Research Square

Preprints are preliminary reports that have not undergone peer review. They should not be considered conclusive, used to inform clinical practice, or referenced by the media as validated information.

Ecological Drivers of Natural Forest Regeneration in a Tropical Moist Forest Protected Area of Bangladesh

Lubaba Noshin
Shahjalal University of Science and Technology
Rabeya Sultana
Shahjalal University of Science and Technology
Kazi Mohammad Masum
kmmasum-for@sust.edu

Shahjalal University of Science and Technology

Research Article

Keywords: Species Diversity, Micro-environmental Factors, Natural regeneration, Protected Area

Posted Date: October 16th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11186326/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Natural regeneration is considered the most cost-effective and practical method of forest recovery, contributing to the maintenance of ecological balance and biodiversity conservation. Understanding the dynamics of natural regeneration is crucial for predicting future vegetation development and maintaining forest ecosystem stability. This study evaluated the natural regeneration status and the influence of selected habitat factors in a tropical moist forest protected area in Bangladesh (Tilaghor Eco-Park). A total of 100 (2 m x 2 m) regeneration plots were studied to elucidate the regeneration condition of the site and to analyze the effects of site factors on them. In those plots, we recorded 314 trees, 102 saplings, and 935 seedlings belonging to 21 distinct species. *Dipterocarpus turbinatus* (Garjan) was the most dominant and abundant among tree and seedling species, whereas *Calamus longisetus* (Bet) was the most dominant among sapling species. We applied Non-metric Multidimensional Scaling (NMDS) and Generalized Linear Models (GLM) to understand community complexity and the specific effects of ecological factors on regeneration, respectively. Our study identified correlations of seedling richness and abundance with 10 selected habitat factors. Among these, tree height and tree richness were significantly correlated with seedling richness and seedling abundance, according to the NMDS ordination. The GLM analysis indicated that seedling richness were significantly influence by tree and sapling richness and abundance where seedling abundance was influenced by elevation, tree diameter and basal area. The study highlights critical aspects that can guide area-specific forest management and the selection of preferred indigenous species for future restoration initiatives.

Introduction

Natural regeneration is the predominant recovery process in natural forests [1]. It plays a prominent role in large scale landscape restoration in tropics [2]. Natural regeneration is frequently utilized when direct planting of seedlings is economically or logistically inefficient [3]. There are many advantages of natural regeneration process over artificial plantation. Because plantation managers often mismatch species, provenances, and genotypes with local site conditions, naturally growing stands ensure more successful establishment. In addition, transplanted individuals often exhibit high mortality rates, slow growth and deformed stems for poor planting techniques [4]. This failure is considered one of the major reasons for the degradation of tropical forests.

Tropical forests, under immense pressure from deforestation, harbor significant biodiversity, regulate climate change, and provide key ecosystem services [5]. These forests store approximately 46% of the world’s living terrestrial carbon pool [6]. They regulate the hydrological cycle by affecting evapotranspiration which takes place in the soil and leaves. On the other hand, these forests provide habitat for two-thirds of the world's biodiversity [7]. In the tropics, natural regeneration is an important vegetation strategy to sequester soil organic materials as well as improve soil quality [1]. Crucially, this type of regeneration is the most cost-effective mechanism of sequestration of almost 24%-35% carbon from fossil fuels and industrial emissions [2]. Again, naturally regenerating plots shows higher probability of achieving reproductive maturity and improve demographic performance that ensures long term forest

success [5]. Study [8] showed that to attain superior biodiversity and structural complexity, natural regeneration is preferred over active tree planting. Through self-producing process a forest can secure its genetic diversity. Species those are found in particular forest by re-producing through seeds, coppices and root suckers can avoid their danger of extinction in the forest [8]. Furthermore, it is claimed that, naturally regenerating forests have complex adaptive system that possess some key properties that promote better resilience to disturbance [9].

Increasing deforestation (almost 64,000 km2 year-1 for the entire tropical biome) has prompted researchers to study in depth about restoration of abandoned land. Study [10] predicted the future of tropical forests where he mentioned about five anthropogenic drivers namely land use change, wood extraction, hunting, atmospheric change, climate change would contribute to the dimension of tropical forests. Previous studies examined different impact of natural regeneration for ecological restoration, biodiversity loss minimization and nutrient cycling regulation over other regenerating processes [2, 8, 11, 12, 13, 14, 15]. Some studies [16, 17, 18, 19] evaluated the effect of different drivers on natural regeneration in tropical forests.

The regeneration process of the forests is regulated by a number of factors [16]. It involves dynamic life cycle of plants and the mortality is higher in the early stage of life. Transition to the next stage of life affected greatly by the site factors upon which success of the establishment depends [18]. Canopy coverage has mix influence on regeneration process [19]. Where it favors species establishment to protect from harsh condition for moderate shade tolerant and shade tolerant species, it also can hinder the growth of shade intolerant species by affecting the temperature and sunlight in the forest floor. In contrary, many studies claimed that regeneration degrades with the increase of elevation because the temperature, precipitation, humidity and nutrient availability greatly alter with gradients [20]. Again, canopy height of the forests in one hand promotes microhabitats, on the other hand it paves the way of light exposure on forest floor [21]. Despite, tree richness, and abundance assist more self-producing forest through seed availability but these factors ignite more competition among the regenerating plants [22]. However, tree height influences regeneration dynamics by controlling light penetration in the forests. Furthermore, sapling richness, abundance and height are good indicators for maintaining favorable condition for future generation but they also facilitate competition. As like trees and saplings seedling richness ensures future diversity of the forest that is more resilient to disturbances where their abundance increases competition that leads to less survival rate.

Through the decades, Tropical forests suffer the risk of degradation as a result of human interventions. The dynamics of this forest is changing over time through human management system and land-use pattern [6]. Fast conversion of forest lands into other land uses emerge a global concern that leads the international organizations to install methods to restore the forest lands [23]. Growing concern about the deforestation influences researcher and foresters to identify most time and cost-effective process for forest restoration. All of them are identified natural regeneration as the most cost-efficient process to forest improvement [3, 16]. Lack of natural regeneration often produces low products which fail to fulfill the market demands. In the aftermath, investors lack interest in forest sector which indirectly impact on

the conversion of forest lands in another land use system [24]. Assessing species diversity is fundamental to understand the interaction among biodiversity recovery, ecosystem functions and ecosystem services [15]. A number of recent studies focused on the natural regeneration dynamics of differential ecological types of forest [25, 26, 27, 28, 29] of Bangladesh. There are studies on species diversity in national parks of the Sylhet division but study about the effect of ecological factors on natural regeneration of the Tilaghor Eco-park is scanty. The aim of this study is to explore the effect of ecological factors of the park on natural regeneration. The imminent degradation of vast areas of the tropics influenced us to analyze the statistical relations among regeneration status with habitat related ecological variables. This study hypothesized that ecological factors like basal area, canopy coverage of each plot, canopy height, elevation, and dominant (taller) tree-related factors like tree richness, abundance, average tree height, sapling richness, sapling abundance, and average sapling height can have a significant effect on regeneration establishment by producing more seeds and recruitment in the Tilaghor Eco-park. We also predicted that these factors greatly would contribute to shape the future community structure of the area. This study will fill up the gap of knowledge in taking decision on the restoration of the protected forest area that are in the vicinity of urban area as it is vulnerable to disturbance but has a great impact on developing general people's empathy to the nature. We assumed this study will be a valuable addition for studying natural regeneration regulating factors in the tropical moist forest in South Asia.

Materials

Site Orientation

Tilaghor eco-park is a well-known Protected Area in north-eastern Bangladesh is part of the Indo-Burma Biodiversity hotspot. The forests are mixed semi-deciduous, containing evergreen understory and the deciduous canopy trees. This eco-park serves as an important recreational place for the Sylhet city dwellers. Since 2006, this park has been serving for the preservation, development and protection of extinct, rare and local flora and fauna [30]. It is promoting local livelihood improvement through eco-tourism and scope for research. It is the third eco-park of Bangladesh which consists 112 acres (45.3 ha) of Tilaghor Reserve Forest. Geographically, this region lies between 23°55' and 25°02' N, and 90°55' and 92°30' E coordination (Fig. 1). The climate of the place is humid subtropical with a predominantly hot and humid summer and a relatively cool winter. The annual average highest temperature is 23°C (August–October) with an average lowest temperature of 7°C (January). Nearly 80% of the annual average rainfall of 3334 mm occurs between May and September. The eco-park comprises several hillocks of different elevations and low-lying valleys [31]. This eco-park has been developed with some hillocks, a stream that has passed through the small hills of the site. These features make this site ideal for some species distribution and habitation.

Data Collection

Vegetation data collection

To assess current tree species (> 5m height and > 5cm DBH) diversity 25 systematic sampling plots (10m × 10m) of 100 sq. m were taken within the study area which covers 0.25 ha area in total. The plots were spaced minimum 200 meters apart in a scientific design avoiding setting plots in cliffs and on foot trails. In each plot we had assessed sapling species (1.3 m < Height ≤ 5 m; 2 cm < DBH ≤ 5 cm) diversity. To assess the natural regeneration, we divided the plots into 4 subplots (2m × 2 m) which were taken four corners in each plot. So, 100 plots of 2 m × 2 m (a total of 400 sq. m) were sampled for seedling following [32]. Regenerated trees (≤ 1.3 m height; ≤ 2 cm DBH) were considered as seedlings. Seedlings of all species in each plot were identified and recorded by local and scientific names. All plant species were identified directly in the field by Lubaba Noshin based on [33] and 'BGD Trees App' that was developed by Bangladesh Forest Department and Bangladesh National Herbarium.

Phytosociological attributes and statistical data Analysis

For evaluating site factors, we measured variables namely basal area, canopy coverage of each plot, canopy height, elevation. We also calculated variables like tree richness, abundance, tree average height, sapling richness, sapling abundance, sapling average height, seedling richness and seedling abundance for understanding the Important value index(IVI), biodiversity indices of the species and understand the stand structure. We used spherical crown densitometer for measuring canopy coverage of each plot following [32] methodology. For estimating elevation, we used hand-held GPS navigator at the center of each plot. The canopy height was calculated by averaging tree heights of each plot. Data regarding tree height, sapling height were measured by range finder. For calculating IVI, we calculated density of species, relative density, frequency of a species, relative frequency, abundance of a species and relative abundance by the formulae mentioned in [34] study (Table 1). Species richness and diversity were calculated by the formulae mentioned in [26] study (Table 1).

Table 1
List of formulae used for calculating the phytosociological characteristics of the vegetation and diversity indices to quantify the species attributes

No.	Formulae
3	Basal Area (BA)$= \pi \left(\frac{D}{2}\right)^2 BH$
8	Important Value Index (IVI) = RD + RF + RA
9	Species Diversity Index, S_{Di} = S/N
10	Shannon- Winner diversity Index, H= - $\sum^{n}_{i=1}$ Pi ln Pi
11	Species evenness index, E = H/ Ln (S)
12	Simpson's diversity index, D = 1/ $\sum^{n}_{i=1} P_i^2$

$\mathrm{a} =$ Total no. of individuals of a spp. in all the quadrat, b $=$ Total no. of quadrat studies, n $= \mathrm{Density\ of\ all\ species}$, N= Total density of all species, c = the number of quadrats in which the species occurs, Fi= number of frequency of one species, $\mathrm{Ai} =$ total number of individuals of a specific species, S= Total number of species, N= Total number of individuals of all the species, Pi = No. of individuals of one species/Total no. of individuals in all the samples, H= Shannon-Winner's diversity index

For data analysis we used PAST 4.10, R 4.2.2 (R Core Team 2022), Excel (office 2019) software and for mapping we used ArcMap 10.8 [35]. In the current study, four measures of plant diversity, namely species diversity index, Simpson diversity index, evenness index and the Shannon diversity index, were calculated and utilized to reflect regeneration diversity. The number of species seen in each plot was used to calculate the species richness. We conducted this study using individual-based (abundance) regeneration data. Confidence ranges for the estimates were created using 50 bootstrap repeats, and they were then used to determine if there was a significant difference between the estimated species richness in the plots. Nonmetric multidimensional scaling (NMDS) ordination have been performed for seedling richness and seedling abundance as response variables where other factors were considered as environmental factors. and Generalized Linear Model (GLM) was implied to understand the specific effect of environmental factors on regeneration dimensions. For the analysis we used R packages like tidyverse, ggplot2, ggrepel, grid, vegan, dplyr, MASS and readr. Study area map was created by ArcMap 10.8. Finally, PAST software was also used to proceed Canonical Correspondence Analysis to find out the effect of environmental variables with seedling abundance and richness.

Results

Qualitative characteristics

In our study we found total 314 individuals from 21 tree species, 102 individual saplings of 11 species and 935 individual seedlings species belong from 10 species. From our investigation we observed that *Dipterocarpus turbinatus* was the most abundant and *Shorea robusta* and *Magolia champaca* was the second and third abundant tree species, respectively. *Calamus longisetus* was the most abundant where *Dipterocarpus turbinatus* was the second abundant sapling species in the studied site. Like tree species, *Dipterocarpus turbinatus* was the most abundant seedling species where *Shorea robusta* was the second abundant in this eco-park. We listed the name of the species in the table below (Table 2).

Table 2
Name and abundance of the tree, sapling and seedling species found in Tilaghor Eco-park

Tree Scientific Name	**Tree abundance**	**Sapling scientific name**	**Sapling abundance**	**Seedling scientific name**	**Seedling abundance**
Dipterocarpus turbinatus	76	*Calamus longisetus*	75	*Dipterocarpus turbinatus*	376
Shorea robusta	54	*Dipterocarpus turbinatus*	10	*Shorea robusta*	346
Magnolia champaca	52	*Artocarpus chama*	4	*Calamus longisetus*	87
Artocarpus chama	31	*Hibiscus rosa-sinensis*	4	*Magnolia champaca*	86
Lagerstroemia speciosa	23	*Areca catechu*	2	*Artocarpus chama*	23
Delonix regia	22	*Polyalthia longifolia*	2	*Bryophyllum calycium salisb*	7
Aquilaria nmalaccensis Lamk	14	*Baccaurea motleyana*	1	*Streblus asper*	6
Elaeocarpus serratus	10	*Diospyros malabarica*	1	*Mangifera indica*	2
Tectona grandis	5	*Ficus racemosa*	1	*Albizia procera*	1
Barringtonia acutangula	7	*Magnolia champaca*	1	*Terminalia chebula*	1
Areca catechu	3	*Mimusops elengi*	1		
Averrhoa carambola	4				
Swietenia mahagoni	3				
Acacia mangium	2				
Albizia procera	1				
Eucalyptus hybrida	1				
Mangifera indica	1				

Tree Scientific Name	Tree abundance	Sapling scientific name	Sapling abundance	Seedling scientific name	Seedling abundance
Mimusops elengi	1				
Polyalthia longifolia	1				
Schima wallachii	1				
Tamarindus indica	1				

Important Value Index (IVI)

Important Value Index (IVI) represents how dominant a species is in a forest. From our estimation, we saw Garjan (*Dipterocarpus turbinatus*) was the most dominant tree species. Champa (*Magnolia champaca*) was the second dominant one where Sal (*Shorea robusta*) placed the third one. For sapling the most dominant species was Bet *(Calamus longisetus*), then Garjan (*Dipterocarpus turbinatus)* was the second most important sapling species (Table 3).

Table 3
Calculated Important Value Index (IVI) for Tree and Sapling Species for Quantifying Ecological Importance of Species

Tree Scientific name	IVI	Sapling scientific name	IVI
Dipterocarpus turbinatus	72.65	*Calamus longisetus*	182.06
Magnolia champaca	42.21	*Dipterocarpus turbinatus*	34.61
Shorea robusta	41.97	*Artocarpus chama*	17.84
Artocarpus chama	37.93	*Hibiscus rosa-sinensis*	12.84
Lagerstroemia speciosa	23.74	*Areca catechu*	8.92
Delonix regia	18.56	*Polyalthia longifolia*	8.92
Aquilaria nmalaccensis	10.43	*Baccaurea motleyana*	6.96
Elaeocarpus serratus	7.88	*Diospyros malabarica*	6.96
Tectona grandis	6.2	*Ficus racemosa*	6.96
Barringtonia acutangula	5.97	*Magnolia champaca*	6.96
Areca catechu	4.94	*Mimusops elengi*	6.96
Averrhoa carambola	4.06		
Swietenia mahagoni	3.43		
Acacia mangium	2.79		
Albizia procera	2.55		
Eucalyptus hybrida	2.55		
Mangifera indica	2.55		
Mimusops elengi	2.55		
Polyalthia longifolia	2.20		
Schima wallachii	2.20		
Tamarindus indica	2.20		

Species Diversity Index

With the help of different biological diversity, we estimated the richness and abundance of the species of the eco-park as it is the prior criteria for considering an ecosystem for conservation. We mentioned all the diversity of the species that we found in our study area (Table 4). Simpson diversity index measure both richness and abundance of species in a forest. It ranges from 0 to1. The higher the value the

greater the diversity is. Here, Simpson diversity index for tree was 0.86, sapling was 0.45 and seedling was 0.68. So, it can be said that here tree diversity was in higher level of condition, sapling diversity was in moderate to lower condition and seeding diversity was moderate condition.

Table 4
Species Diversity Indices of the Study Area

Parameter	Tree	Sapling	Seedling
Taxa_S	21	11	10
Individualls	314	102	935
Simpson_1-D	0.8629	0.4498	0.6837
Shannon_H	2.273	1.087	1.368
Evenness_e^H/S	0.735	0.2354	0.3572

Shannon diversity index also tells us about the forest richness and abundance condition of species. This index range is 1.5 to 3.5. The high value indicates high diversity. Shannon diversity index for tree, sapling and seedling was 2.27, 1.08 and 1.37, respectively. From this value it can be said that tree diversity was in high, sapling was in moderate to lower and seedling was in moderately good conditions. Evenness index is the relative abundance of species in a forest. Evenness index range is 0 to 1.1 means perfect evenness and 0 is perfect unevenness. Here, the evenness index was for tree, sapling and seedling 0.73, 0.24 and 0.36 respectively. It can be said that tree was in more even condition than sapling and seedling in this area. From the rank abundance curve (Fig. 2), it was evident that Garjan (*Dipterocarpus turbinatus*) was the most abundant tree and seedling species where Bet (*Calamnus longisetus)* was the most abundant sapling species in the study area.

Non-metric Multidimensional Scaling (NMDS) Analysis

The NMDS analysis illustrates the diverse pattern among all the factors in the study site. It is used generally to rank among factors based on their similarities and differences. The stress value 0.13 which is lower than 0.2 indicates the reliability of the analysis. From the graph, it can be seen that tree height and tree richness were the major two drivers of seedling community (Fig. 3). Among these two factors, tree height had the strongest effect on seedling establishment (r^2= 0.30, p = 0.020) as well as tree richness had the significant effect on them (r^2= 0.29, p = 0.035). Alternatively, elevation had shown non-significant trend on seedling species (r^2= 0.21, p = 0.080) along with the factors like basal area r^2= 0.13, p = 0.23, canopy coverage r^2= 0.09, p = 0.35 of each plot, canopy height r^2= 0.06, p = 0.48, tree abundance r^2= 0.005, p = 0.95, sapling richness r^2= 0.10, p = 0.29, sapling abundance r^2= 0.12, p = 0.24, sapling average height r^2= 0.02, p = 0.79 on regenerating species.

Generalized Linear Model (GLM) Analysis

We implied the generalized linear model (Poisson and negative binomial negative family distribution, respectively) to examine the effect of ecological variables on seedling richness and seedling abundance (Fig. 4). The model for explaining the effect of variables on seedling richness explained a substantial proportion of variation in regeneration (null deviance = 33.04, residual deviance = 7.55) which indicated a strong fit. In contrast, the model for seedling abundance showed best fit after reducing collinearity (null deviance = 49.34, residual deviance = 28.27).

According to the GLM model it was seen that tree richness (p = 0.02), tree abundance (p = 0.04), sapling richness (p = 0.01) and sapling abundance (p = 0.04) had significantly affect the seedling richness. The other factors like elevation (p = 0.62), canopy coverage (p = 0.12), canopy height (p = 0.97), tree height (p = 1.18), tree diameter (p = 0.68), basal area (p = 0.71), sapling height (p = 0.32) and sapling diameter (p = 0.51) had no significance on the seedling richness of the study area. After reducing collinearity, elevation (p = 0.07), tree diameter (p = 0.06) and basal area (p = 0.05) showed marginally significant to seedling abundance. As well as, other variables including canopy coverage (p = 0.11), canopy height (p = 0.33), tree height (p = 0.34), tree richness (p = 0.17), tree abundance (p = 0.97), sapling height (p = 0.19), sapling diameter (p = 0.46), sapling richness (p = 0.11), sapling abundance (p = 0.12) had no significant effect on seedling abundance.

Canonical correspondence analysis

Canonical correspondence analysis was applied to pair seedling abundance with a second matrix of four habitat variables that have significant effect in NMDS and GLM analysis, namely tree richness, tree abundance, tree height, sapling richness, and sapling abundance (Fig. 5).

First two axes from the canonical correspondence test explained 59.89% and 28.01% of the variance in plant traits data, respectively. Axis 1 primarily defined a structural gradient separating dense, rich tree stands (negative side) from areas characterized by taller forest canopies and high sapling abundance (positive side). Tree height and tree richness exhibited the strongest environmental influence on plot ordination, while severe directional alignment between abundance and richness vectors highlights potential structural collinearity within both the tree and sapling strata

Discussion

The study had been conducted in the Tilaghor Eco-park which is considered as a major recreational eco-tourism site for the northern region of Bangladesh. It appeared that *Dipterocarpus turbinatus* solely dominate the forest in terms of number of trees and seedlings. Though, earlier studies claimed other species had high IVI rate than *Dipterocarpus turbinatus* [25, 36] in this region. Reportedly, this region was dominated by species like *Shorea robusta* and *Dipterocarpus turbinatus* [37]. In addition, trees and seedlings diversity were mentionable according to our analysis. The number of tree species was lower than the number mentioned in [25] study. Besides, the number of tree species and diversity of natural regeneration species in this place was lower than the other forests of the Sylhet region [25, 26]. Moreover, the amount of tree species was noticeably poor than the other region of hill forests of

Bangladesh [29, 36]. The correlation among seedling richness and seedling abundance with 10 habitat drivers had been examined where we found that tree height and tree richness were mostly influenced seedling richness as well as seedling abundance.

Species Composition and effect of dominant species on regeneration

From our findings, we enlisted 22 tree species, 11 sapling species and 10 seedling species. There is no such documentation of consistent plantation program in the studied eco-park after 1922 (Choudhury 2004). Although the area is considered as potential region for eco-tourism and biodiversity conservation, it is in threat of edge effect and urbanization [37]. We concluded that *Dipterocarpus turbinatus* was the major tree and regenerating species in this eco-park. This finding represented the effect of dominant species in regeneration establishment. Previously, Study [38] mentioned dominant species showed good regeneration quantity where it is either the dominant one or associated with other co-dominant species. Another study [39] also mentioned that about 70% overstorey species generated offspring in the forest. Whereas, one study [40] mentioned the effect of dominant species on regeneration species that it has negative effect on species diversity. In the study plots, there had been seen a few or no regenerations where saplings of Bet (*Calamnus longisetus*) were abundant. This degradation in sapling diversity was a clear statement that this forest would be less diverse in near future. Lesser number of regeneration species indicated that immediate conservation measurement should be taken in this forest. We also suggest that continuous plantation program as well as assisted natural regeneration (ANP) program can contribute in ensuring the diversity of the eco-park.

Effect of tree height and tree richness on regeneration

According to the outcomes, seedling richness and abundance had significantly influenced by tree height and richness. This situation suggested that these factors had mentionable effect on regeneration by changing microclimate. We observed tree height can influence the regeneration dynamics through litter deposition, fluctuation of temperature and light. This finding contradicted with the results of study [22] that claimed there was no significant relationship between regeneration and average height of trees. We found the other habitat factors basal area, canopy coverage of each plot, canopy height, elevation, tree abundance, sapling richness, sapling abundance, sapling average height had no effect on regeneration. The study [41] also said understory and over story species competition is more important than species abundance. However, study [38] showed that understory species has minimal role in regeneration abundance. In addition, we found that tree richness played major role in regeneration species diversity (Fig. 3). Tree richness could help regeneration process by varying habitat heterogeneity, patchy soil nutrient conditions and seed availability. Besides, we found that all the tree species were not showing for regeneration that is similar with the study done by study [25].

From the NDMS analysis it was seen that, factors like basal area, canopy coverage of each plot, canopy height, tree average height, sapling richness, sapling abundance, sapling average height did not have any

significance on seedling richness and abundance. Our result supported the previous findings by study [42] who stated that canopy height does not have any correlation with species richness. In their studies, they claimed canopy gap has immense effect on species richness as well as diversity because it influences the radiation and precipitation. On the other hand, the GLM analysis showed different results which indicated seedling richness had affected by the tree richness, tree abundance, sapling richness and abundance. Tree richness and sapling richness influenced the seedling richness positively where tree abundance and sapling abundance negatively influenced the regeneration richness which could be density dependent suppression. The other factors had no significance on tree richness. Study [43] showed among the several concurrent factors, elevation plays negligible role by dropping temperature in limiting seedling abundance. All the other factors showed zero impact on seedling abundance.

Tree height and tree richness emerged as the most ecologically influential vectors, displaying the longest environmental arrows in CCA. This indicates that canopy height and overstory diversity exert the strongest deterministic pressure on the ordination of these forest plots. A notable finding is the acute, almost parallel alignment between the richness and abundance vectors within both the tree and sapling strata (e.g., tree abundance tightly tracking tree richness). This severe directional alignment highlights structural collinearity within the strata. From an ecological standpoint, this suggests that as species richness increases in these communities, individuals accumulate proportionally without shifting the overall community composition in a novel direction. While this confirms that community density and diversity scale predictably together, it also indicates that future predictive modeling could potentially consolidate these metrics to avoid statistical redundancy, particularly when isolating overstory controls on the regeneration layer [27].

Based on the verified structural data and statistical relationships found in the study, several management strategies are recommended for Tilaghor Eco-Park to ensure future forest diversity and structural balance. First, management must control *Calamus longisetus* (Bet) monopolization by selectively clearing or thinning its dense understory layers, as it currently compromises the sapling stratum by accounting for 75 out of 102 recorded saplings. Second, to mitigate the canopy dominance of *Dipterocarpus turbinatus* (Garjan) - which completely dominates both the tree (76/314) and seedling (376/935) strata—managers should halt further planting of this species and instead introduce under-represented indigenous varieties to prevent a monoculture. Third, the park should implement Assisted Natural Regeneration (ANR) through active enrichment planting in highly degraded pockets vulnerable to urban edge effects, focusing specifically on native species with low natural regeneration counts like *Albizia procera* or *Magnolia champaca* to rebuild balanced vertical strata. Finally, because canopy height and overstory tree richness are foundational structural drivers of seedling dynamics, management must preserve taller, mature overstory trees by strictly banning the logging or clearing of large individuals that maintain the essential microclimate, seed rain, and habitat heterogeneity required for successful forest regeneration.

Conclusion

This study provides crucial insights into the current status of natural regeneration within Tilaghor Eco-Park, a vital protected habitat located within the Indo-Burma biodiversity hotspot. Our findings demonstrate that seedling community dynamics are highly dependent on specific overstory structural and topographic habitat factors. Multivariate analyses successfully isolated these distinct ecological drivers, revealing that canopy tree height and overstory species richness serve as primary determinants shaping seedling community composition. Furthermore, Generalized Linear Models confirmed that while seedling richness is directly regulated by tree and sapling strata diversity, seedling abundance is driven by localized structural variables including elevation, tree diameter, and basal area. Crucially, the extreme dominance of *Dipterocarpus turbinatus* across the seedling layer, coupled with the severe understory monopolization by *Calamus longisetus* saplings, points to potential long-term diversity declines and density-dependent suppression. Because this protected area is closely bordered by an expanding urban landscape, maintaining its ecological stability is vital for both regional biodiversity conservation and urban ecosystem services. To ensure successful and sustainable forest recovery, management authorities must shift toward target-driven conservation strategies. This includes preserving mature overstory trees to secure microclimatic stability, executing selective understory thinning to alleviate competition, and introducing under-represented indigenous species through assisted natural regeneration (ANR) techniques. While this study establishes a strong structural baseline, future research incorporating soil properties and quantifying localized anthropogenic disturbances will be essential to fully decipher and safeguard the long-term regeneration trajectories of tropical moist forests in South Asia.

Declarations

Acknowledgment:

We are thankful to National Science and Technology Fellowship under the Ministry of Science and Technology, Bangladesh for funding the study. Sincere attitude to Bangladesh Forest Department for permitting the research and providing all out help. We also acknowledge two anonymous reviewers for suggesting improvements of this manuscript.

Ethical Approval: Not applicable.

Consent to participate: Not applicable.

Consent to publish: Not applicable.

Name of plant/plant part identifier: Species identification was carried out by the first author Lubaba Noshin and co-operated by Kazi Mohammad Masum

Permission statement: Permission to conduct field survey and collect data was obtained from the Bangladesh Forest Department (Attached as related file).

Plant guidelines: This study was based on non-destructive field observations. No protected species or plants were collected. The research complied with Bangladesh forest and biodiversity conservation regulations named 'Bangladesh Biodiversity Act 2017'.

Funding: Lubaba Noshin received funding from National Science and Technology Fellowship under The Ministry of Science and Technology, Bangladesh.

Competing Interests: The authors have no relevant financial or non-financial interests to disclose.

Author Contributions: All authors contributed to the study conception and design. Lubaba Noshin and Rabeya Sultana conduct the field work and wrote the manuscript, Lubaba Noshin, Rabeya Sultana,and Kazi Mohammad Masum done the analysis. All authors reviewed and approved the manuscript.

Data availability

All data generated or analyzed during this study are included in this published article. The authors declare no competing interests.

References

1. Cheng H, Zhou X, Dong R, Wang X, Liu G, Li Q. Natural vegetation regeneration facilitated soil organic carbon sequestration and microbial community stability in the degraded karst ecosystem. CATENA. 2023;222:106856. https://doi.org/10.1016/j.catena.2022.106856.
2. Chazdon RL, Guariguata MR. Natural regeneration as a tool for large-scale forest restoration in the tropics: prospects and challenges. Biotropica. 2016;48(6):716–30. https://doi.org/10.1111/btp.12381.
3. Grebner DL, Bettinger P, Siry JP. (2013). Common forestry practices. Introduction Forestry Nat Resour, 255–85.
4. Burley J. Encyclopedia of forest sciences. Academic; 2004.
5. Uriarte M, Chazdon RL. Incorporating natural regeneration in forest landscape restoration in tropical regions: synthesis and key research gaps. Biotropica. 2016;48(6):915–24. https://doi.org/10.1111/btp.1241.
6. Löf M, Madsen P, Metslaid M, Witzell J, Jacobs DF. Restoring forests: regeneration and ecosystem function for the future. New Forest. 2019;50(2):139–51. https://doi.org/10.1007/s11056-019-09713-0.
7. Giam X. (2017). Global biodiversity loss from tropical deforestation. *Proceedings of the National Academy of Sciences*, *114*(23), 5775–5777. https://doi.org/10.1073/pnas.1706264114
8. Reid JL, Fagan ME, Zahawi RA. Positive site selection bias in meta-analyses comparing natural regeneration to active forest restoration. Sci Adv. 2018;4(5):eaas9143. https://doi.org/10.1126/sciadv.aas9143.

9. Filotas E, Parrott L, Burton PJ, Chazdon RL, Coates KD, Coll L, Messier C. Viewing forests through the lens of complex systems science. Ecosphere. 2014;5(1):1–23. https://doi.org/10.1890/ES13-00182.1.
10. Wright SJ. The future of tropical forests. Ann N Y Acad Sci. 2010;1195(1):1–27.
11. Poorter L, Bongers F, Aide TM, Almeyda Zambrano AM, Balvanera P, Becknell JM, Rozendaal DM. Biomass resilience of Neotropical secondary forests. Nature. 2016;530(7589):211–4. https://doi.org/10.1038/nature16512.
12. Crouzeilles R, Ferreira MS, Chazdon RL, Lindenmayer DB, Sansevero JB, Monteiro L, Strassburg BB. Ecological restoration success is higher for natural regeneration than for active restoration in tropical forests. Sci Adv. 2017;3(11):e1701345.
13. Taylor BN, Chazdon RL, Menge DN. Successional dynamics of nitrogen fixation and forest growth in regenerating Costa Rican rainforests. Ecology. 2019;100(4):e02637. https://doi.org/10.1002/ecy.2637.
14. Pillay R, Venter M, Aragon-Osejo J, González-del-Pliego P, Hansen AJ, Watson JE, Venter O. Tropical forests are home to over half of the world's vertebrate species. Front Ecol Environ. 2022;20(1):10–5. https://doi.org/10.1002/fee.2420.
15. Chazdon RL, Norden N, Colwell RK, Chao A. Monitoring recovery of tree diversity during tropical forest restoration: lessons from long-term trajectories of natural regeneration. Philosophical Trans Royal Soc B. 2023;378(1867):20210069. https://doi.org/10.1098/rstb.2021.0069.
16. Moeslund JE, Arge L, Bøcher PK, Dalgaard T, Svenning JC. Topography as a driver of local terrestrial vascular plant diversity patterns. Nord J Bot. 2013;31(2):129–44. http://dx.doi.org/10.1111/j.1756-1051.2013.00082.x.
17. Dyderski MK, Gazda A, Hachułka M, Horodecki P, Kałucka IL, Kamczyc J, Jagodziński AM. Impacts of soil conditions and light availability on natural regeneration of Norway spruce Picea abies (L.) H. Karst. in low-elevation mountain forests. Ann For Sci. 2018;75:1–13. https://doi.org/10.1007/s13595-018-0775-x.
18. Rodriguez-Garcia E, Gratzer G, Bravo F. Climatic variability and other site factor influences on natural regeneration of Pinus pinaster Ait. in Mediterranean forests. Ann For Sci. 2011;68:811–23. https://doi.org/10.1007/s13595-011-0078-y.
19. Osuri AM, Mudappa D, Kasinathan S, Raman TS. Canopy cover and ecological restoration increase natural regeneration of rainforest trees in the Western Ghats, India. Restor Ecol. 2022;30(5):e13558. https://doi.org/10.1111/rec.13558.
20. Cagnacci J, Estravis-Barcala M, Lía MV, Martínez-Meier A, Polo MG, Arana MV. The impact of different natural environments on the regeneration dynamics of two Nothofagus species across elevation in the southern Andes. For Ecol Manag. 2020;464:118034. https://doi.org/10.1016/j.foreco.2020.118034.
21. Ramos de Andrade J, Andrade da Silva K, Fraga dos Santos JM, Melo dos Santos D, Guerra P, T., de Lima, Araújo. E. (2015). Influence of microhabitats on the performance of herbaceous species in

areas of mature and secondary forest in the semiarid region of Brazil. *Revista de Biologia Tropical*, *63*(2), 357–368.

22. Hammond ME, Pokorný R, Okae-Anti D, Gyedu A, Obeng IO. The composition and diversity of natural regeneration of tree species in gaps under different intensities of forest disturbance. J Forestry Res. 2021;32(5):1843–53. https://doi.org/10.1007/s11676-020-01269-6.
23. Masum KM, Mansor A, Sah SAM, San Lim H. Effect of differential forest management on land-use change (LUC) in a tropical hill forest of Malaysia. J Environ Manage. 2017;200:468–74. https://doi.org/10.1016/j.jenvman.2017.06.009.
24. Mattsson A, Radoglou K, Kostopoulou P, Bellarosa R, Simeone MC, Schirone B. Use of innovative technology for the production of high-quality forest regeneration materials. Scand J For Res. 2010;25(S8):3–9. https://doi.org/10.1080/02827581.2010.485825.
25. Rahman MH, Khan MASA, Roy B, Fardusi MJ. Assessment of natural regeneration status and diversity of tree species in the biodiversity conservation areas of Northeastern Bangladesh. J Forestry Res. 2011;22:551–9. https://doi.org/10.1007/s11676-011-0198-0.
26. Sultana R, Rahaman MM. Natural Regeneration and Diversity of the Tree Species at Satchari National Park in Bangladesh. SUST J Sci Technol. 2019;31(2):7–14.
27. Rahman MR, Rahman MM, Chowdhury MA. Assessment of natural regeneration status: the case of Durgapur hill forest, Netrokona, Bangladesh. Geol Ecol Landscapes. 2020;4(2):121–30. https://doi.org/10.1080/24749508.2019.1600911.
28. Azad MS, Kamruzzaman M, Kanzaki M. Canopy gaps influence regeneration dynamics in cyclone affected mangrove stands in medium saline zone of the Sundarbans, Bangladesh. Acta Ecol Sin. 2021;41(4):296–303.
29. Baul TK, Chowdhury AI, Uddin MJ, Hasan MK, Schmidt LH, Nandi R, Nath TK. Diversity and Phytosociology of Natural Regeneration in a Sub-tropical Forest of Chittagong Hill Tracts, Bangladesh: Implications for Conservation. J Sustainable Forestry. 2022;41(9):895–908. https://doi.org/10.1080/10549811.2022.2059517.
30. Mojaharul MI. Ecopark. In: Mojaharul MI, editor. Banglapedia: National Encyclopedia of Bangladesh. 2nd ed. Asiatic Society of Bangladesh; 2021.
31. Deb JC, Salman MHR, Halim MA, Chowdhury MQ, Roy A. Characterising the diameter distribution of Sal plantations by comparing normal, lognormal and Weibull distributions at Tilagarh Eco-park, Bangladesh. South Forests: J For Sci. 2014;76(4):201–8. https://doi.org/10.2989/20702620.2014.947077.
32. Masum KM, Islam MS, Fahim MSI, Parvej M, Majeed M, Hasan MM, Mansor A. Temporal comparison of land-use changes and biodiversity in differential IUCN protected-area categories of Bangladesh in the context of co-management. Geol Ecol Landscapes. 2025;9(1):356–71.
33. Dey TK. Useful Plants of Bangladesh, The Add Communication. Bangladesh: Dhaka; 2018. p. 1056.
34. Chowdhury B, Hossain MK, Hossain MA, Khan BM. (2018). Native tree species diversity of Rampahar natural forest reserve in Rangamati South forest division, Bangladesh. Ceylon J Sci,

47(2).

35. Jaiswal N, Jayakumar S. (2024). Elevation gradients and environmental variables shaping tree diversity and composition in Srivilliputhur Wildlife Sanctuary, Western Ghats. *Geology, Ecology, and Landscapes*, 1–21.
36. Alamgir M, Al-Amin M. (2007). Regeneration status in a proposed biodiversity conservation area of Bangladesh. *Proceedings of the Pakistan Academy of Sciences*, *3*, 165–172.
37. Choudhury JK. Biodiversity of [natural Ecosystems of Bangladesh]: Biodiversity of Jaflong, Sylhet. Volume 2. IUCN Bangladesh Country Office; 2004.
38. Singh S, Malik ZA, Sharma CM. Tree species richness, diversity, and regeneration status in different oak (Quercus spp.) dominated forests of Garhwal Himalaya, India. J Asia-Pacific Biodivers. 2016;9(3):293–300. https://doi.org/10.1016/j.japb.2016.06.002.
39. Pham VV, Ammer C, Annighöfer P, Heinrichs S. Tree regeneration characteristics in limestone forests of the Cat Ba National Park, Vietnam. BMC Ecol Evol. 2022;22(1):6. https://doi.org/10.1186/s12862-021-01957-9.
40. Bartha, S., Szentes, S., Horváth, A., Házi, J., Zimmermann, Z., Molnár, C., … Molnár,Z. (2014). Impact of mid-successional dominant species on the diversity and progress of succession in regenerating temperate grasslands. *Applied vegetation science*, *17*(2), 201–213. https://doi.org/10.1111/avsc.12066.
41. De Lombaerde E, Verheyen K, Van Calster H, Baeten L. Tree regeneration responds more to shade casting by the overstorey and competition in the understorey than to abundance per se. For Ecol Manag. 2019;450:117492. https://doi.org/10.1016/j.foreco.2019.117492.
42. Cazzolla Gatti R, Di Paola A, Bombelli A, Noce S, Valentini R. Exploring the relationship between canopy height and terrestrial plant diversity. Plant Ecol. 2017;218:899–908. https://doi.org/10.1007/s11258-017-0738-6.
43. McIntire EJ, Piper FI, Fajardo A. Wind exposure and light exposure, more than elevation-related temperature, limit tree line seedling abundance on three continents. J Ecol. 2016;104(5):1379–90. https://doi.org/10.1111/1365-2745.12599.

Figures

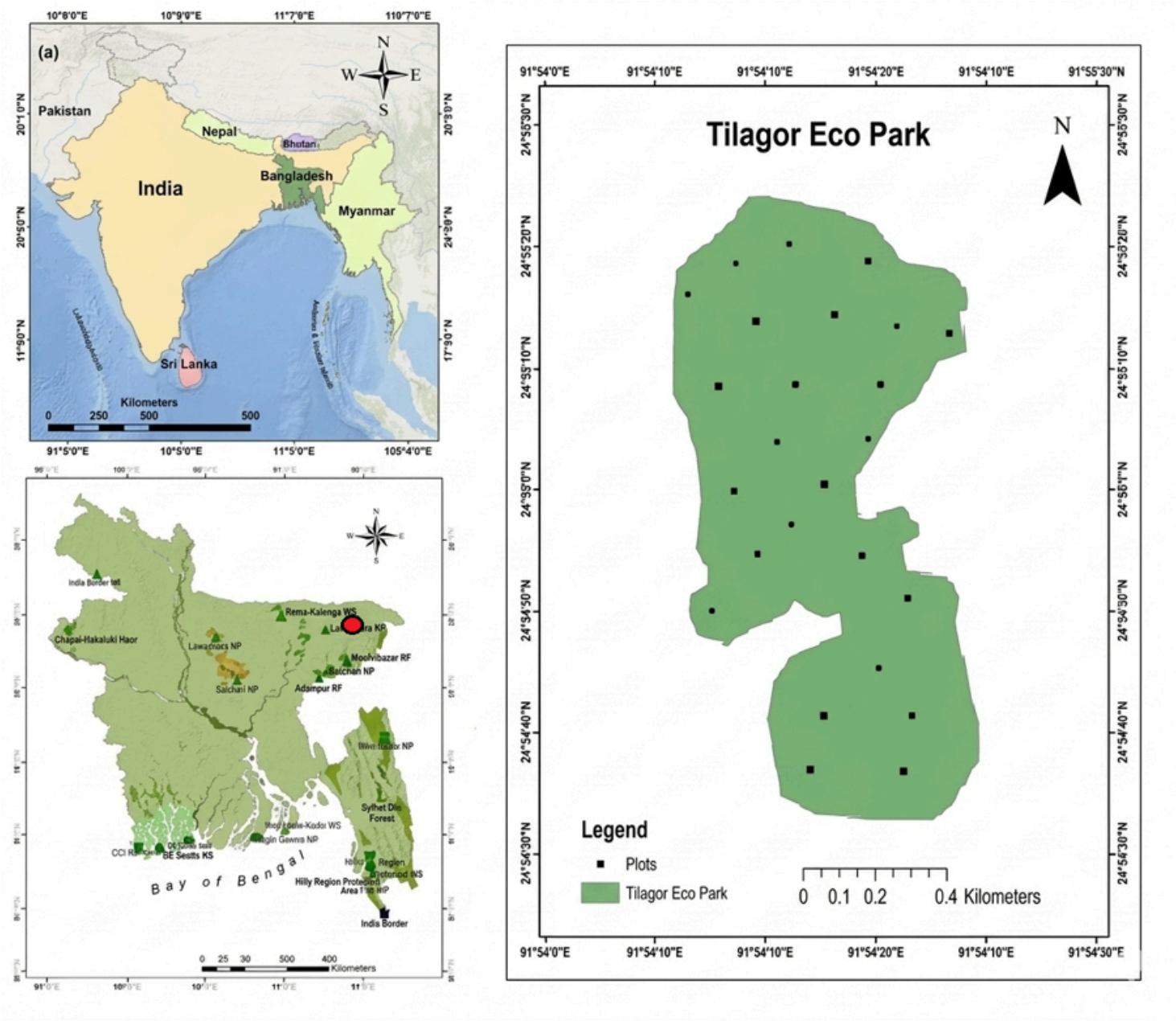

Figure 1

Study area including sampling plots

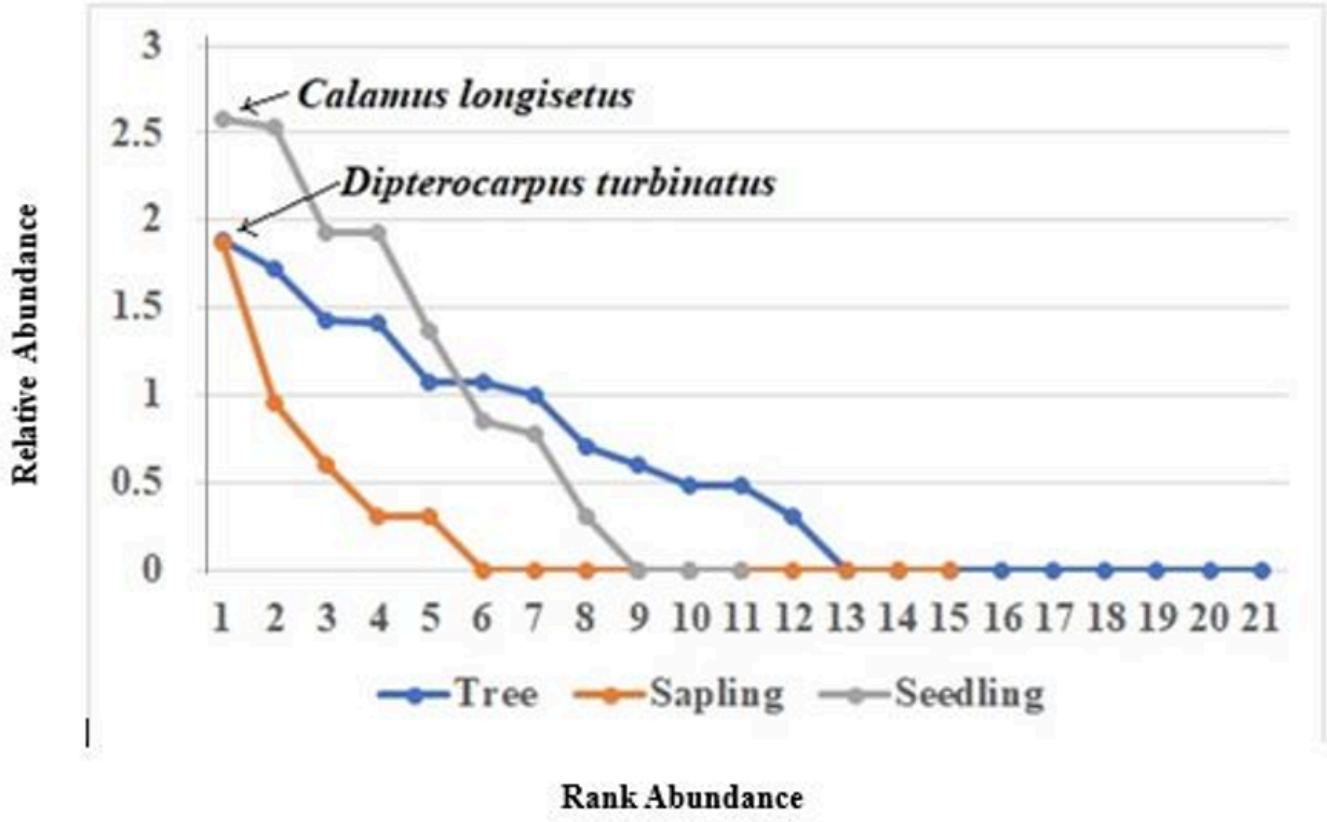

Figure 2

Rank Abundance curve for Tree, Sapling and Seedling species representing the community structure of the study area

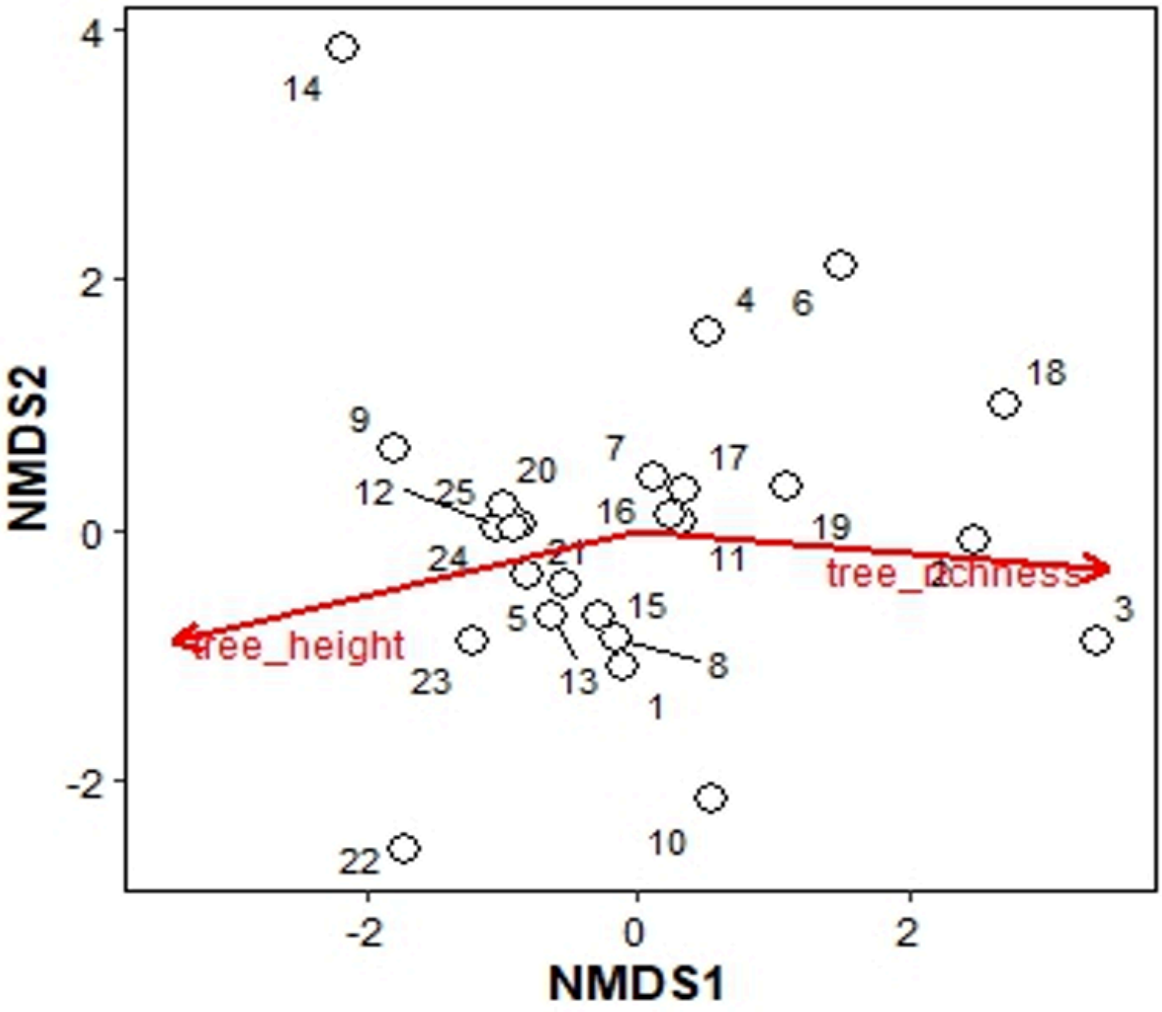

Figure 3

Nonmetric Multidimensional Scaling (NMDS) Ordination for multivariate species composition analysis

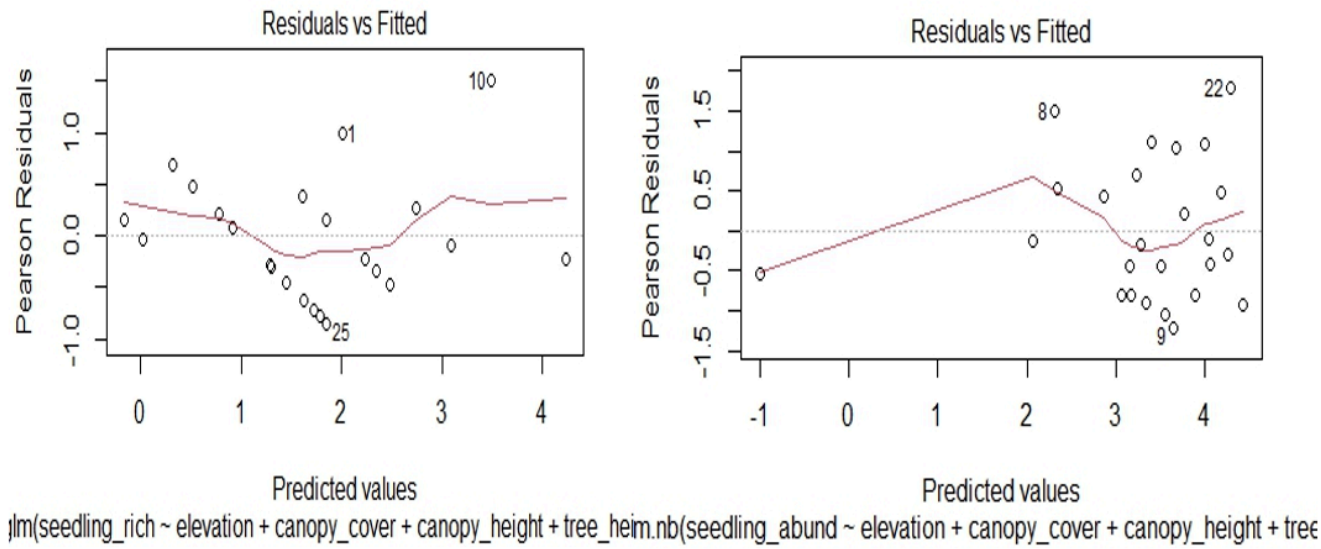

Figure 4

Generalized Linear Model represents specific effect of variables on regeneration

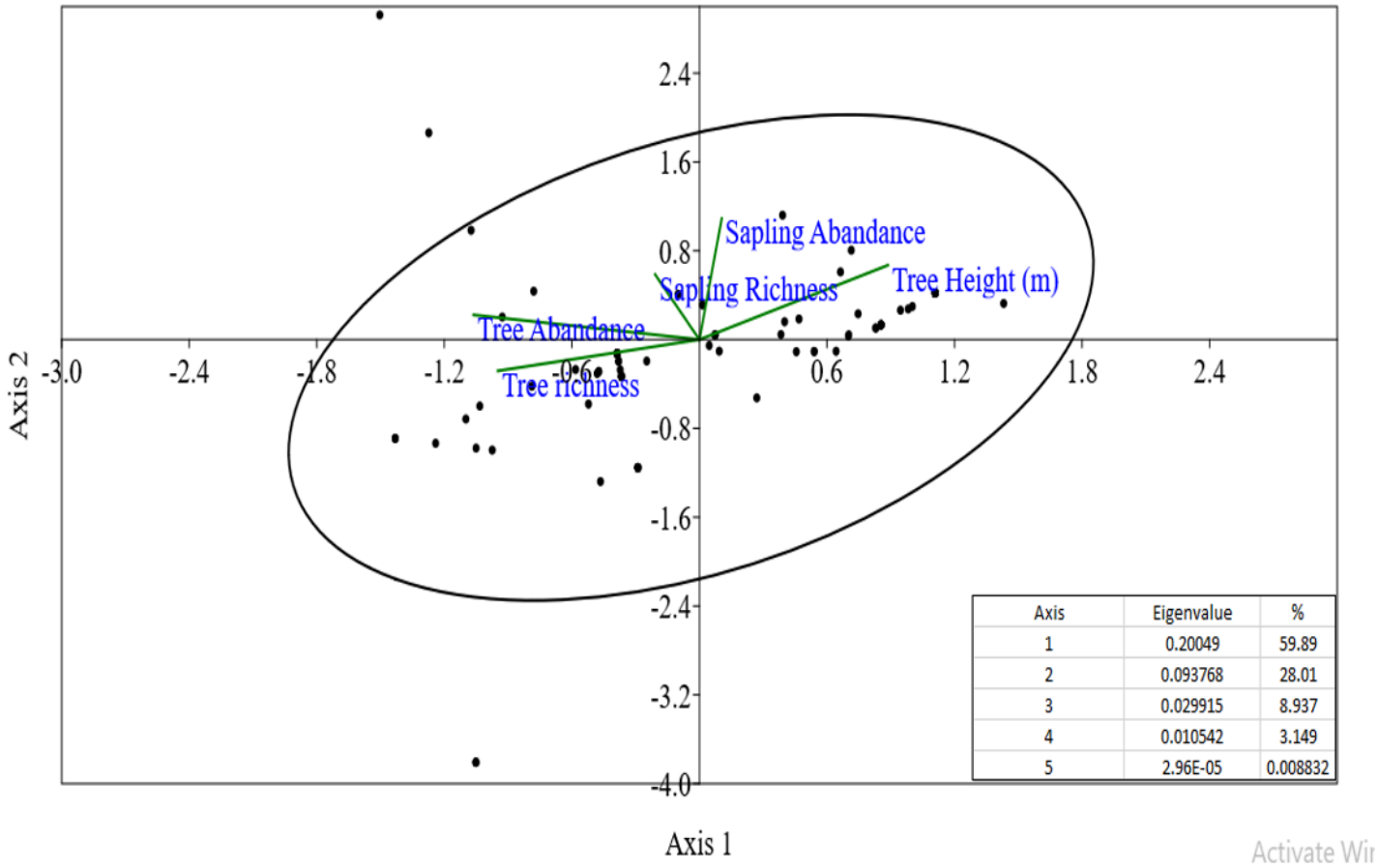

Figure 5

Canonical correspondence analysis of a primary matrix of seedling species abundance with a second matrix of five correlated habitat variables