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Research Article

Impacts of Industrialization on Plant Species Composition, Diversity, and Tree Population Structure in Tropical Moist Deciduous Forest in Bangladesh

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Industrial activities have various effects on biodiversity, posing significant threats to forest ecosystems. The current study describes the species composition, taxonomic diversity, and stand structure at Bhawal Sal forest, Gazipur, Bangladesh, as they are affected by industrialization. To achieve the goal, 30 different categorized industries within the forest were considered sampling points and three distance gradient sites viz. Site-1 = Adjacent to industries (0 m), Site-2 = 160 m distance and Site-3 = 320 m distance from industries were designated as treatments. A total of 90 quadrate plots (10 m × 10 m) were taken randomly, of which 30 plots were from each site. Through forest inventory, 46 species (24 trees, 8 shrubs, 5 climbers, and 9 saplings) were recorded from three sites. The study revealed that the stand density and basal area of mature trees (257 stems ha^{-1} and $8.06 \pm 0.60\ m^2 \cdot ha^{-1}$) at Site-1 were significantly lower due to diverse industrial operations than other sites. Statistically, all the biodiversity indices of mature trees; Shannon–Wiener's index (1.72), Simpsons index (0.82), Margalef's index (1.38), Pielou's evenness Index (0.39) was found to be lower at proximity to industries. The lowest species richness (12) of all plants was recorded from Site-1. However, the diameter and height distributions of Site-1 comprised young (10–20 cm·dbh) to medium-sized (20.1–30 cm·dbh) trees, while the medium to large sized (>30 cm·dbh) trees was contained at Site-3 in this study. The population structure of tree species at Site-1 also showed a fluctuating curve. Overall, this study highlights that plant ecosystems and tree population structure have declined tremendously due to industrialization. Hence, the current research could be significant for developing the management framework for the disturbed deciduous forest.

1. Introduction

The tropical forest is crucial for maintaining the world's most diverse plant communities and controlling the earth's climate and biodiversity. However, tropical moist deciduous Sal forests in South Asia are the most disturbed forests because of the high demand for forest resources [1]. Bangladesh is a biodiversity-rich country with 2.52 million ha of forest land (hill forest, deciduous and tidal mangrove forest), accounting for 17.47% of the country's total land area [2, 3]. Deciduous forests are one of the most prevalent forest types in Bangladesh, encompassing 0.12 million hectares of land and accounting for roughly 4.7% of the forest area [4]. The Madhupur tract consists of two national parks: Madhupur and Bhawal, and it is one of Bangladesh's most important moist deciduous forest regions. Although tropical moist deciduous Sal (*Shorea robusta*) forests are rich in diverse plant communities, they are also vulnerable to deforestation and environmental degradation [5–7]. This Sal forest had 66% forest cover in 1985, but by 2009, it had shrunk to 45% forest cover [8].

In Bangladesh, Bhawal Sal forest is a historically significant and ecologically diverse tropical moist deciduous Sal ecosystem. It has a tremendous influence on the ecological and economic balance, but the forest's biodiversity is currently endangered [9]. Industrialization, agricultural expansion, land grabbing, tree plantations (including invasive species), lack of management, and unauthorized logging contribute to its rapid extinction [10]. Bhawal Sal forest is in peril due to the industrial revolution and is gradually evolving into an industrial and recreational zone. Thousands of workers from various businesses live in and around the buffer zone, which is home to more than 150 different industries [11]. In 2013, about 354 illegal industrial set-ups in the protected areas seized approximately 255.3 ha of forest land [12]. Industrial effluents are wreaking havoc on the landscape, causing natural plant communities to be disrupted and depleted ecosystems, making plant development extremely difficult. As a result, ecosystem productivity and biological diversity are lost, and the area suffers from overall environmental degradation [13, 14].

Nowadays, the pollution from industrial activities significantly affects every ecosystem component. According to its management plan, industrialization harms the park's flora, wildlife, hydrology, and quality of air [15]. In addition, a lack of forest employees encourages illicit land grabbing to establish industries within the forest. The forest floor is disturbed by industrial development activities such as infrastructure, road networks, labor settlement, labor walking, gathering, transportation systems, and other related activities within the forest region. The coppicing potential of Sal species is rapidly dwindling due to industrial waste discharge channels. Human disturbances influence diversity and the regrowth and dominance of tree species after they have been disturbed [16]. Long-term deposition of industrial effluents in the forest floor reduces soil productivity and fertility. However, industrialization and its impacts negatively influence forest dynamics and diversity.

Several researchers [1, 5, 7, 8, 17–20] have studied anthropogenic disturbance and its consequences on plant species diversity in Bangladesh's moist deciduous forest and other forest ecosystems in world perspective. Previous studies have elucidated how human disruptions affect species composition, structure, and regeneration. There have been several studies on the effects of coal mining on vegetation composition in Bangladesh and other countries [14, 21–23]. However, no research has been conducted in Bangladesh, especially on the impacts of industrialization on plant communities of the forest region. However, there is still a research void, notably regarding the effects of industrial activities on forest vegetation in the Bhawal Sal forest. Therefore, it is crucial to determine how industrialization has affected forest plant communities and conduct a comparative analysis of species diversity and population structure changes. This study's findings will assist forest policymakers in assessing the possible causes of industrialization, understanding the overall impacts on the vegetation, and providing critical information for further research and forest ecosystem conservation. We hypothesized that industrialization had negative impacts on forest plant communities and population structure for this study. Thus, this study was undertaken to address the following research questions:

(1) What are the compositions of plant species in three distant sites of the Bhawal Sal forest?

(2) What are the impacts of industrialization on plant communities and tree population structure along the distance gradient of the Bhawal Sal forest?

2. Materials and Methods

2.1. Study Area. The present study was conducted at three sub-divisions: Park and Baupara under the National Park Range and Bishawakuribari under the Bhawal range in Bhawal National Park (BNP) at Gazipur district in Bangladesh. Geographically, it stands at 24°02 to 24°11°N latitude and 90°21 to 90°28°E longitude (Figure 1) in the Gazipur district of the Dhaka Forest Division. It is located 40 kilometers north of Dhaka on the Dhaka–Mymensingh highway [24]. It is one of Bangladesh's most enormous belts of tropical moist deciduous forests. Sal (Shorea robusta) is a common species in this deciduous forest [25]. All the physiochemical characteristics of Bhawal forest soils are low compared to the forest covered areas [26]. It is mixed with manganese ferrous iron ore, commonly known as "Bhawal Kankar." The yearly rainfall is 1500 mm and temperatures range from 11.5°C to 38.5°C. The annual relative humidity (RH) is 85.2 percent, with total evaporation of 1023.5 mm [19].

2.2. Data Collection Methods. The frequency of industrial activities in this forest was evaluated subjectively by observing the location and utilizing a Google map of the area. Distance gradient analysis was done to analyze the influence of industrialization on vegetation cover and tree species composition. This study dealt with 30 different categorized industries considered as the sampling point which covered 8.47% of the total number of industries inside the forest. Each sampling point's spatial bounds were specified and geographic coordinates were obtained through Geographical Positioning System (GPS). A total of 90 quadrate plots were taken randomly of which 30 plots from near to industries (0 m distance) which considered as Site-1. Another 30 quadrate plots were selected within a distance of 150 m from Site-1 which was classified as Site-2 and the rest 30 plots were taken from another 150 m distance from Site-2, which is considered as Site-3 (Figure 2). Disturbance status of three sites were presented at Table 1. Each quadrate plot was $10 \times 10\ m^2$ (area = $100\ m^2$) for the inventory of mature trees ≥10 cm·dbh and saplings (5–10 cm·dbh) [8]. Within the $100\ m^2$ plot, a subplot of $5 \times 5\ m^2$ area was used for shrubs and climbers and another subplot $2 \times 2\ m^2$ for seedling [8]. Grasses and herbs were not inventoried in this study. The girth at breast height (gbh) of all the mature trees were measured at 1.37 m from the ground. Suunto Clinometer was used to measure the total height of all mature trees. However, the known tree species were recognized in the field, while forest officials identified the unfamiliar tree species. The identification of unknown species was done with the help of https://www.worldfloraonline.org/ [27].

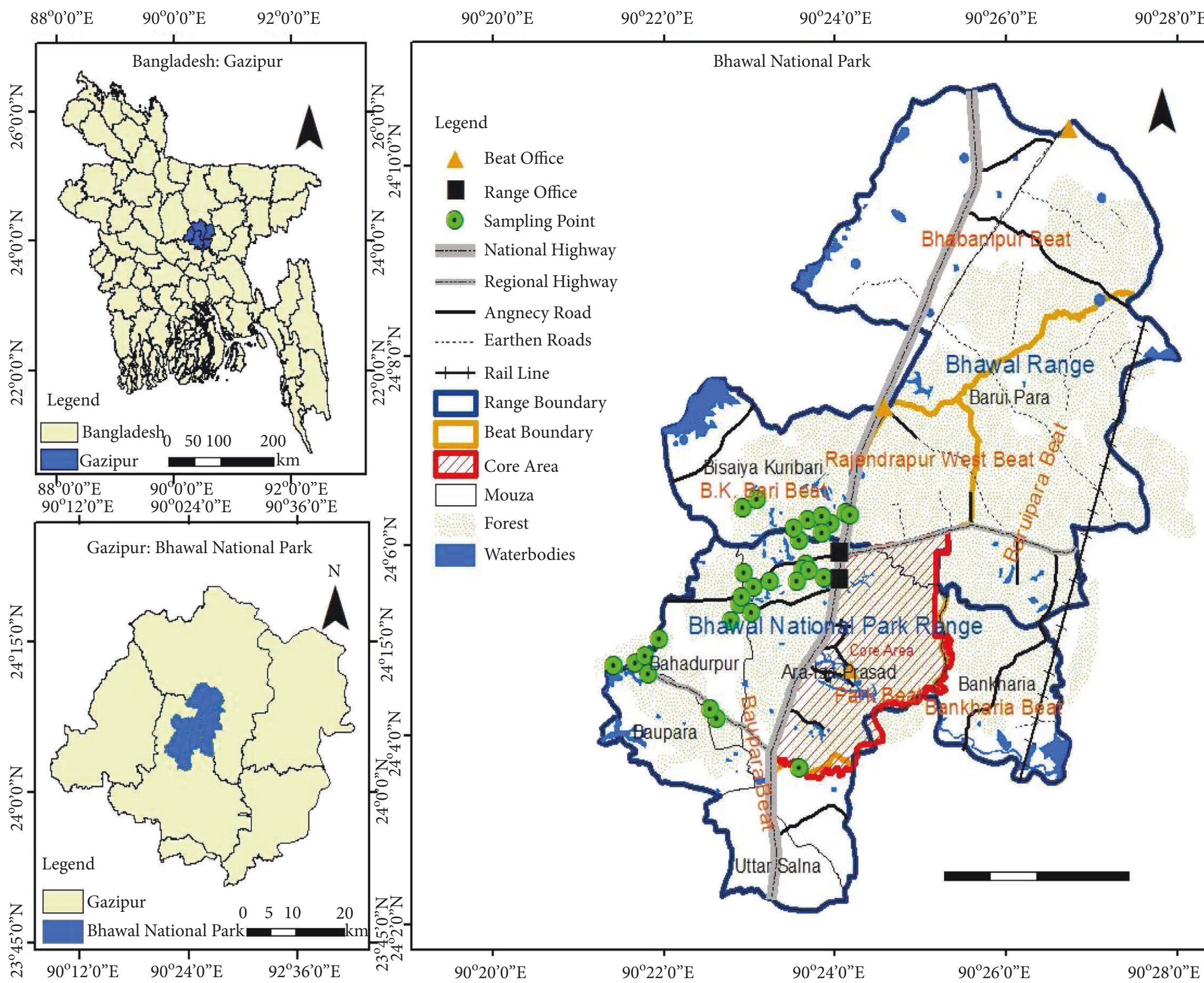


FIGURE 1: Location map of the study area showing the selected industries as sampling points (source: the author).

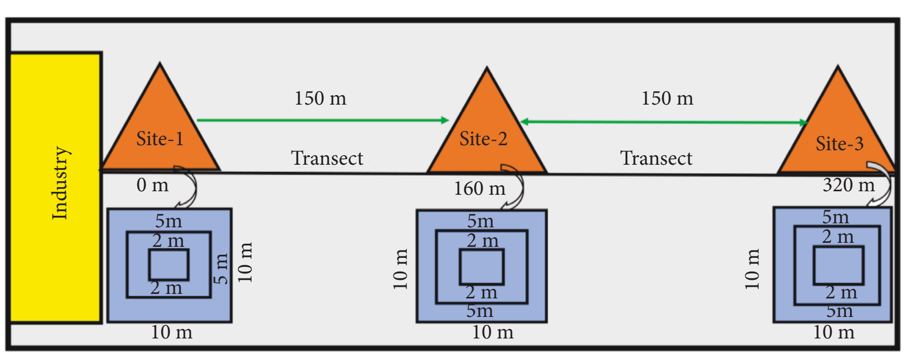


FIGURE 2: Diagram of sampling design of the study area of the Bhawal Sal forest (source: the author).

2.3. Analysis of Data. The collected data were analyzed to determine phytosociological characters of the vegetation and biodiversity indices following equations that were enlisted in Tables 2 and 3. The abundance-to-frequency ratio was used to explain the species' distribution pattern [41]. If the ratio is <0.025, it indicates regular distribution, random distribution between 0.025 and 0.05, and contagious distribution if it is >0.05 [42].

The total number of plant species found at various sample sizes was used to generate species area curves [8]. PAST software program version (4.08) was used to perform rank abundance curve and a hierarchical cluster dendrogram [43]. Also, the location map was constructed using ArcGIS software (Version 10.8). One-way ANOVA test was done to compare the difference in taxonomic diversity and forest structure by Minitab 17 software.

Table 1: Disturbance status of three distance sites in the study area.

Sites	Distances	Elements of disturbance	Severity	Other anthropogenic disturbances
Site-1	Adjacent to industries	Industrial development, infrastructure of roads, boundary, buildings, clearing forest species, plantation of exotic species, waste discharge channel, dumping site	High	Forest resources destruction, logging, lopping, regeneration destruction, litter sweeping, soil disturbance
Site-2	160 m distance to industry	Labor settlement, minor road, stall, waste dumping, cleaning forest floor, lopping, loss of native species	Medium	Forest resources destruction, logging, regeneration destruction, litter sweeping, soil disturbance
Site-3	320 m distance from industry	Litter sweeping, human gathering	Less	Leaves collection, logging

Table 2: The list of equations used for calculating phytosociological characters of the vegetation.

Phytosociological attributes	Formula	References
Basal area (m^2/ha) (BA)	$\text{Basal area } (m^2/ha) = (\sum \pi \times (D^2/4)/\text{Area of all quadrates}) \times 10000$	[28, 29]
Frequency, (F%)	$\text{Frequency}(\%) = (c/b) \times 100$	[29]
Relative frequency (RF%)	$\text{RF}(\%) = (Fi/\sum_{i=1}^{\infty} Fi) \times 100$	[30, 31]
Density (D)	$\text{Density}, D = (a/b)$	[29]
Relative density (RD%)	$\text{RD}(\%) = (\text{Density of single species}/\text{Total density of all species}) \times 100$	[30, 31]
Abundance, A	$\text{Abundance}, A = (n/c)$	[29]
Relative dominance (RD_0%)	$RD_0\% = (\text{Total basal area of a species in all quadrates}/\text{Total basal area of all species in all quadrates}) \times 100$	[28]
Diameter at breast height (cm)	$\text{DBH} = (\text{GBH}/\pi)$	[32]
Important value index (IVI)	$\text{IVI} = \text{RD} + \text{RF} + \text{RD}_0$	[26, 29]

Here, a = Total number of individual species in all quadrates, b = Total number of quadrates of studied, c = Total number of quadrates in which the species occurs, n = Total number of individuals of the species; Fi = Frequency of one species; GBH = Girth at breast height.

Table 3: The list of equations used for calculating biodiversity indices of the vegetation in the study area.

Biodiversity indices	Formula	References
Shannon–Wiener's index (H')	$H' = -\sum_1^s pi \ln pi$	[33, 34]
Margalef's index (R)	$R = ((S-1)/\ln(N))$	[35]
Simpson's index (D)	$D = 1 - (\sum n(n-1)/N(N-1))$	[36]
Pielou's evenness index (E)	$E = (H/\ln S)$	[37]
Menhinik's index	$\text{Db} = S/\sqrt{N}$	[38]
Similarity index	Jaccard index $= j/(a+b+c-j)$ Sorensen index $= 2S/(A+B+C)$	[39, 40]

Here; $Pi = Pi$ is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N); S = numbers of species encountered, n = the total number of individuals of a particular species, N = the total number of individuals of all species, j/S = the number of species common among the three sites, a/A = the number of species in site-1, b/B = The number of species in site-2, c/C = the number of species in site-3.

3. Results

3.1. Impacts of Industrialization on Species Composition, Taxonomic Diversity at the Three Distant Sites in the Study Area

3.1.1. Species Composition, Stand Density, and Basal Area. The field inventory of the 0.9 ha tropical moist deciduous forest yielded a total of 46 plant species. Of the 46 plant species, 24 were trees, 8 were shrubs, 5 were climbers, and 9 were saplings (Table 4). The number of genera and families was found to be lower in Site-1 (adjacent to industries) than in Site-3 (320 m distance) due to industrial activities (Table 5). The density (257 stems ha^{-1}) and basal area ($8.06 \pm 0.602\ m^2 \cdot ha^{-1}$) of mature tree species at Site-1 was significantly lower compared to density (713 stems$\cdot ha^{-1}$) and basal area ($24.52 \pm 4.06\ m^2 \cdot ha^{-1}$) of mature tree species at Site-3. The density of shrubs, sapling, seedling, and climbers was statistically lowest at proximity to industries but increased with distance from the industrial zone (Table 5).

3.1.2. Cluster Analysis. A hierarchical cluster dendrogram was constructed which depicted the distribution of identified number of plant individuals across all study's sample plots (Figure 3). The data matrix contained 90 plots and 46 plant

Table 4: List of recorded species in three distant sites arranged by common name, scientific name, and families with their habitats.

SI no.	Common name	Scientific name	Family	Habit
Mature tree species (dbh ≥10 cm)				
1	Ajuli	*Dillenia pentagyna* roxb.	Dilleniaceae	Tree
2	Akhasmoni	*Acacia auriculiformis* A. Cunn ex benth	Mimosaceae	Tree
3	Bajna	*Zanthoxylum rhetsa* (roxb.) DC.	Rutaceae	Tree
4	Bayan/bot	*Ficus benghalensis* L.	Moraceae	Tree
5	Bohera	*Terminalia bellirica* (gaertn.) roxb	Combretaceae	Tree
6	Bon amra	*Spondias pinnata* (L.f.) kurz	Anacardiaceae	Tree
7	Capalish	*Artocarpus chaplasha* roxb	Moraceae	Tree
8	Datai	*Microcos paniculata* L.	Tiliaceae	Tree
9	Dumor	*Ficus racemosa* L.	Moraceae	Tree
10	Eucalyptus	*Eucalyptus camaldulensis* dehnhardt	Myrtaceae	Tree
11	Gadhila/kumbi	*Careya arborea* roxb	Lecythidaceae	Tree
12	Garjan	*Dipterocarpus turbinatus* gaertn.	Dipterocarpaceae	Tree
13	Ghandi gajari	*Miliusa velutina* (dunal) Hk.f. & Thoms	Annonaceae	Tree
14	Gora neem	*Melia sempervirens* (L.) sw.	Meliaceae	Tree
15	Haldu	Adina cordifolia (roxb.) hook. f. ex	Rubiaceae	Tree
16	Hybrid	*Acacia* spp.	Fabaceae	Tree
17	Jackfruit/kanthal	*Artocarpus heterophyllus* lamk	Moraceae	Tree
18	Kadam	*Anthocephalus cadambo* (roxb)	Rubiaceace	Tree
19	Koroi	*Albizia procera* (roxb.) benth	Mimosaceae	Tree
20	Lohakath	*Xylia xylocarpa* (roxb.) taub	Fabaceae	Tree
21	Mahogony	*Swietenia macrophyla* king *f.*	Meliaceae	Tree
22	Sal	*Shorea robusta* gaetrn.	Diptercarpaceae	Tree
23	Segun	*Tectona grandis* L. f.	Verbenaceae	Tree
24	Sonalu	*Cassia fistula* L.	Fabaceae	Tree
Shrubs				
1	Anantakata	*Dalbergia spinosa* roxb.	Fabaceae	Shurbs
2	Banjam	*Syzygium fruticosum* (roxb.)	Myrtaceae	Shurbs
3	Bhat	*Clerodendrum infortunatum* L.	Lamiaceae	Shurbs
4	Fulkhari	*Agentum convzoiodes* L.	Compositae	Shurbs
5	Kuteshwar	*Holarrhena antidysenterica* wall. Ex a. DC.	Apocynaceae	Shurbs
6	Lantena	*Lantena camara*	Verbenacea	Shurbs
7	Mankata	*Randia dumetorum* lamk.	Rubiaceace	Shurbs
8	Mouhati	*Glycosmis pentaphylla* (retz.) DC	Rutaceae	Shrubs
Climbers				
1	Barabet/bet	*Calamus viminalis* var. *fasciculatas.*	Arecaceae	Climbers
2	Dumurlata	*Ficus scandens* roxb.	Moraceae	Climbers
3	Kumarilata	*Smilax perfoliata* lour.	Smilacaceae	Climbers
4	Pianalata	*Cissus Adnata* roxb	Vitaceae	Climbers
5	Kalalata	*Pothos scandens* L.	Araceae	Climbers
Saplings (5–10 cm dbh)				
1	Ban jolpai	*Elaeocarpus floribundus* blume	Elaeocarpaceae	Saplings
2	Jhangli boroi	*Ziziphus mauritiana*	Rhamnaceae	Saplings
3	Jarul	*Lagerstroemia speciosa* (L.) pers.	Lythraceae	Saplings
4	Jiga	*Lamnea coromandelica* (houtt.) merr.	Anacardiaceae	Saplings
5	Kanchan	*Bauhinia variegate*	Caesalpiniaceae	Saplings
6	Mahogony	*Swietenia macrophyla* king *f.*	Meliaceae	Saplings
7	Mango	*Mangifera indica* L.	Anacardiaceae	Saplings
8	Pitraj	*Aphanamixis polystachya* (wall.) parker	Meliaceae	Saplings
9	Polash	*Butea monosperma* taub.	Papilionaceae	Saplings

species. Three sites were differentiated from each other based on their number of individuals (Figure 3).

3.1.3. Species Area Curve. Species-area curves showed that the number of sampling plots abundantly captured the array of plant species available at three distance sites (Figure 4). In Site-3 (320 m distance to industries), the number of plant species continued to increase in up to 30 plots, but in Site-1, it increased to 15 plots slowly then it increased rapidly. The maximum number of species was captured at all the plots of Site-3 that is less affected natural forest site (Figure 4).

3.1.4. Rank Abundance Curve. A rank abundance curve, also known as a Whittaker plot, is a graph that depicts a community's pattern of species distribution based on species richness and evenness (Figure 5). The number of distinct species

Table 5: Phytosociological analysis of forest species in three distant sites of the study area.

Classes	Site-1	Site-2	Site-3	*F* value	*P* value
Number of families	9	19	30	—	—
Number of genera	10	24	34	—	—
Density (N ha $^{-1}$ *)*					
Mature trees	257 ± 16.03^{c}	587 ± 75.10^{b}	713 ± 124.58^{a}	368.70	0.000
Saplings	103 ± 4.15b	213 ± 17.71a	233 ± 10.86a	12.40	0.0006
Shrubs	37 ± 11.67^{c}	447 ± 51.07^{b}	1103 ± 264.02^{a}	21.29	0.0002
Seedlings	147 ± 4.16^{c}	1130 ± 167.47^{b}	2327 ± 254.95^{a}	638.32	0.0000
Climbers	—	26.67 ± 1.02^{b}	56.67 ± 14.97^{a}	25.00	0.0055
Basal area (m^2 ha^{-1}) of mature trees	8.06 ± 0.60^{c}	19.62 ± 2.54^{b}	24.52 ± 4.06^{a}	46.32	0.0000

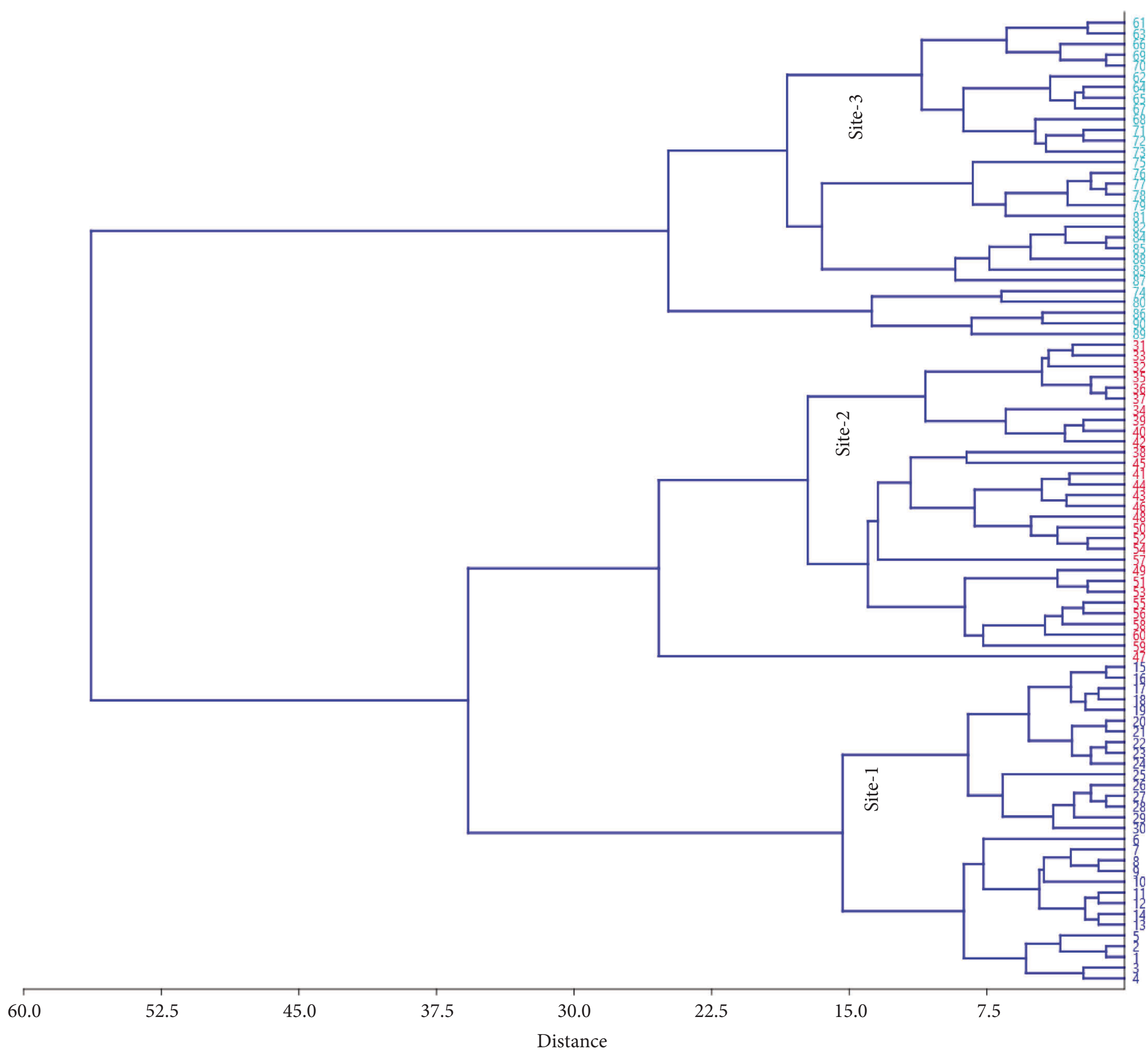


Figure 3: Dendrogram showing the number of plant species of sample plots in three distance sites of the study area.

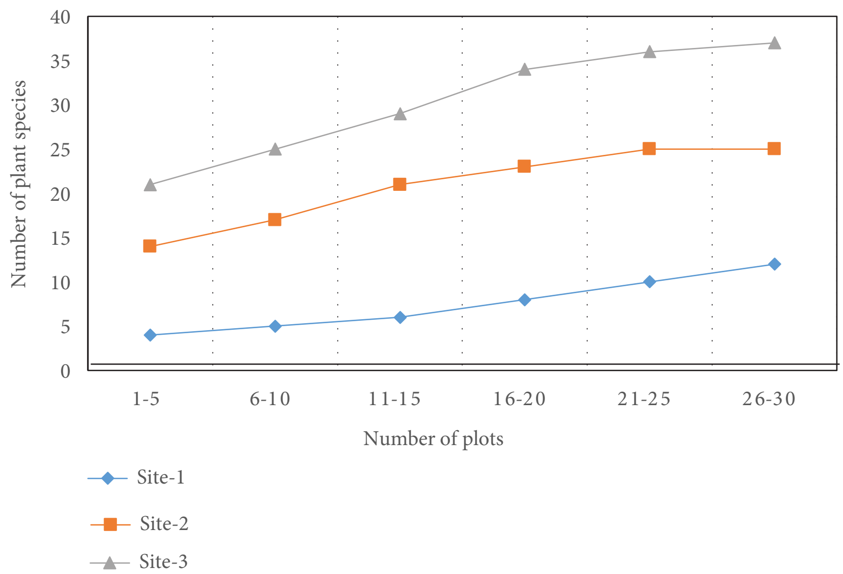


FIGURE 4: Species richness-area curves for all three distance sites in the Bhawal Sal forest.

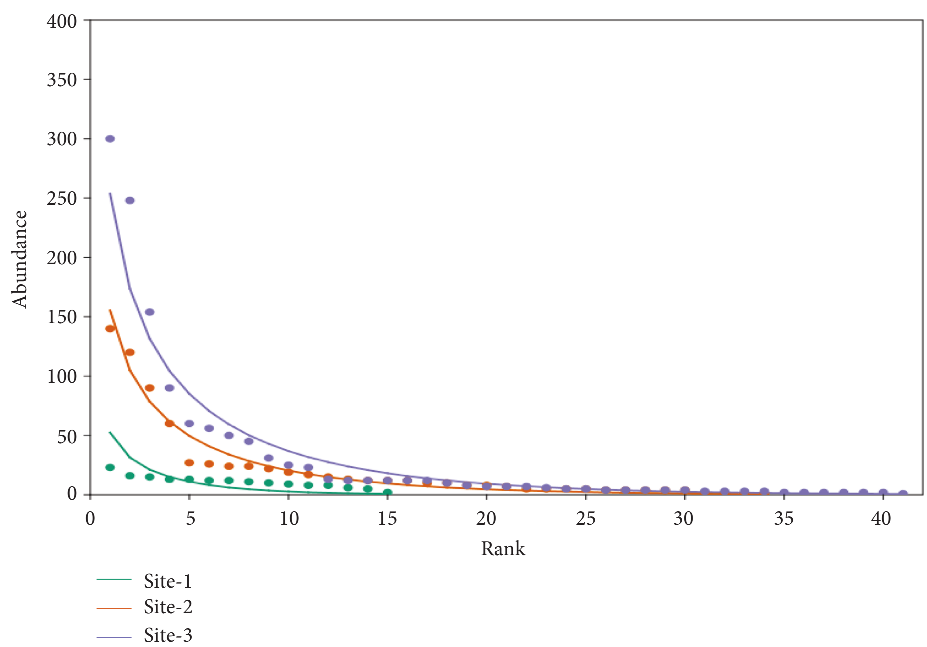


FIGURE 5: Rank abundance curve for plant species of three distance sites of the study area.

TABLE 6: Species richness, overlapping, and similarity index of plant species for three sites in study area.

Plant species	*Species richness*			All	*Species overlapping*			*Similarity index*		
	Site-1	Site-2	Site-3		Site-1 & Site-2	Site-1 & Site-3	Site-2 & Site-3	Site-1 & Site-2	Site-1 & Site-3	Site-2 & Site-3
Mature tree	6	13	16	24	3	1	7	0.18	0.05	0.32
Shrub	2	4	8	8	1	1	4	0.20	0.11	0.50
Saplings	4	6	9	9	3	4	3	0.43	0.44	0.25
Climbers	0	2	4	5	0	0	1	0	0	0.20
All plants	12	25	37	46	7	6	15	0.23	0.14	0.32
Seedling	3	9	12	15	2	1	6	0.2	0.07	0.44

on the graph represents species richness, whereas the slope of the line that fits the graph represents species evenness. The steep gradient in the Site-2 and Site-3 rank abundance curves on species abundance data indicated low evenness, as the high-ranking species have substantially larger abundances than the low-ranking species (Figure 5). The analysis revealed that Site-3 had the highest abundance compared to the other sites.

3.1.5. Species Richness, Overlapping, and Similarity Index. Industrial activities along with variety of factors contribute to species extinction. Within the whole study area, 24 mature tree species were found (Table 6). Site-1 has the fewest mature tree species (6), followed by Site-2 (13) and Site-3 (16). The lowest plant species richness (12) was found in Site-1 compared to Site-3 (37). According to the result, the greatest 15 plant species (7 mature trees, 4 shrubs, 3saplings and 1 climbers) overlapped in between Site-2 and Site-3 that followed by in between Site-1 and Site-2 where 3 is mature tree, 1 is shrubs, 3 is saplings. The highest similarity index (0.32) of all plant species was found within Site-1 and Site-2 followed by other combined sites of the study area (Table 6).

3.1.6. Diversity Indices. Industrial activities had a huge impact on the diversity indices in the study sites. In almost all cases, statistically diversity indices were the lowest at close distance to industries, but it increased gradually with increasing distance. After statistical analysis it was found that the Shannon–Wiener index, Simpson's index, Margalef's index, Pielou's evenness index, and Menhinick index of mature trees of Site-1 had the significantly lowest diversity compared to other sites (Table 7). The Simpson index, Margalef's index, Pielou's evenness index, and Menhinick index of sapling, shrubs, climbers, and seedlings at Site-1 were comparatively lower than other two sites (Table 7).

3.1.7. Distribution Pattern of Plant Species at Three Sites. The analysis of the distribution pattern of all the recorded species is shown in Table 8. In cases of all the sites, the majority of species in the industrial area of forest were contagiously distributed (Table 8), with only a few species having regular or random distribution. However, a comparison shows that the species in Site-2 were more regularly distributed, whereas those in Site-3 were more randomly distributed. In Site-1, mostly recorded species had a contagious distribution pattern (Table 8).

3.2. Impacts of Industrialization on Structural Composition of Tree Species in Three Sites

3.2.1. Girth Class of Tree Species. The girth classes demonstrated an increasing trend with increasing tree density in all three sites at certain level (Figure 6). At adjacent to industries (Site-1), the lowest stand density (4.0 stems ha^{-1}) was found in the girth class (40.1–45 cm) whereas the highest stand density (77 stems ha^{-1}) was found in the girth class (60.1–65 cm) (Figure 6). The results of Site-2 revealed that tree density (stems ha^{-1}) of tree species gradually grew up to a girth class range of 61.1–70 cm (Figure 6). The lowest stand density (3 stems ha^{-1}) was belonged to (>80 cm) the girth class while the girth class (65.1–70 cm) had the highest stand density (314 stems ha^{-1}). In Site-3 (320 m distance to industries), the girth class (60.1–65 cm) had the highest stand density (523 stems ha^{-1}) with (Figure 6).

3.2.2. Diameter and Height Class of Tree Species. The diameter distributions of the sampled trees followed a fluctuating distribution in all individual plots in three sites. With an increase of the diameters at breast height (DBH), the tree density increased at certain point (Figure 7(a)). The highest percentage of trees of Site-1 (adjacent to industries) was belonged to 15.1–20 cm diameter class range. However, the highest percentage of tree species of Site-3 (320 m distance to industries) was belonged to 20.1–25 cm diameter class followed by Site-2 (Figure 7(a)). The highest percentage of comparatively larger trees in terms of diameter was found at Site-3.

The height of mature trees of near to industrial sites (Site-1) did not exceed 20 m, whereas the tree height in the Site-3 that was low industrial affected site exceeded 20 m (Figure 7(b)).

3.2.3. Relative Density, Relative Frequency, Relative Dominance, and Importance Value Index (IVI). The importance value index of the tree species indicates the overall dominancy of different species in forest area. *Swietenia macrophylla* King. f (IVI = 91.06) was the dominant species in the Site-1 (adjacent to industries) that was severely industrial affected site with relative density (29.87%), relative frequency (33.33%) and relative dominance (27.85%). In Site-2 (160 m distance to industries), *Shorea robusta* Gaetrn (IVI = 124.45) was the dominant species with relative density (51.14%), relative frequency (21.11%) and relative dominance (52.20%), followed by *Artocarpus heterophyllus* Lamk, *Anthocephalus cadambo* (Roxb) (Table 8). *Shorea robusta* (IVI = 173.08) was the most dominant species of Site-3 (320 m distance to industries) with relative density (71.96%), relative frequency (32.86%), and relative dominance (68.21%), followed by *Microcos paniculata* L, *Dillenia pentagyna* Roxb, *Albizia lebbek* (L) Benth, and *Careya arborea* Roxb (Table 9).

4. Discussion

It is well accepted that industrialization in the forest zone and human disturbances reduce species richness and contribute to species extinction [44]. The total number of species in the investigated area (46 plant species under 38 genera and 27 families: 24 trees, 8 shrubs, 5 climbers, and 9 saplings) is similar to the findings of [19]. 49 plant species (24 mature trees, 4 shrubs, 7 climbers, and 14 herb species); 43 plant species (22 trees, 10 shrubs, 6 climbers, and 5 herbs) were enlisted at Bhawal National Park [25]. However, it looks to be poor in plant species diversity compared to other South Asian tropical deciduous forests. Compared to 139 tree species (100 genera and 40 families) in the Madhupur National Park, Bangladesh [26]; 135 species (105 genera of

Table 7: Taxonomic diversity indices of the recorded species in the three sites of Bhawal sal forest.

Biodiversity indices	Plant species	Site-1	Site-2	Site-3	*F* value	*P* value
Shannon–Wiener index	Mature trees	1.72[c]	2.03[b]	2.23[a]	88.91	0.0000
	Saplings	1.32[c]	1.67[b]	2.10[a]	49.68	0.0000
	Shrubs	0.23[c]	1.29[a]	0.91[b]	18.45	0.0001
	Seedlings	1.09[c]	1.44[b]	1.92[a]	52.78	0.0000
	Climbers	—	0.69[b]	0.92[a]	15.47	0.0043
Simpson's index	Mature trees	0.82[b]	0.78[c]	0.89[a]	269.89	0.0000
	Saplings	0.38[b]	0.80[a]	0.83[a]	11.94	0.0007
	Shrubs	0.32[b]	0.29[b]	0.58[a]	18.78	0.0001
	Seedlings	0.28[c]	0.69[b]	0.77[a]	56.06	0.0000
	Climbers	—	0.57[a]	0.50[b]	14.70	0.0049
Margalef's index	Mature trees	1.38[c]	2.51[b]	2.79[a]	94.95	0.0000
	Saplings	1.16[c]	1.44[b]	2.11[a]	52.35	0.0000
	Shrubs	0.83[b]	0.82[b]	1.37[a]	24.05	0.0000
	Seedlings	0.79[c]	1.54[b]	1.83[a]	64.22	0.0000
	Climbers	—	0.96	1.41	17.29	0.0032
Pielou's evenness index	Mature trees	0.39[c]	0.41[b]	0.49[a]	216.92	0.0000
	Saplings	0.74[a]	0.40[c]	0.44[b]	51.66	0.0000
	Shrubs	0.19[b]	0.26[a]	0.15[c]	24.97	0.0000
	Seedlings	0.68[a]	0.25[c]	0.29[b]	71.64	0.0000
	Climbers	—	0.33	0.32[Ns]	0.013	0.185
Menhinick index	Mature trees	0.68[c]	0.98[b]	1.02[a]	37.11	0.0000
	Saplings	0.78[b]	0.75[c]	1.07[a]	51.66	0.0000
	Shrubs	0.60[a]	0.34[c]	0.44[b]	19.78	0.0001
	Seedlings	0.45[b]	0.48[a]	0.45[b]	16.65	0.0000
	Climbers	—	0.71[b]	0.97[a]	15.47	0.0043

Table 8: Distribution pattern (%) of plant species in three distance sites of the Bhawal Sal forest.

Categories	Distribution pattern (%) of plant species								
	Regular			*Random*			*Contagious*		
	Site-1	Site-2	Site-3	Site-1	Site-2	Site-3	Site-1	Site-2	Site-3
Mature trees	16.67	23.07	6.67	16.67	15.4	30.83	66.66	61.53	62.5
Saplings	—	16.67	11.11	—	16.67	33.33	100	66.67	55.56
Shrubs	—	16.67	12.5	50	16.67	12.5	50	75	75
Climbers	—	50	25	—	—	25	—	50	50
Seedlings	25	11.11	8.3	—	22.22	16.67	75	66.67	75

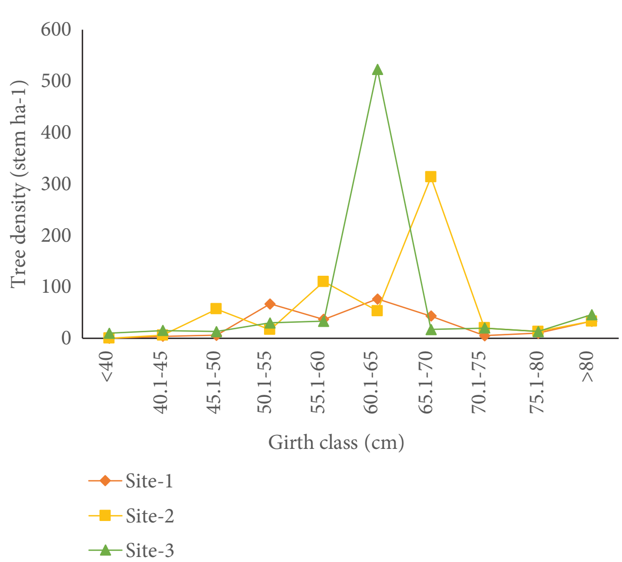
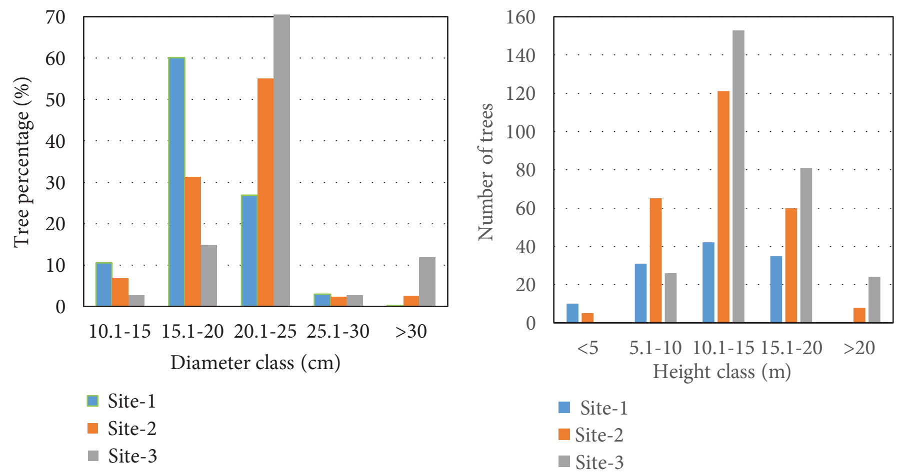


Figure 6: Stand structure based on the girth class (*m*) in the three sites of study area.

45 families) in the North Central Eastern Ghats of India [45]; and 89 plant species (34 trees, 15 shrubs, 25 herbs, and 15 climbers) in the tropical moist deciduous forest of Assam, northeast India [46], 58 plant species were recorded the Subba et al. [47] in the Sumbuk reserve forest in South Sikkim, India, composition of the current study is relatively low. However, the species composition of Site-1 (12 plant species; 6 mature tree species, 2 shrubs, and 4 saplings) is quite low, indicating that industrial activities hurt species composition. The present result is similar to the findings of other studies, such as Rabha [48] found 18 species (14 families) in disturbed Sal forests. Borah et al. [5] reported that the lowest number of species (42 species from 26 families) in the disturbed forest; 14 tree species in the severely disturbed sites in the southern part of India [49]; only 10 species were recorded in the significantly disrupted forest in Nepalese Sal forests [1]. This may be due to the rapid industrialization, urbanization, logging, forest resource exploitation, and other disturbances that have resulted in species extinctions in diverse plant ecosystems.



(a) (b)

Figure 7: Distribution of trees based on DBH class (cm) and height class (*m*) of three sites of the study area.

Table 9: Relative density, relative frequency, relative dominance, and important value index (IVI) of the enlisted mature tree species of all three sites.

Scientific name of species	*Relative density (RD%)*			*Relative frequency (RF%)*			*Relative dominance (RD o %)*			*Important value index (IVI)*		
	Site-1	Site-2	Site-3	Site-1	Site-2	Site-3	Site-1	Site-2	Site-3	Site-1	Site-2	Site-3
Acacia auriculiformis A. Cunn ex benth	14.29	—	—	12.5	—	—	11.93	—	—	38.07	—	—
Acacia spp.	12.98	2.27	—	8.33	2.81	—	23.41	2.62		44.73	7.71	—
Adina cordifolia (roxb.) hook. f. ex brandis	—	—	0.94	—	—	2.86	—	—	1.74	—	—	5.53
Albizia lebbek (L) benth.	—	0.57	1.87	—	1.11	2.86	—	0.72	8.73	—	2.40	13.46
Anthocephalus cadambo (roxb.)	—	5.68	—	—	12.22	—	—	4.25		—	22.16	—
Artocarpus chaplasha roxb.	—	2.27	1.40	—	4.44	5.71	—	2.28	1.33	—	9.01	8.45
Artocarpus heterophyllus lamk	15.58	7.38	—	20.83	13.33	—	10.17	5.56	—	46.58	26.28	—
Careya arborea roxb.	—	2.84	2.80	—	3.33	8.57	—	1.62	2.23	—	7.80	13.60
Cassia fistula L.	—	—	2.34	—		4.29	—	—	2.60	—	—	9.22
Dillenia pentagyna roxb.	—	—	3.27	—	—	8.57	—	—	1.99	—	—	13.83
Dipterocarpus turbinatus gaertn.	—	6.82	—	—	8.89	—	—	6.13	—	—	6.82	—
Eucalyptus camaldulensis dehnhardt	10.39	—	—	8.33	—	—	7.12	—	—	25.84	—	—
Ficus benghalensis	—	0.59		—	1.11		—	5.41	—	—	7.08	—
Ficus racemosa L.	—	6.18	1.87	—	5.55	2.86	—	3.32	0.55	—	15.70	5.27
Melia sempervirens (L.) sw.	—	—	1.87	—	—	2.86	—	—	0.87	—	—	5.60
Microcos paniculata L.	—	—	3.27	—	—	10.01	—	—	2.50	—	—	15.77
Miliusa velutina (dunal) Hk.f. & Thoms	—	—	2.33	—	—	7.14	—	—	1.85	—	—	11.33
Shorea robusta gaetrn	16.89	51.14	71.96	16.67	21.11	32.86	19.52	52.20	68.21	53.07	124.45	173.03
Spondias pinnata (L.f.) kurz	—	—	1.86	—	—	2.86	—	—	3.58	—	—	8.31
Swietenia macrophylla King.f	29.87	8.52	—	33.33	9.86	—	27.85	6.90	—	91.06	25.28	—
Tectona grandis L. f.	—	2.27	1.87	—	4.44	5.71	—	5.41	2.51	—	12.14	10.09
Terminalia bellirica (gaertn.) roxb.	—	—	1.87	—	—	2.86	—	—	0.99	—	—	5.72
Xylia xylocarpa (roxb.) taub.	—	2.84	—	—	4.44	—	—	3.55	—	—	10.84	—

Among the three sites, Site-1 (adjacent to industries) appears to have the lowest tree stand density and basal area compared to Site-3, which is 320 m away from industries (Table 4). This study's finding raises concerns about the viability of the Sal forest ecosystem. The tree density obtained in this study's industrially damaged site is comparable to earlier results from extremely disturbed stands (338 stems ha^{-1}) by Bhuyan et al. [50]; (246 trees ha^{-1}) in the disturbed tropical forests of Borah et al. (2012); and (515 stems ha^{-1}) in the mined regions by Sarma et al. [14]. Tenzin and Hasenauer [51] found that in Bhutan's broad-leaved forests, tree density declined from 373 $N{\cdot}ha^{-1}$ in the natural forest zone to 114 $N{\cdot}ha^{-1}$. The study found that crushing and trampling of seedlings during leaf litter collection reduced species richness and density near industries. The tree basal area ($8.06 \pm 0.602\, m^2{\cdot}ha^{-1}$) of Site-1 measured in this study is comparable to values reported in previous studies, such as ($14.7 \pm 4.1\, m^2{\cdot}ha^{-1}$) in the frequently used Bhawal National Park by Rahman and Vacik [25]; ($18.44\, m^2{\cdot}ha^{-1}$) in the disturbed forest in India [5]; and ($12.22\, m^2{\cdot}ha^{-1}$) in the highly disturbed forest of the Western Himalaya, India [52]. This could be due to industrial activity and waste disposal channels that harm forest regeneration. A continuous pattern type species-area curve was found in this study that is similar to Behera et al. [53]; Rahman et al. [8]; Rahman and Vacik [25]; and Yeom and Kim [54]. The rank abundance curve of the study exhibited a steep gradient similar to Ismail et al. [55], indicating a pattern of species distribution in which one species is highly abundant and the rest are moderately to relatively rare [56]. The Shannon–Wiener diversity index values for three sites' tree species forests are all within a narrow range (1.72–2.23), which is similar to the findings of Mishra et al. [57]; Tripathi et al. [58]; Borah and Garkoti [59]; Borah et al. [60]; Borah et al. [5]; Bajpai et al. [61]; Tahir et al. [62] that fall within the range (0.56–3.57). Industrial development and human disturbances are probably responsible for the smallest value of the Shannon–Wiener diversity index in degraded forests. The proximity to an industrial site had a lower Simpson's index (0.82) for mature trees than other sites, which was supportive of the Simpson's index value (0.94) in severely disturbed oak forests in Iran by Eshaghi et al. [17]. The Shannon–Wiener index, as well as Simpson's diversity and its components (richness and evenness), had a relationship with the distance gradient. In similar findings, Simpson's concentration of dominance (0.04) and similarity index (0.07) were found in the severely disturbed site of a tropical wet evergreen forest reported by Bhuyan et al. [50]. A progressive reduction of all biodiversity indices from 320 m distance to the proximity of industries revealed how industrial activities influenced natural communities. Majumdar and Datta [63] found Simpson's dominance index (0.30 to 0.09), and Pielou's evenness index (0.06 to 0.84) in disturbed forest in Northeast India. Eshaghi et al. [64] revealed that extensively disturbed stands had the lowest Margalef's index (0.794), which is lower than in the current study. Awan et al. [65] found lower values of species diversity (2.88) in the Kashmir Himalayas, Pakistan due to severe grazing pressure. As a result of increased industrialization within the forest, human settlement and road networks are fast expanding, resulting in resource exploitation and encroachment, diminishing biodiversity. The majority of the plant species in this study are clumped together or spread out contagiously. The contagious distribution of the species indicates natural vegetation is fragmented due to mining industries, as reported by Sarma [23]. Nandy and Das [66] discovered 51.06% and 62.05% regular distribution patterns of plant species in Badshahitila and Loharbond, respectively, but 64.29% contagious distribution patterns in the Sultani area of natural forests in the Barak valley, Northeast India, which supports the current findings. The similarity index of these three sites for plant species (0.23, 0.14, and 0.32) is similar to the Jaccard similarity index of 0.35 (35%) in the sacred groves of Manipur, North East India, reported by Khumbongmayum et al. [67].

Anthropogenic activities such as development of industries, human settlement, construction of roads network, labor gathering, etc., triggers the changes the phytodiversity and structure of forest. These factors have impacts on biodiversity, species richness, regeneration percentage, and forest community composition. Midha and Mathur [68] mentioned several activities as the cause of fragmentation of habitats in the Terai ecosystem. The shift in dominance (based on IVI) in plant communities was the most notable change in species composition due to the rise of illegal industries, waste water discharge channels and other factors. The main species at Site-1 was Swietenia macrophylla King. f (IVI = 91.06), whereas *Shorea robusta* (IVI = 173.08) was the most common species at Site-3. Similar results were found in some earlier works by Rahman et al. [26]; Borah and Garkoti [59]; and Sharma et al. [69]. Mondol et al. [19] reported that based on IVI value *Shorea robusta* (121.584) was the dominant species in this Sal forest which supports the findings of this study.

In the present study, the largest number of tree individuals were found at 40.1–45 cm girth at a distance of 0 m from industries. However, at a distance of 320 m from industries, the highest tree density was recorded in the 60.1–65 cm girth class. However, the tree density in all the girth classes of Site-1 was low, which could be due to the rampant and random clearing of forest for industrial development purposes that has led to the drastic change in the tree population structure of the forest. The present findings are similar to earlier reports from different tropical forests of India [59–62]. The highest percentage of trees was found in the 15.1–20 cm diameter range of Site-1. With an increase in the diameter at breast height (DBH), the relative abundance of trees decreased. Rahman et al. [8] reported that the diameter distributions followed a reverse *J*-shaped distribution in Madhupur and Bhawal National Parks, which supports this study. The height of the mature tree at Site-1 did not exceed 20 m; whereas, at Site-3, the height of the tree exceeded 20 m. Rahman and Vacik [25] found a similar finding, which is supportive of the present study. Due to industrialization, the vegetation of this park is now in an endangered condition. Within the study area, the species richness of all plant groups tended to decrease close to the industries. The construction of infrastructure for industries may degrade the forest land through erosion, sedimentation, and pollutant runoff. As a result, root oxygen uptake is reduced, resulting in decreased water and nutrient absorption and slowed water transport through soils. Camping and strolling have the most visible effects on the environment, including the crushing, shearing off, and uprooting of vegetation [70]. These effects may cause changes in the vegetation, which indicates possible reasons for lower diversity and richness in the vicinity of the industries of the present study. Massive human pressure from industry settlement resulted in a decrease in species richness and diversity in this forest. Illicit industrial set-ups trigger other disturbances such as picnic sites, logging of native species, seedling damage, leaf litter sweeping, and livestock grazing.

5. Conclusions

The significantly lower biodiversity and stand features close to industries corroborate the growing industrial activities and their harmful influence on biodiversity. The disturbance for the establishment of industries has limited the chances of regeneration of species, thereby reducing the number of species. Industrial activities are "a double-edged sword for the socioeconomic movement," in that they are reviled and revered at the same time. It has been criticized for its repercussions and praised for fostering long-term economic growth. Implementing biodiversity conservation activities in Bhawal National Park is difficult due to its proximity to the mega-city. However, industrialization's consequences can be mitigated in numerous ways. The forest authorities should prosecute industrialists who set up businesses illegally by grabbing land. Scientific industries have to be appropriately established to minimize further damage to the vegetation. However, additional comprehensive research activities are required to assess the effects of industrial activities on soil properties and their function in ecological processes. This study's findings will aid in monitoring and protecting tropical moist deciduous forests in Bangladesh.

Data Availability

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary material. Raw data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflicts of Interest

The authors declare that thy have no potential conflicts of interest.

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References

[1] I. P. Sapkota, M. Tigabu, and P. C. Oden, "Spatial distribution, advanced regeneration and stand structure of Nepalese Sal (Shorea robusta) forests subject to disturbances of different intensities," *Forest Ecology and Management*, vol. 257, no. 9, pp. 1966–1975, 2009.

[2] Bangladesh Forest Department (BFD), *Forest Fact Sheet: National Tree Planting Campaign and Tree Fair 2016*, Bangladesh Forest Department, Dhaka, Bangladesh, 2016.

[3] M. H. Rahman and M. D. Miah, "Are protected forests of Bangladesh prepared for the implementation of REDD+? a forest governance analysis from rema-kalenga wildlife sanctuary," *Environments*, vol. 4, no. 2, p. 43, 2017.

[4] M. H. Rahman, M. A. S. A. Khan, M. J. Fardusi, and B. Roy, "Status, distribution and diversity of invasive forest undergrowth species in the tropics: a study from northeastern Bangladesh," *Journal of Environmental Sciences*, vol. 26, no. 3, pp. 149–159, 2010.

[5] N. Borah, F. D. Athokpam, S. C. Garkoti, A. K. Das, and D. K. Hore, "Structural and compositional variations in undisturbed and disturbed tropical forests of Bhuban hills in south Assam, India," *International Journal of Biodiversity Science, Ecosystem Services & Management*, vol. 10, no. 1, pp. 9–19, 2014.

[6] J. V. La Frankie, P. S. Ashton, G. B. Chuyong et al., "Contrasting structure and composition of the understory in species rich tropical rainforests," *Ecology*, vol. 87, no. 9, pp. 2298–2305, 2006.

[7] X. T. Lu, J. X. Yin, and J. W. Tang, "Structure, tree species diversity and composition of tropical seasonal rainforests in Xishuangbanna, south-west China," *Journal of Tropical Forest Science*, vol. 1, pp. 260–270, 2010.

[8] M. M. Rahman, A. Nishat, and H. Vacik, "Anthropogenic disturbances and plant diversity of the Madhupur Sal forests (Shorea robusta C.F. Gaertn) of Bangladesh," *International Journal of Biodiversity Science and Management*, vol. 5, no. 3, pp. 162–173, 2009.

[9] E. Hasan and M. B. Khalid, "Community's perception and involvement in co management of bhawal national park, Bangladesh," *Journal of Natural Sciences Research*, vol. 4, no. 3, pp. 60–67, 2014.

[10] K. Islam and N. Sato, "Deforestation, land conversion and illegal logging in Bangladesh: the case of the Sal (Shorea robusta) forests," *IFOREST*, vol. 5, no. 1, pp. 171–178, 2012.

[11] R. I. Chowdhury, "Attitudes towards co-management: is satchari national park a suitable model for bhawal national park?," in *Connecting Communities and Conservation: Co-management Initiatives Implemented by IPAC in Wetlands and Forests of Bangladesh*, F. Jefferson, M. G. Mustafa, R. B. Bryan, M. B. Stephen, and D. Laurie, Eds., USAID, Dhaka, Bangladesh, 2013.

[12] K. M. Masum, M. N. Islam, N. Saha, M. Z. Hasan, and A. Mansor, "Assessment of land grabbing from protected forest areas of Bhawal National Park in Bangladesh," *Landscape Research*, vol. 41, no. 3, pp. 330–343, 2016.

[13] U. B. Ruba, K. Chakma, J. Y. Senthi, and S. Rahman, "Impact of industrial waste on natural resources: a review in the context of Bangladesh," *Current World Environment*, vol. 16, no. 2, pp. 348–361, 2021.

[14] K. Sarma, S. P. S. Kushwaha, and K. J. Singh, "Impact of coal mining on plant diversity and tree population structure in Jaintia Hills district of Meghalaya, North East India," *New York Science Journal*, vol. 3, no. 9, pp. 79–85, 2010.

[15] M. Alam, Y. Furukawa, S. K. Sarker, and R. Ahmed, "Sustainability of Sal (Shorea robusta) forest in Bangladesh: past, present and future actions," *International Forestry Review*, vol. 10, no. 1, pp. 29–37, 2008.

[16] M. J. Lawes, R. Joubert, M. E. Griffiths, S. Boudreau, and C. A. Chapman, "The effect of the spatial scale of recruitment on tree diversity in afromontane forest fragments," *Biological Conservation*, vol. 139, no. 3-4, pp. 447–456, 2007.

[17] R. Eshaghi, V. Gelare, S. Osman, and M. Hosein, "Effects of anthropogenic disturbance on plant composition, plant diversity and soil properties in oak forests, Iran," *Journal of Forest Science*, vol. 64, no. 8, pp. 358–370, 2018.

[18] M. K. Hasan, N. Huda, R. Akter, and M. T. Islam, "Effects of human disturbances on vegetation parameters and soil nutrient status in the Madhupur Sal forest of Bangladesh," *Journal of Agriculture & Rural Development*, vol. 10, pp. 43–55, 2018.

[19] M. A. Mondol, M. A. Wadud, and G. M. M. Rahman, "Soil, plant species and encroachment status of sal forest in Bangladesh," *Advances in Image and Video Processing*, vol. 9, no. 4, pp. 154–171, 2021.

[20] K. B. Shrestha, I. E. Maren, E. Arneberg, J. P. Sah, and O. R. Vetaas, "Effect of anthropogenic disturbance on plant species diversity in oak forests in Nepal, Central Himalaya," *International Journal of Biodiversity Science, Ecosystem Services & Management*, vol. 9, no. 1, pp. 21–29, 2013.

[21] S. K. Barik, H. N. Pandey, B. K. Tiwari, K. Sarma, and B. Singh, *Coal Mining in Meghalaya: An Environmental Perspective*, Regional Centre, National Afforestation and Eco-Development Board, North Eastern Hill University, Shillong, India, 2006.

[22] Y. Huang, F. Tian, Y. Wang, M. Wang, and Z. Hu, "Effect of coal mining on vegetation disturbance and associated carbon loss," *Environmental Earth Sciences*, vol. 73, no. 5, pp. 2329–2342, 2015.

[23] K. Sarma, *Coal mining and its impact on environment of nokrek biosphere reserve, Meghalaya*, Ph.D. thesis, North Eastern Hill University, Shillong, India, 2002.

[24] M. Alauddin, M. N. Hossain, M. B. Islam, S. Islam, and M. K. Islam, "Management strategies for sustainable forest biodiversity conservation in protected areas of Bangladesh: a Study of Bhawal National Park, Gazipur," *Grassroots Journal of Natural Resources*, vol. 3, no. 3, pp. 56–72, 2020.

[25] M. M. Rahman and H. Vacik, "Can picnic influence floral diversity and vitality of trees in Bhawal National Park of Bangladesh?" *Forestry Studies in China*, vol. 11, no. 3, pp. 148–157, 2009.

[26] M. R. Rahman, M. K. Hossain, and M. A. Hossain, "Diversity and composition of tree species in Madhupur national park, tangail, Bangladesh," *Journal of Environmental Sciences*, vol. 35, no. 3, pp. 159–172, 2019.

[27] WFO, *World Flora Online*, World Federation of Orthodontists, Rome, Italy, 2022.

[28] M. A. Chowdhury, K. N. Islam, N. Hafiz, and K. Islam, "Diversity of trees in a community managed forest: the case of Komolchori VCF, Khagrachari, Bangladesh," *Geology, Ecology, and Landscapes*, vol. 3, no. 2, pp. 95–103, 2019.

[29] R. S. Shukla and P. S. Chandel, *Plant Ecology and Soil Science*, S. Chand & Company Limited, New Delhi, India, 2000.

[30] F. Dallmeier, M. Kabel, and R. Rice, "Methods for long-term biodiversity inventory plots in protected tropical forests," in *Ling-term Monitoring of Biological Diversity in Tropical Forest Areas: Methods for Establishment and Inventory of Permanent Plots*UNESCO, Paris, France, 1992.

[31] R. Misra, *Ecology Workbook*, Oxford and IBH Publishing Company Ltd, New Delhi, India, 1968.

[32] M. S. Islam, T. R. Tusher, M. H. Kabir, M. R. Hassan, and M. N. H. Khan, "Carbon storage and sequestration potentiality of tree species in Madhupur Sal Forest of Bangladesh," *Bangladesh Journal of Environmental Science*, vol. 30, pp. 33–39, 2016.

[33] A. F. Magurran, *Ecological Diversity and its Measurement*, Princeton University Press, Princeton, NJ, USA, 1988.

[34] C. E. Shannon and W. Wiener, *The Mathematical Theory of Communities*, University of Illinois Press, Urbana, IL, USA, 1963.

[35] R. Margalef, "Information theory in ecology," *International Journal of General Systems*, vol. 3, pp. 36–71, 1958.

[36] E. H. Simpson, "Measurement of diversity," *Nature*, vol. 163, no. 4148, p. 688, 1949.

[37] E. C. Pielou, "Species-diversity and pattern-diversity in the study of ecological succession," *Journal of Theoretical Biology*, vol. 10, no. 2, pp. 370–383, 1966.

[38] R. H. Whittaker, "Evolution and measurement of species diversity," *Taxon*, vol. 21, no. 2-3, pp. 213–251, 1972.

[39] P. Jaccard, "The distribution of the flora of the alpine zone," *New Phytologist*, vol. 11, no. 2, pp. 37–50, 1912.

[40] T. Sorensen, "A method of estimating group of equal amplitude in plant society based on similarity of species content," *Kongelige Danske Videnskabernes Selskab Biologiske Skrifter*, vol. 5, pp. 1–34, 1948.

[41] P. B. Whitford, "Distribution of woodland plants in relation to succession and clonal growth," *Ecology*, vol. 30, no. 2, pp. 199–208, 1949.

[42] J. T. Curtis and G. Cottam, "Plant Ecology Work Book Laboratory Field and References Manual," *Minneapolis, Edina, Burgess Publishing Company*, p. 193, 1956.

[43] O. Bajpai, V. Dutta, R. Singh, L. B. Chaudhary, and J. Pandey, "Tree community assemblage and abiotic variables in tropical moist deciduous forest of himalayan Terai eco-region," *Proceedings of the National Academy of Sciences, India—Section B: Biological Sciences*, vol. 90, no. 4, pp. 873–883, 2020.

[44] M. L. Mc Kinney, "Urbanization, biodiversity, and conservation," *BioScience*, vol. 52, no. 10, pp. 883–890, 2002.

[45] M. Tarakeswara Naidu, D. Premavani, S. Suthari, and M. Venkaiah, "Assessment of tree diversity in tropical deciduous forests of north central Eastern Ghats, India," *Geology, Ecology, and Landscapes*, vol. 2, no. 3, pp. 216–227, 2018.

[46] G. Dutta and A. Devi, "Plant diversity and community structure in tropical moist deciduous Sal (Shorea robusta Gaertn.) forest of Assam, northeast India," *Journal of Environmental and Applied Bioresearch*, vol. 1, no. 3, pp. 1–4, 2013.

[47] S. Subba, K. Gurung, S. Subba, and S. Nepal, "Quantitative analysis of vegetation structure, composition and species diversity of moist Sal bearing tropical forest of Sumbuk reserve forest in South Sikkim, India," *Tropical Plant Research*, vol. 7, no. 1, pp. 245–254, 2020.

[48] D. Rabha, "Species composition and structure of Sal (Shorea robusta Gaertn. f.) forests along distribution gradients of Western Assam, Northeast India," *Tropical Plant Research*, vol. 1, 2014.

[49] C. Sunil, R. Somashekar, and B. Nagaraja, "Impact of anthropogenic disturbances on riparian forest ecology and ecosystem services in Southern India," *International Journal of Biodiversity Science, Ecosystem Services & Management*, vol. 7, no. 4, pp. 273–282, 2011.

[50] P. Bhuyan, M. L. Khan, and R. S. Tripathi, "The tree diversity and population structure in undisturbed and human impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India," *Biodiversity & Conservation*, vol. 12, pp. 1753–1773, 2003.

[51] J. Tenzin and H. Hasenauer, "Tree species composition and diversity in relation to anthropogenic disturbances in broadleaved forests of Bhutan," *International Journal of Biodiversity Science, Ecosystem Services & Management*, vol. 12, no. 4, pp. 274–290, 2016.

[52] Z. A. Malik, R. Pandey, and A. B. Bhatt, "Anthropogenic disturbances and their impact on vegetation in Western Himalaya, India," *Journal of Mountain Science*, vol. 13, no. 1, pp. 69–82, 2016.

[53] M. Behera, S. Kushwaha, P. Roy, S. Srivastava, T. Singh, and R. Dubey, "Comparing structure and composition of coniferous forests in Subansiri district, Arunachal Pradesh," *Current Science*, vol. 82, no. 1, pp. 70–76, 2002.

[54] D. J. Yeom and J. H. Kim, "Comparative evaluation of species diversity indices in the natural deciduous forest of Mt. Jeombong," *For Sci Tech Lux*, vol. 7, 2011.

[55] W. N. W. Ismail, W. J. W. Ahmad, M. R. Salam, and A. Latiff, "Structural and floristic pattern in a disturbed mangrove tropical swamp forest: a case study from the langkawi UNESCO global geopark forest," *Peninsular Malaysia Sains Malays*, vol. 47, no. 5, pp. 861–869, 2018.

[56] B. J. Mc Gill, R. S. Etienne, J. S. Gray et al., "Species abundance distributions: moving beyond single prediction theories to integration within an ecological framework," *Ecology Letters*, vol. 10, no. 10, pp. 995–1015, 2007.

[57] B. P. Mishra, O. P. Tripathi, R. S. Tripathi, and H. N. Pandey, "Effects of anthropogenic disturbance on plant diversity and community structure of a sacred grove in Meghalaya, northeast India," *Biodiversity & Conservation*, vol. 13, no. 2, pp. 421–436, 2004.

[58] O. P. Tripathi, K. Upadhaya, R. S. Tripathi, and H. N. Pandey, "Diversity, dominance and population structure of tree species along fragment-size gradient of subtropical humid forest of northeast India," *Research Journal of Environmental and Earth Sciences*, vol. 2, pp. 97–105, 2010.

[59] N. Borah and S. C. Garkoti, "Tree species composition, diversity and regeneration patterns in undisturbed and disturbed forests of Barak Valley, South Assam, India," *International Journal of Ecology & Environmental Sciences*, vol. 37, pp. 131–141, 2011.

[60] N. Borah, A. K. Das, and S. C. Garkoti, "Community structure and diversity of tropical forests along with disturbance gradients in Barak Valley of Assam, India," *Assam University Journal*, vol. 9, pp. 38–45, 2012.

[61] O. Bajpai, A. Kumar, A. K. Mishra et al., "Recongregation of tree species of katerniaghat wildlife sanctuary, Uttar Pradesh, India," *Journal of Biodiversity and Environmental Sciences*, vol. 2, no. 12, pp. 24–40, 2012.

[62] T. Abdela, A. Sufiyan, B. Mewded, and K. Gemechu, "Floristic composition, structure and regeneration status of hamdo natural forest, gursum woreda East hararghe zone, Ethiopia," *International Journal of Ecotoxicology and Ecobiology*, vol. 6, no. 3, pp. 50–58, 2021.

[63] K. Majumdar and B. K. Datta, "Effects of anthropogenic disturbances on vegetation diversity and structure: a case study in the remnant forests surrounding the village ecosystems of Tripura, Northeast India," *Chinese Journal of Population Resources and Environment*, vol. 13, no. 4, pp. 332–340, 2015.

[64] J. E. Eshaghi, G. Valadi, and M. R. Zargaran, "Effect of man-made disturbances on understory plant richness of oak forests in Iran," *Folia Oecologica*, vol. 44, no. 2, pp. 61–68, 2017.

[65] M. S. Awan, M. E. U. I. Dar, H. Shaheen, R. W. A. Khan, S. Aziz, and T. Habib, "Diversity and distribution pattern of alpine vegetation communities from ratti gali lake and its adjacent areas, Kashmir Himalayas, Pakistan," *Pakistan Journal of Botany*, vol. 53, no. 2, pp. 665–672, 2021.

[66] S. Nandy and A. Kumar Das, "Comparing tree diversity and population structure between a traditional agroforestry system and natural forests of Barak valley, Northeast India," *International Journal of Biodiversity Science, Ecosystem Services & Management*, vol. 9, no. 2, pp. 104–113, 2013.

[67] A. Devi Khumbongmayum, M. L. Khan, and R. S. Tripathi, "Biodiversity conservation in sacred groves of Manipur, northeast India: population structure and regeneration status of woody species," *Biodiversity & Conservation*, vol. 15, no. 8, pp. 2439–2456, 2006.

[68] N. Midha and P. K. Mathur, "Assessment of forest fragmentation in the conservation priority Dudhwa landscape, India using FRAGSTATS computed class level metrics," *Journal of the Indian Society of Remote Sensing*, vol. 38, no. 3, pp. 487–500, 2010.

[69] K. P. Sharma, S. P. Bhatta, and S. K. Lamsal, "Species diversity and regeneration status of community-managed hill Sal (Shorea robusta) forest in Central Nepal," *Current Science*, vol. 119, no. 1, pp. 83–92, 2020.

[70] D. Newsome, S. A. Moore, and R. K. Dowling, *Natural Area Tourism: Ecology, Impacts and Management*, Channel View Publications, Sydney, Australia, 2002.