance (RD), and Importance Value Index (IVI) of the tree species (≥5 cm DBH) recorded from Kadigarh National Park, Bangladesh

Scientific Name	Stem ha^{-1}	RD (%)	RF (%)	RA (%)	RD (%)	IVI
Semecarpus anacardium L.fil.	1.29	0.59	0.97	0.83	0.17	0.97
Miliusa velutina (Dunal) Hook. f. & Thom.	4.31	1.45	1.79	2.58	0.75	2.19
Holarrhena antidysenterica (L.) Wall. ex A.DC.	1.29	0.59	0.97	0.83	0.17	0.97
Oroxylum indicum (L.) Kurz	0.43	0.23	0.32	0.27	0	0.25
Bixa orellana L.	0.86	0.39	0.61	0.49	0.09	0.53
Lannea coromandelica (Houtt.) Merr.	6.47	1.78	2.08	2.92	0.91	2.77
Protium serratum (Wall. ex Colebr.) Engl.	3.88	1.31	1.47	2.21	0.64	1.69
Bauhinia malabarica Roxb.	0.86	0.39	0.61	0.49	0.09	0.53
Garcinia cowa Roxb. ex DC.	1.72	0.72	1.27	1.49	0.38	1.25
Terminalia bellirica (Gaertn.) Roxb.	25.43	2.89	3.95	5.08	1.43	6.42
Terminalia chebula Retz.	32.56	3.3	4.11	6.17	1.88	8.59
Dillenia scabrella Roxb. ex Wall.	1.72	0.72	1.27	1.49	0.38	1.25
Shorea robusta Gaertn.	1,193.72	57.84	40.76	28.62	81.34	185.12
Antidesma acuminatum Wall. in Wight.	0.43	0.23	0.32	0.27	0	0.25
Aporosa sp.	0.86	0.39	0.61	0.49	0.09	0.53
Bischofia javanica Bl.	0.86	0.39	0.61	0.49	0.09	0.53
Bridelia tomentosa Bl.	0.86	0.39	0.61	0.49	0.09	0.53
Mallotus philippensis (Lam.) Müll.Arg.	4.74	1.55	1.83	2.67	0.78	2.38
Ricinus communis L.	1.29	0.59	0.97	0.83	0.17	0.97
Gliricidia sepium (Jacq.) Kunth ex Walp.	0.86	0.39	0.61	0.49	0.09	0.53
Cryptocarya amygdalina Nees.	1.72	0.72	1.27	1.49	0.38	1.25
Litsea glutinosa (Lour.) Robinson	3.88	1.31	1.47	2.21	0.64	1.69
Careya arborea Roxb.	1.72	0.72	1.27	1.49	0.38	1.25
Lagerstroemia parviflora Roxb.	0.43	0.23	0.32	0.27	0	0.25
Azadirachta indica A. Juss.	0.86	0.39	0.61	0.49	0.09	0.53
Melia azedarach L.	6.47	1.78	2.08	2.92	0.91	2.77
Toona ciliata M. Roem.	3.02	0.21	1.02	0.64	0.01	1.51
Acacia auriculiformis A. Cunn. ex Benth.	14.22	2.39	2.98	3.97	1.06	3.89
Aphanamixis polystachya (Wall.) R.N. Parker.	0.86	0.39	0.61	0.49	0.09	0.53
Artocarpus lacucha Buch.-Ham.	1.72	0.72	1.27	1.49	0.38	1.25
Ficus benghalensis L.	3.88	1.31	1.47	2.21	0.64	1.69
Ficus hispida L.f.	0.86	0.39	0.61	0.49	0.09	0.53
Ficus racemosa L.	1.72	0.72	1.27	1.49	0.38	1.25
Ficus religiosa L.	0.43	0.23	0.32	0.27	0	0.25
Streblus asper Lour.	0.86	0.39	0.61	0.49	0.09	0.53
Syzygium firmum Thw.	0.86	0.39	0.61	0.49	0.09	0.53
Ziziphus rugosa Lam.	1.72	0.72	1.27	1.49	0.38	1.25
Haldina cordifolia (Roxb.) Ridsdale	3.88	1.31	1.47	2.21	0.64	1.69
Hymenodictyon orixensis (Roxb.) Mabb.	22.41	2.82	3.77	4.81	1.35	4.27
Murraya paniculata (L.) Jack	1.72	0.72	1.27	1.49	0.38	1.25
Zanthoxylum rhetsa (Roxb.) DC.	1.29	0.59	0.97	0.83	0.17	0.97
Lepisanthes rubiginosa (Roxb.) Leenh.	4.31	1.45	1.79	2.58	0.75	2.19
Schleichera oleosa (Lour.) Oken.	1.29	0.59	0.97	0.83	0.17	0.97
Madhuca longifolia (J.Koenig ex L.) J.F.Macbr.	0.43	0.23	0.32	0.27	0	0.25
Abroma augustum (L.) L.f.	0.86	0.39	0.61	0.49	0.09	0.53
Sterculia villosa Roxb. ex Smith	4.31	1.45	1.79	2.58	0.75	2.19
Grewia asiatica L.	1.29	0.59	0.97	0.83	0.17	0.97
Trema orientalis (L.) Bl.	1.72	0.72	1.27	1.49	0.38	1.25
Total	1373.18	100	100	100	100	255.73

Structural composition based on height class distribution

The total height of the tree individuals of different species considered in six height classes with an interval of 6 m. The six height classes are 2≤7 m, 7≤12 m, 12≤17 m, 17≤22 m, 22≤27 m, and 27≤32 m. The lowest height of the tree species is recorded at 2 m for habitually small trees. The study reveals that the number of species is maximum (49 species) in the height range of 2≤7 m, followed by 7≤12 m (36) and 12≤17 m (13) in Figure 3. The relative number of individuals is high in the first height class (2≤7 m), then gradually reduced with the increase in height growth. The tree species and individuals are very few in the higher height ranges of 22≤27 m and 27≤32 m. The relative distribution of both tree individuals and species indicates that tree species of KNP are distributed mainly in 3 strata, i.e., 2≤7 m, 7≤12 m, and 12≤17 m (Figure 3). Tree species distribution within the different height classes reveals that *S. robusta* (26.73%) and *T. chebula* (3.82%) are common in the lowest height ranges. In the 7≤12 m height range, *S. robusta* (39.16%) is very common, and *T. bellirica* (2.45%) and *Hymenodictyon orixensis* (Roxb.) Mabb. (2.72%) are found in comparatively higher numbers.

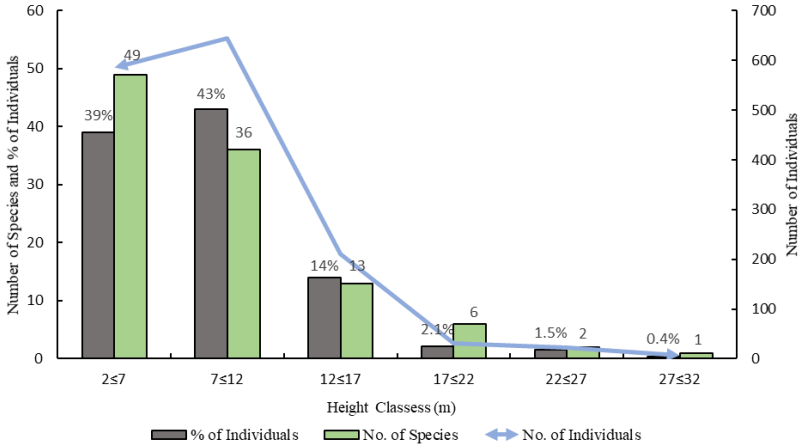

Figure 3. Tree species distribution and tree individuals into different height classes

Discussion

The tree species composition of the KNP is naturally homogeneous. The present study in the Mymensingh Forest Division reveals a lower tree species composition than in other tropical forests. Rahman et al. (2019a) found 139 tree species belonging to 100 genera and 40 families in the Madhupur National Park. Hossain et al. (2015) reported the presence of 107 tree species belonging to 72 genera and 37 families in the sample plots of the Kamalachari Natural Forest of Chittagong South Forest Division. Naidu et al. (2018) found 135 species and 105 genera belonging to 45 families in India's tropical deciduous forests of North-Central Eastern Ghats. Moreover, other studies found 93 tree species in Chunati Wildlife Sanctuary (Nath et al. 2016), 151 tree species in the Inani Protected Forest (Nath et al. 2000), 150 tree species in Teknaf Wildlife Sanctuary (Uddin et al. 2013), and 400 tree species in the forests of Sylhet (Alam 2008) in Bangladesh. However, the tree species diversity of this park is comparatively higher than that of 56 tree species belonging to 50 genera and 29 families in Durgapur Hill Forest (Rahman et al. 2019b), 50 tree species belonging to 28 families in Rampahar Natural Forest (Malaker et al. 2010), 52 tree species in Kaptai National Park (Rahman et al. 2016), 62 tree species in the Tankawati Natural Forest (Motaleb and Hossain 2011), 77 species in the Dudhpukuria natural forest (Hossain et al. 2012), and 78 tree species in Lawachara forest (Malaker et al. 2010).

The diversity index value indicates that tree species diversity is relatively poor in the natural forest. The Shannon-Wiener diversity index (0.791±0.06) of KNP is significantly lower than other natural forests, such as 3.762 of Chunati Wildlife Sanctuary, 3.25 of Tankawati natural forest of Chittagong South Forest Division, 4.45 of Dudhpukuria-Dhopachori WS, 2.98 of Sitapahar reserve forest of Chittagong South Forest Division, 4.27 in Garo Hills of India and 4.37 in Tropical Moist Forests of Mizoram, Northeast India (Nath et al. 2000; Kumar et al. 2006; Motaleb and Hossain 2011; Hossain et al. 2013b; Hossain and Hossain 2014; Devi et al. 2018). Similarly, the Simpson diversity index (0.583±0.04), Margalef species richness index (1.278±0.10), and Pielou species evenness index (0.429±0.01) also suggest poor diversity in comparison to Chunati Wildlife Sanctuary and Dudhpukuria-Dophachari Wildlife Sanctuary (Hossain et al. 2013b; Hossain and Hossain 2014). This poor diversity is due to factors such as the higher occurrence of *Sal* than associated tree species, habitat degradation, human interference, or natural disturbances. The homogeneous topography and climatic and edaphic conditions over the KNP area also contribute to the poor diversity and almost homogeneous distribution of the different tree species.

The Importance Value Index (IVI) indicates a comprehensive understanding of the phytosociological characteristics of a species within the forest. The study reveals that 72% of tree individuals in KNP are *Sal* (*S. robusta*), making it the most dominant tree species and highlighting its crucial ecological functions, such as providing habitat for wildlife, carbon sequestration, and soil stabilization. This dominance contributes to the structural complexity of the forest and supports a diverse range of plant species. Furthermore, the Basal area of KNP is greater than that of the Kaptai Deer Breeding Centre (14.36 m^2 ha^{-1}) in the Rangamati South Forest Division (Mohajan et al. 2016). Additionally, the density in KNP is higher than the 555 stems ha^{-1} in the Chunati Wildlife Sanctuary (Hossain and Hossain 2014), 855 stems ha^{-1} in the Durgapur hill forest (Rahman et al. 2019b), and 709 stems ha^{-1} in the Tropical Forest of Eastern Ghats, India (Reddy et al. 2011). Hossain et al. (2013b) reported a tree species (≥10 cm DBH) density of 468 stems ha^{-1} in the Dudhpukuria-Dhopachari Wildlife Sanctuary. The study by Malaker et al. (2008) in the Jaus beat of Madhupur *Sal* forest revealed that *S. robusta* was represented by maximum density (226.67 trees ha^{-1}), total Basal cover (99.11 m), IVI (72.60), and species diversity (0.145), which is lesser than the current result. Hossain et al. (2013b) also reported that *D. turbinatus* showed the highest IVI (13.74), followed by *L. acuminata* (10.81). Chowdhury et al. (2018) found *P. serratum* to be a dominant regenerating tree species with the highest relative density (15.24%), relative frequency (16.30%), and IVI (50.09) in the Rampahar natural forest reserve in Rangamati, where the values are lower in comparison with the present findings.

Regarding the DBH class distribution, Nath et al. (2016) recorded that 90% of trees belonged to the 5-to-15-cm DBH class in the Chunati Wildlife Sanctuary, which is similar to the present study. However, Hossain et al. (2017) reported that the maximum number of species (169 species) was found to occur within the DBH range of 10≤24.5 cm in the Dudhpukuria Dhopachori Wildlife Sanctuary, Chittagong, Bangladesh. Bhuju and Yonzon (2001) revealed that the majority of species were most frequently found within the 4-10 m height range. In contrast, Hossain et al. (2015) demonstrated a higher number of tree species and a greater percentage of tree individuals, except for a lower number (97 species, 77.99%, 404 individuals, respectively) within the 4.5-14.4 m height range. This suggests that KNP is a comparatively more or less well-vertically stratified forest. Species such as *S. robusta*, *T. bellirica*, *A. carambola*, *D. turbinatus*, and *N. cadamba* dominate the upper canopy of KNP.

The structural composition of the study indicates potential regeneration status but also highlights threats from human disturbances. The severe encroachment and deforestation by surrounding communities over the past few decades pose a significant threat to the ecosystem and biodiversity of the area. Expansion of agricultural land, settlements, and infrastructure development has led to the loss of forest cover, disrupting the natural habitat of numerous plant and animal species. Illegal felling of mature trees in the park area further exacerbates the problem, leading to a decline in forest health and ecological balance. However, the Forest Department has enhanced the protection status of the KNP by involving some local people as community forest workers in the last 10 years. Collaborative efforts to protect and conserve the forests and forest resources have resulted in partial recovery of the forest coverage, indicating progress in restoring and preserving the forest. Overall, a combination of law enforcement, community involvement, habitat restoration, sustainable land use planning, collaboration, and research can help address the threats of encroachment and deforestation and conserve the *Sal* Forest ecosystems. Therefore, maintaining biodiversity conservation as the primary purpose for establishing this protected area as a National Park is essential.

In conclusion, the study reveals a land characterized by poorly diverse tree species and stratified tree populations. The IVI values reveal the most important tree species in the forest economically and ecologically and those to be prioritized for conservation. The height class distribution indicates occurrences of illegal removal of trees from the forest. Moreover, the DBH class distribution shows a poor regeneration status in some species, which may be due to human disturbance and livestock grazing. Firing and encroachment have caused extensive loss of regenerated seedlings of important native tree species in the last decades. Therefore, such detrimental intrusion must be stopped immediately, which makes the area more fragmented and reduces the natural forest restoration capacity in Kadigarh National Park of Bangladesh. Both ex-situ and in-situ conservation measures could be initiated to conserve the rare native plant species in the forest.

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