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Factors Influencing the Natural Forest Regeneration at Khadimnagar National Park, Bangladesh

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ABSTRACT

Natural regeneration is an indicator of a healthy forest, hence, understanding the influence of site factors on natural regeneration is a significant concern for ecologists. This work aimed to assess the impact of site factors on natural tree regeneration at Khadimnagar National Park (KNP). Biotic factors (tree density, tree species richness, and basal area), physical factors (elevation, canopy openness), and soil properties (bulk density, moisture content, soil pH, organic matter, sand, silt, and clay) data were investigated from 71 sample plots to examine their effects on natural regeneration density and richness in KNP. Stepwise multiple linear regression analysis was done to predict both regeneration density and regeneration richness. The results showed that soil pH ($p<0.001$), canopy openness ($p<0.001$), tree species richness ($p<0.01$), and bulk density ($p<0.01$) had a significant effect on regeneration density, explaining 42% of the total variation. Regeneration richness was driven by four factors: tree species richness ($p<0.01$), soil pH ($p<0.001$), elevation ($p<0.01$), and canopy openness ($p<0.01$) with a model that explained 60% of the total variation. This study observed that soil pH, tree species richness, and canopy openness are the main controlling factors that influenced both the density and richness of regenerating species in KNP. Therefore, these findings have implications for natural resource management, especially in selecting suitable silvicultural systems in a tropical forest under protected area management where enhanced tree cover and conservation of biodiversity are needed.

Keywords: Abiotic factors, biotic factors, Khadimnagar National Park, regeneration density and richness

INTRODUCTION

Tropical forests provide a wide range of ecosystem services due to their high diversity, which allows them to pack in more species and biomass than other forests (Brandon, 2014). Tropical forests provide a variety of benefits to their surrounding communities including timber (Uddin *et al*., 2013), non-timber products, clean air, safe water, biodiversity, carbon sequestration, and storage (Donato *et al*., 2011; Lee *et al*., 2014) as well as recreational and spiritual services (MEA, 2005; UNEP, 2014). Tropical forests once covered around 12% of the Earth's land surface, but now only make up around 5% (600 million ha.) of the earth's terrestrial surface or approximately 28% of land in the tropics (Corlett & Primack, 2011; Hansen *et al*., 2013; Brandon, 2014). Throughout human history, the worldwide area of naturally regenerating forests has decreased, halving in the last three centuries. Forests have effectively vanished in 25 countries, with another 29 countries losing more than 90% of their historical forest cover (MEA, 2005).

To conserve and maintain biodiversity, the natural regeneration of the plant species plays a crucial role in a forest (Hossain *et al*., 2004). The nature of the forest community depends upon the ecological character such as sites, species diversity, and regeneration status of species (Choudhury *et al*., 2014). The long-term sustainability of a forest can be triggered by successful regeneration potential (Malik & Bhatt, 2016). Several biotic (i.e. floristic composition, seed production, competition, predation etc.) and abiotic factors (i.e. soil, water, light, topography etc.) within a given climatic region often influence natural regeneration success in a forest (Tinya *et al*., 2019). Knowledge regarding plant regeneration status can help in developing management options and as well as priority setting (Zegeye *et al*., 2011). It is essential to maintain forest renewal through natural and artificial regeneration depending on the management objectives (Rahman *et al*., 2011).

The vegetation of Bangladesh (with 7000 plant species) is a part of the Indo-Myanmar region, which is one of the ten global biodiversity hot spot areas (Hossen & Hossain, 2018), and it is species-rich because of its unique geophysical location (Hossain, 2001). Presently, Bangladesh has 2.6 million ha of forest cover that comprises about 17% of the country's total land area (Reza & Hasan, 2019). Several factors such as population pressure, inappropriate and poor management practices are causing severe stress on the country's natural forest (Haider *et al*., 2017). According to Rahman *et al*. (2000), a continuous decrease in native species was also accelerating at an alarming rate, causing rapid loss and forest degradation in Bangladesh. Bangladesh lost 2600 hectares of primary forest per year (at an annual deforestation rate of 0.2 percent) between 1990 and 2015. From 1.494 million hectares in 1990 to 1.429 million hectares in 2015, primary forest acreage has gradually reduced (FAO, 2015). Therefore, the natural regeneration of forest tree species needs to be enhanced by using suitable artificial and natural regeneration processes to conserve forest flora and maintain sustainable yield, goods, and services (Haider *et al*., 2017).

Several studies were conducted at Khadimnagar National Park (KNP) focusing on assessing the natural regeneration status, diversity, and distributional pattern of different tree species (Rahman *et al*., 2011; Sobuj & Rahman, 2011), tree species distribution along with soil variables (Ara *et al*., 2021) and forest cover change (Redowan *et al*., 2014). However, our study was first to investigate the factors influencing the natural tree regeneration at Khadimnagar National Park (KNP). We asked a specific question, which site factors influence the natural tree regeneration density and richness in KNP? We hypothesise that multiple biotic and abiotic factors in combination, rather a single factor, influence the natural tree regeneration of KNP.

MATERIALS AND METHODS

Study Area

The study was carried out at KNP (24º 56'-24º58' N and 91º55'-91º59'E), located in the Khadimnagar Union of Sylhet Sadar Upazila in the district of Sylhet, Bangladesh (Figure 1). The total area of the park is around 679 ha and was declared as a national park in 2006 (Sobuj & Rahman, 2011). KNP undulates with slopes and hillocks, locally known as "tilla" which usually ranges between 10-50 m in height (Redowan *et al*., 2014).

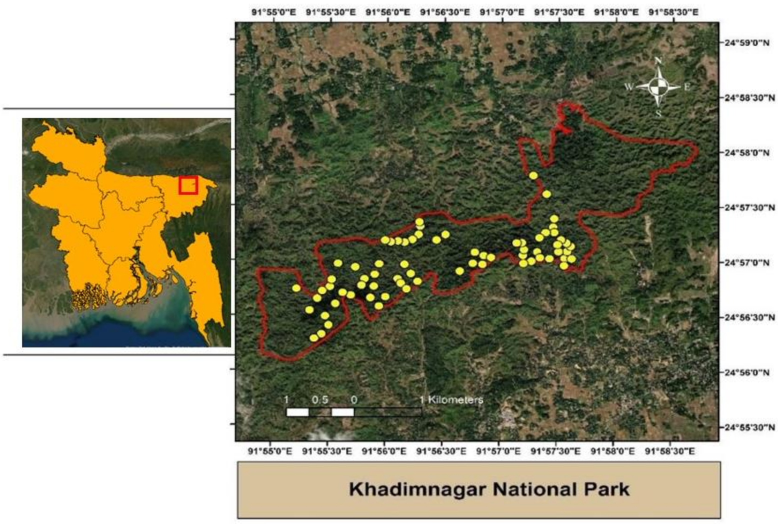

Figure 1. Location of the study area (Khadimnagar National Park, Bangladesh). The yellow circle representing studied sample plots (Shapefile Source: www.protectedplanet.net)

The natural characteristics of the climate in these areas are much warmer and humid. The tropical climate is in general subjected to heavy rainfall. During December, the temperature increases, and in January, it is much cooler. These areas have a maximum average temperature of 30.7 ºC with an average minimum temperature of 18.9 ºC (Rahman *et al*., 2011). KNP is located in a region that is prone to heavy rainfall. The total average annual rainfall is 3931 mm and most of which falls between June and September (Rahman *et al*., 2011). The topsoil of the Khadimnagar Hills is generally hard and clayey. The soil texture of the KNP is usually clay loam which is acidic in nature (Ara *et al*., 2021). The common growing tree species in KNP are *Dipterocarpus turbinatus* (Garjan), *Artocarpus chapalasha* (Chapalish), *Chukrasia tabularis* (Chickrasi), *Aquilaria sinensis* (Agar), *Toona ciliate* (Toon), *Tectona grandis* (Teak), *Syzigium cumini* (jam), *Senna siamia* (Minjiri), *Mangifera indica* (Aam) and different bamboo species.

Study Variables

We considered different biotic factors (tree density, tree species richness, and basal area), physical factors (elevation and canopy openness), and soil properties (pH, bulk density, moisture content, organic matter, sand, silt, and clay) as explanatory variables, while regeneration density & richness as the response variables for the study (Table 1).

Table 1. List of variables considered in the study

Variables	
Response	Regeneration Density (ha^{-1}) Regeneration Richness ($plot^{-1}$)
Biotic factor	Tree Density (ha^{-1}) Tree Species Richness ($plot^{-1}$) Basal Area (m^2ha^{-1})
Physical Factor	Elevation (m) Canopy Openness (%)
Soil Properties	Soil pH Soil BD (gcm^{-3}) Soil MC (%) Soil OM (%) Sand (%) Silt (%) Clay (%)

Notes: MC: Moisture Content; BD: Bulk Density; OM: Organic Matter

Vegetation Survey

Field data were collected during November and December of 2018. A total number of 71 plots with a size of (15 m × 15 m) were established throughout the forest randomly to collect different vegetation data. Sufficient efforts were made to distribute the plots throughout the whole forest to cover a wide range of forest areas (Figure 1). All the trees greater than or equal to 5 cm diameter at breast height (dbh) (1.30 m height above the ground level) (Pearson *et al*., 2007) were recorded on each plot and their dbh were measured using a diameter tape. For multi-stem tree species with forking below breast height, we measured the diameters of all stems independently. Haga-altimeter was used to measure the tree height of the studied forest. To ensure optimal monitoring and recording of all tree species regeneration, five sub-plots (2 m × 2 m) within these plots were taken: four at every corner of the plot and one in the center of the plot. All the tree regeneration (less than 5 cm dbh and greater than or equal to 20 cm in height) were considered as regenerating seedlings, thereafter, counted from the sub-plots. Tree species were identified with the help of an experienced local guide. The species, which were not possible to identify in the field, photographs were taken, and samples of those unidentified species were collected and identified with the help of taxonomic textbooks (e.g., Hossain, 2015) and web-based data. Regeneration density was calculated as the total number of individuals of a tree species per plot then it was converted into density per hectare. Regeneration richness was calculated by counting the total number of tree species present in the regeneration stage within the plot. Both regeneration density and richness per plot were considered as response variables. Tree density was also calculated as the total number of individuals of a species per plot. Then the tree density of the plot was converted into density per hectare. At the same time, tree richness was calculated by counting the total number of different species present within the sample plot.

The canopy openness of the studied plot was measured by using the Spherical Crown Densiometer. The basal area per plot was calculated by using the following Eq. (1):

$$\text{Basal area per tree} = 3.14 \times \left(\frac{D^2}{4}\right) \quad (1)$$

Where, D= Diameter at breast height in (m)

The basal area per plot was then converted to the basal area per hectare. Each plot's geographic location and elevation were taken at the center of the plot using a hand-held Global Positioning System (GPS, 12 Channel, Garmin International Inc, USA).

Similarity Index

The Sorensen similarity (K) coefficient was used to calculate similarities of species between the plot-level tree and tree regeneration samples based on the presence or absence of certain species (Ifo *et al*., 2016) following the Eq. (2).

$$K\ (\%) = \frac{(2a \times 100)}{(2a+b+c)} \qquad (2)$$

Where a = number of common presences for both floristic samples, b = number of unique presences in the first floristic sample, c = number of unique presences in the second floristic sample.

Soil Sampling and Analysis

Soil pH, moisture content, bulk density, organic matter, soil texture (sand, silt, and clay) were considered for this study. Five soil samples, four from each corner and the center of the plot, were taken. Each of the samples was taken at 10 cm depth using soil cores. A solid ring or volumetric cylinder was pressed into the soil to take a core sample. The samples from each plot were then mixed all-together to form one composite sample prior to analysis. All the coarse materials like stones, branches, undecomposed materials, roots were removed by passing through a sieve (2 mm). The analysis of soil was conducted in the Soil Laboratory of Forestry and Environmental Science, Shahjalal University of Science and Technology. Soil pH and moisture content were measured with Kelway Soil Tester and a digital moisture meter (FSI, New Jersey, USA), respectively. Soil bulk density (g/cm^3) was calculated by using the oven-dry method at 105 ºC (Blake & Hartge, 1986). The loss ignition method was used to measure organic matter and the standard Hydrometer method was used to calculate soil texture (sand, silt, and clay).

Data Analysis

Descriptive statistics were performed to describe the basic features of all variables considered. To investigate the relationship between regeneration patterns and different biotic and abiotic factors, stepwise multiple linear regression analyses were done and excluded the model's non-significant factors. The Kolmogorov-Smirnov test was used to check the normality of the residuals before doing the analysis. All the analyses were performed by using SPSS version 21.0.

RESULTS

Regeneration Patterns and Other Stand Characteristics of KNP

A total number of 19 regenerating species and 22 tree species were recorded (Table 2). Regeneration density ranged from 0 to 7500 individuals per hectare with a mean density of 3140 individuals per hectare.

Average regeneration richness was 1.9 per plot. The number of trees per hectare ranged between 178 and 889 across the plots. The mean density was 421.9 individuals per hectare, and the mean tree species richness was 2.04 per plot. The mean basal area per hectare was 28.49 m^2. The elevation ranged from 28 m to 51 m above sea level in the studied plots. Mean canopy openness was 16.9%. The mean soil moisture content was 24.82%, whereas the mean bulk density and mean soil pH were 1.17 g/cm^3 and 5.23, respectively. Mean soil organic matter was 18.27%, and the mean sand, silt, and clay were 93.28%, 5.42%, and 1.29%, respectively (Table 3). The value of the calculated coefficient of similarity for the Sorenson index was 48.10%.

Influence of Site Factors on Regeneration Density

Stepwise multiple regression analysis revealed that four variables (such as pH, canopy openness, bulk density, and tree species richness) significantly affected the regeneration density (Figure 2) out of twelve explanatory variables (Table 1). The regression model explained 42% variations in total. Soil pH (standardized coefficient, β= 0.389, $p<0.001$) positively affected regeneration density. However, canopy openness (β= -0.442, $p<0.001$), bulk density (β= -0.299, $p<0.01$) and tree species richness (β= -0.299, $p<0.01$) had negative effect on regeneration density (Table 4). No significant influences were found for tree density, basal area, elevation, soil moisture content, soil organic matter, sand, silt, and clay.

Table 2. List of tree species and regenerating species recorded from Khadimnagar National Park

Family	Scientific Name	Nativity	Usage	Source(s)
Anacardiaceae	*Mangifera indica**	Native	Fd, Fo, M, T	1
Combretaceae	*Terminalia arjuna**	Native	Fd, M, N, T	1, 2, 3
	*Terminalia catappa**	Exotic	Fd, Fo, M, N	1, 2
Dipterocarpaceae	*Dipterocarpus turbinatus**	Native	Fu, M, N, T	1, 3
Fabaceae	*Acacia auricuiformis**	Exotic	Fu, N, T	1, 2, 4
	*Xylia xylocarpa**	Exotic	M, N, T	1, 2, 3, 4
	*Acacia mangium**	Exotic	Fd, Fu, T, N	1, 2, 4
	*Senna siamea**	Native	Fo, Fu, N, T	1
Lamiaceae	*Tectona grandis**	Exotic	M, T	1, 2, 4
Lythraceae	*Lagerstroemia speciosa**	Native	O, T	1
Magnoliaceae	*Magnolia champaca**	Native	N, T	1
Meliaceae	*Chukrasia tabularis**	Native	N, T	1, 2
	*Toona ciliate**	Native	M, N, T	1, 3
Moraceae	*Ficus benghalensis*	Native	Fd, Fo, M, N	2, 3
	*Ficus racemose**	Native	Fd, Fo, M, N	2, 3
	*Artocarpus chaplasha**	Native	Fd, Fo, T	1, 2, 3
	*Artocarpus heterophyllus**	Native	Fd, Fo, N, T	1, 3
	*Streblus asper**	Exotic	M	5
Myrtaceae	*Syzygium cumini**	Native	Fd, Fo, Fu, N, T	1, 2, 3
Phyllanthaceae	*Baccaurca ramiflora**	Native	Fo, M	6
Santalaceae	*Santalum album*	Exotic	M, T	2
Thymelaceae	*Aquilaria sinensis*	Exotic	N	2, 3

Notes: Marks represent tree regenerating species; Usage: Fd= Fodder, Fo= Food, Fu= Fuel, M=Medicine, N= non-timber use, T= Timber, O= ornamental; Source(s): 1- (Hossain, 2015), 2- Dutta *et al.* (2015), 3- Rahman *et al.* (2019), 4-Mukul *et al.* (2021), 5- Rastogi *et al.* (2006), 6- Nesa *et al.* (2018)

Table 3. Descriptive statistics of different variables at Khadimnagar National Park

Stand characteristics	Plot no. (N)	Mean	Std. Error (±)	Max.	Min.
Regeneration density (ha^{-1})	71	3140.8	185.59	7500	0
Regeneration species richness ($plot^{-1}$)	71	1.9	0.1	4	0
Tree density (ha^{-1})	71	421.9	18.2	888.88	177.77
Tree species richness ($plot^{-1}$)	71	2.04	0.11	5	1
Basal area (m^2ha^{-1})	71	28.49	1.79	64.25	2.62
Elevation (m)	71	40.37	0.67	51	28
Canopy openness (%)	71	16.9	0.76	36.25	7.18
Soil MC (%)	71	24.82	0.4	16.53	5.8
Soil BD (gcm^{-3})	71	1.17	0.01	1.52	0.93
Soil pH	71	5.23	0.04	5.8	4.5
Soil OM (%)	71	18.27	0.43	25.51	11.13
Sand (%)	71	93.28	0.2	96.7	88.6
Silt (%)	71	5.42	0.22	9.6	0.7
Clay (%)	71	1.29	0.09	3.1	0

Notes: MC: Moisture Content; BD: Bulk Density; OM: Organic Matter

Influence of Site Factors on Regeneration Richness

The stepwise regression model for regeneration richness identified four factors (i.e. tree species richness, pH, elevation, and canopy openness) that significantly affected regeneration richness (Figure 3), and the model explained 60% of the total variation (Table 5). No other factor significantly affected the regeneration richness.

Whereas tree species richness (β= 0.280, $p<0.01$) and soil pH (β= 0.325, $p<0.001$) positively affected regeneration richness, elevation (β= -0.283, $p<0.01$) and canopy openness (β= -0.235, $p<0.01$) affected it negatively.

DISCUSSION

Natural regeneration assessment plays a vital role in sustainable forest management, as natural regeneration is key to the successful establishment of the mature forest community (Bose *et al*., 2016). Hence, we studied the influence of some selected site factors on the natural tree regeneration pattern (density and richness) in a tropical semi-evergreen forest of Bangladesh.

A total number of 19 regenerating species were found in the studied sample plots with a density of 3140 individuals per ha in KNP. Motaleb and Hossain (2007) reported 29 regenerating species in the Chittagong South Forest Division. Alamgir and

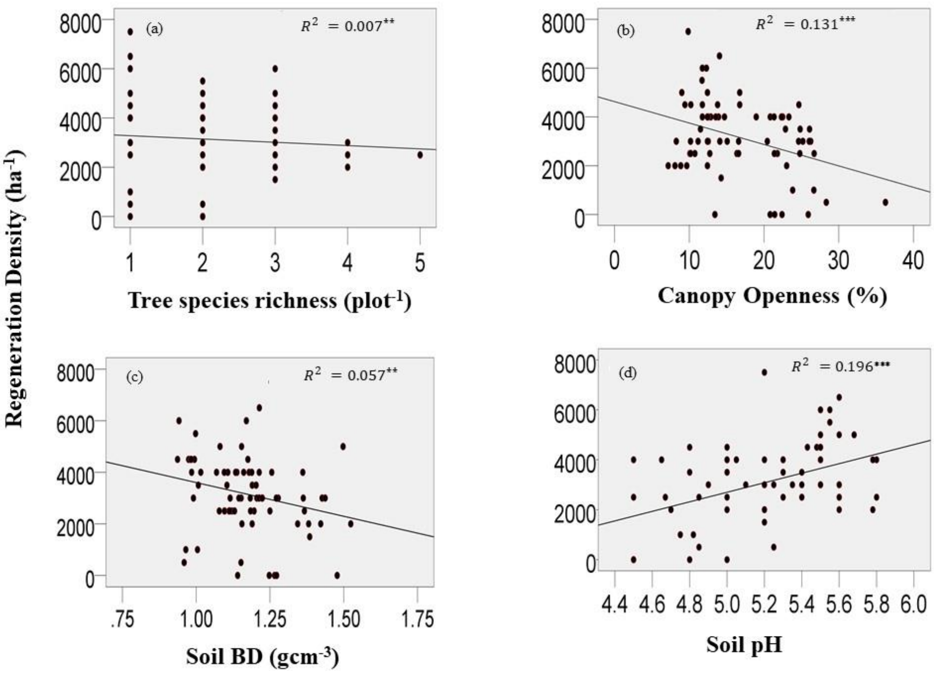

Figure 2. Bivariate relationship between regeneration density and different significant biotic and abiotic factors (a) Tree species richness; (b) Canopy openness; (c) Soil BD; and (d) Soil pH) represented in a clockwise manner at Khadimnagar National Park. Soil BD: Soil Bulk Density; Significance level- $^{**}p< 0.01$, $^{***}p< 0.001$

Table 4. The stepwise regression model for the natural regeneration density at Khadimnagar National Park

Model	Variables	Standardized Coefficients (β)	R^2	F	p
Regeneration Density	Soil pH	0.389	0.428	12.35	0.000
	Canopy Openness	-0.442			0.000
	Bulk Density	-0.299			0.004
	Tree Species Richness	-0.299			0.005

Excluded variables: Tree density, elevation, basal area, soil moisture content, soil organic matter, sand, silt, and clay.

Table 5. The stepwise regression model for the natural regeneration richness at Khadimnagar National Park

Model	Variables	Standardized Coefficients (β)	R^2	F	p
Regeneration Richness	Tree Species Richness	0.280	0.608	25.59	0.003
	Soil pH	0.325			0.000
	Elevation	-0.283			0.002
	Canopy Openness	-0.235			0.007

Excluded variables: Tree density, basal area, soil moisture content, soil bulk density, soil organic matter, sand, silt, and clay.

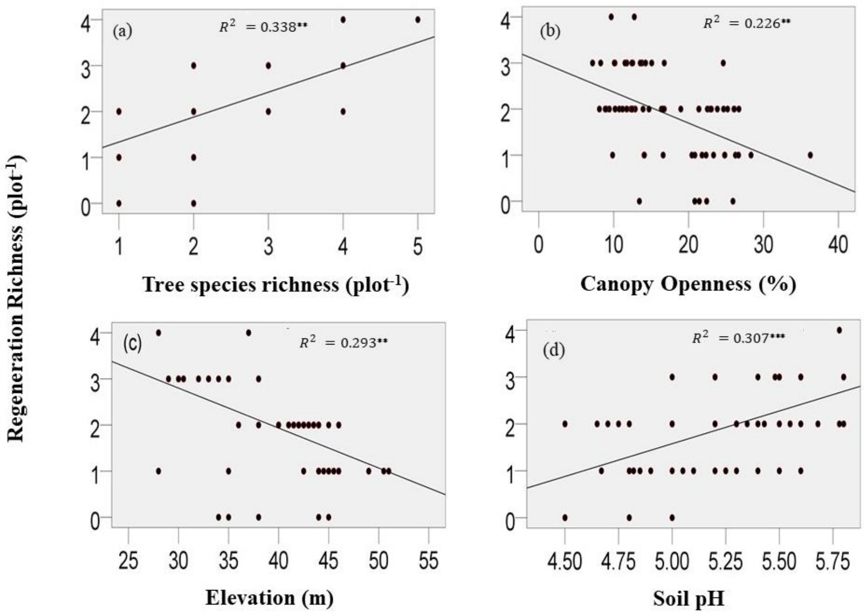

Figure 3. Bivariate relationship between regeneration richness and different significant biotic and abiotic factors (a) Tree species richness; (b) Canopy openness; (c) Elevation; and d. Soil pH) at Khadimnagar National Park
Significance level- **p< 0.01, ***p< 0.001

Al-Amin (2007) documented 39 regenerating species in a proposed biodiversity conservation area in Chittagong, Bangladesh. Haider *et al*. (2017) found 70 regenerating species from Moulvibazar natural forest. Rahman *et al*. (2011) reported 55 regenerating species from KNP and Tilagor Eco-Park. However, it is inappropriate to compare the findings of this study with theirs as they have considered not only seedlings but also treelets that are 2 cm ≤ dbh and height < 10 cm. Our study demonstrates a very low status of tree regeneration relative to other compared studies. Though one of the main objectives of the national park is to facilitate natural regeneration and thus to conserve and protect biodiversity, the studied forest is still far behind the satisfactory level. Despite prohibition, local inhabitants often enter the forest to collect fuelwoods and forest litters due to the lack of alternative cooking fuel. By doing so, they often damage seedlings of trees which may have led to the poorer condition of the regeneration status in the studied forest. Another serious threat to newly regenerated species is grazing and trampling by adjacent people's cattle. However, the natural regeneration in tropical forests is not controlled only by anthropogenic disturbances but also many biotic and abiotic factors (Hartshorn, 1995; Chazdon, 2003).

The study results revealed that various site factors such as soil pH, bulk density, tree species richness, and canopy openness significantly affect the regeneration density of KNP (Figure 2). While, species richness, soil pH, elevation, and canopy openness were among the factors that control natural regeneration richness in the KNP (Figure 3).

Influence of Biotic Factors on Regeneration

In this study, a positive trend was found between regeneration richness and tree richness. Khaine *et al*. (2018), observed a similar trend in a tropical forest of Myanmar. The resulted Sorensen similarity index (48.01%) in this study also suggests that almost all the tree species were likely to reproduce regardless of their reproduction rate. It agrees with the expectation that regeneration richness would increase along with tree richness because tree species richness in a tree community ensures the availability of diverse propagules for the understory (Bose *et al*., 2016). Olson and Wagner (2011) also reported that overstory diversity significantly influences regeneration species richness positively. However, we found a negative relationship between tree species richness and regeneration density. The underlying cause of this association may be the competition for space and nutrients increases as the number of different tree species increases, which might ultimately affect the tree regeneration.

Influence of Abiotic Factors on Regeneration

In line with our expectation, regeneration density and regeneration richness increased along with soil pH which was slightly acidic and ranged between 4.5 and 5.8 in the study site. The pH range regulates the availability of soil nutrients for the plants. Soil pH oversees many plant-soil chemical relations, especially the cation/anion exchange capacities, the accessibility of micronutrients and toxic particles, because of its impact on solubility (Offord *et al*., 2014), thus influence the nutrient uptake by plants. It has been suggested that at low soil pH levels aluminium, iron, and manganese become available for plants to uptake, while in soil with high pH levels, calcium and potassium become abundant. However, soil pH lower than 4.5 and greater than 8.5 may make some of these nutrients inaccessible for plant uptake (Londo *et al*., 2006). According to Lončarić *et al*. (2008), most micronutrients become readily accessible to plant in slightly acid soils compared to neutral-alkaline soils that favour the plant. The effect of pH on the growth pattern of the plant through altering nutrients availability was also reported by Joshi and Ghosh (2003).

Soil bulk density significantly affected regeneration density negatively and contributed 10% when included in the regression model (Table 4). The underlying cause may be that high bulk density is an indicator of low soil porosity through soil compaction which, in turn, may restrict plant root growth by the inadequate movement of water and impaired air circulation (Arshad *et al*., 1997). Whereas low soil bulk density indicates the larger soil pores where roots can easily penetrate and absorb nutrients.

The elevation is an important physical factor affecting the composition, growth, and distribution of tropical forests (Enoki & Abe, 2004). The negative relationship found between elevation and regeneration richness in KNP conforms to Rapoport's elevation rules, which state that with the increasing elevation, the richness of trees, mammals, grasshoppers, reptiles decrease (Bhattarai & Vetaas, 2006). Although the elevation range in our study area is relatively low, it is most likely because of differential microhabitat (i.e. soil texture, availability of nutrients etc.) associated even with low elevational differences.

Canopy openness has a direct influence on regeneration growth and survival (Piiroinen *et al*., 2014) and indirectly influences regeneration by affecting the physical environment (Beckage & Clark, 2003). Canopy openness decreased along with both the regeneration density and regeneration richness. The underlying cause may be due to the increased competition of regenerating tree species with ground vegetation in an open spot (Modrý *et al*., 2004). Nicotra *et al*. (1999) also observed a similar result in a study at a tropical forest of north-eastern Costa Rica. Canopy openness and soil moisture content collectively regulate seed germination, seedling establishment, and seedling survival in tropical forests (Khurana & Singh, 2001).

Finally, the present study was limited to a single data collection period. However, long-term monitoring of the variation in regeneration as well as other potentially limiting resources (i.e. light, water, nutrients availability) is needed to determine how spatial regeneration structure varies over time within the forest.

CONCLUSION

The study was performed to determine the influence of factors on natural regeneration patterns in Khadimnagar National Park. Findings revealed that bulk density affected tree regeneration density but not richness whereas, elevation did the opposite. Soil pH, tree species richness, and canopy openness are the factors that influenced both the regeneration density and regeneration richness in the forest. Overall, all the above five site variables have a collective influence on the natural regeneration pattern in the studied forest. These findings have implications for natural resource management, especially in selecting suitable silvicultural systems under protected area management in the tropical forest where enhanced tree cover is needed. This study investigated few soil properties. Still, there is a need to examine the influence of some other soil chemical properties (e.g., soil nutrients) on regeneration. Other factors such as undergrowth, litter layer, and anthropogenic disturbances were also not measured, but for a better understanding of the regeneration pattern, further research is required on them and as well as on individual tree species responses.

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