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The effect of soil moisture content and forest canopy openness on the regeneration of *Dipterocarpus turbinatus* C.F. Gaertn. (Dipterocarpaceae) in a protected forest area of Bangladesh

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Abstract: We investigated the effect of soil moisture content and forest canopy openness on the establishment of *Dipterocarpus turbinatus* saplings in Lawachara National Park (LNP) of Bangladesh. LNP is a tropical semi-evergreen forest and managed by protected area co-management approach. We established 50 sample plots (plot size 20 × 20 m): 25 plots in each of the buffer and core zones by a stratified random sampling procedure. Results showed that sapling density, soil moisture content and canopy openness significantly varied between buffer and core zones ($P < 0.001$). Soil moisture positively affected the sapling density in the buffer zone ($N = 25$, $r = 0.63$, $P < 0.01$) where as in the core zone, soil moisture had no significant effect. Canopy openness was negatively related to sapling density of *D. turbinatus* in the core zone ($N = 25$, $r = 0.52$, $P < 0.01$) but had no significant effect in the buffer zone. These findings suggest that soil canopy openness is a determinant of sapling establishment in the core zone where as in the buffer zone, soil moisture content is crucial for *D. turbinatus* regeneration. The results have implications for the conservation and management of such a critically endangered species under protected area management in Bangladesh.

Key words: Buffer zone, core zone, Lawachara National Park, natural regeneration, physical factors, sapling density.

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Introduction

Regeneration is the process of building a forest by which trees and forests survive, replace or re-establish (Cremer 1990). Unlike homogeneous plantations, management of natural forests largely depends on successful natural regeneration of valuable species. The practice of natural regeneration over many decades had contributed a store of knowledge of silvicultural practices in forest management (Nair 1961; Nair 1986). Many known and unknown factors affect the natural regeneration processes in forests (Singh *et al.* 1997; Swarupanandan & Sasidharan 1992), including both physicochemical and biotic factors (Singh *et al.* 1997). Among these factors natural regeneration is more likely regulated by canopy openness (Piiroinen *et al.* 2013; Zhang *et al.* 2013) and soil moisture content (Lieberman & Li 1992; Marod *et al.* 2002; McLaren & McDonald 2003a, b) in many of the forests. Although there is a growing body of literature about the physical and biological factors of natural regeneration in general, the effect of these factors on a particular species like Garjan, *Dipterocarpus turbinatus* C.F. Gaertn., is still inadequate.

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Garjan is an important timber-yielding species generally recorded in Bangladesh, Myanmar, India and Malaya Peninsula (Champion 1936). Study of natural regeneration of this species is particularly important because this species shows different functional traits in terms of light requirements at the different stages of its life cycle (Zabala 1989). At the early stages of the development, it can tolerate partial shade, but at later stages, it turns into a light demanding pioneer species (Zabala 1989), suggesting that forest canopy openness may have significant effect on the natural regeneration of this species. Water availability may also limit seed germination (Hosseini *et al.* 2009; Schütz *et al.* 2002) and early seedling establishment of many species in tropical forests, making soil moisture an important parameter determining the survival of seedlings (Swarupanandan & Sasidharan 1992). Nevertheless, how *D. turbinatus* saplings respond to soil moisture content and forest canopy openness in tropical forests is poorly understood. More particularly, such study is notably absent in Bangladesh where this species is found in almost all the forest types, including tropical semi-evergreen, tropical wet evergreen and tropical moist deciduous forests.

The forest management paradigm in Bangladesh has recently shifted from a traditional management approach to community-based forest management under protected area management scheme (Ahmed 2008). The framework of protected area management includes delineation of forest core zone from buffer zone (Fig. 1). Forest dwelling local people are permitted to extract minor forest products only from the buffer zone and, hence, the buffer zone is relatively disturbed with less canopy density. On the other hand, the core zone has been left intact in order to conserve the native forest species and maximize ecosystem services. Lawachara National Park (LNP) is an important nature reserve and one of the 34 protected areas of Bangladesh. The park harbors around 20 % of the threatened species listed in the red databook of vascular plants of Bangladesh (Khan *et al.* 2001; Uddin & Hasan 2010). Among all species found in LNP, *D. turbinatus* is of particular importance since it is listed as critically endangered in the IUCN red list of threatened species (Ashton 1998). Successful natural regeneration may offer a viable population of this species and is of utmost importance for its conservation. However, the natural regeneration dynamics of *D. turbinatus* was not studied before in this protected forest area.

Although most of the physical and biological factors remain more or less uniform in small forest areas (Tyagi *et al.* 2013), in case of larger areas, like LNP (1250 ha), it is hypothesized that they will vary significantly. Importantly, variation in light availability and soil moisture content should be obvious between buffer and core forest zones because of variation of canopy density and intensity of disturbances (Fischer & Lindenmayer 2007; Gehlhausen *et al.* 2000). Nevertheless, how saplings of *D. turbinatus* respond to this variation between buffer and core zones is very poorly understood. The current study is, therefore, aimed at investigating the effects of soil moisture content and forest canopy openness on the natural regeneration of *D. turbinatus* both in the core and buffer zones of LNP, Bangladesh. The main research questions included: (a) How do soil moisture content, forest canopy openness and sapling density of *D. turbinatus* vary between the core and buffer zones of LNP? (b) Does soil moisture affect natural regeneration of *D. turbinatus* in the core and buffer zones of LNP? (c) What is the effect of forest canopy openness on the natural regeneration of *D. turbinatus* in the core and buffer zones of LNP?

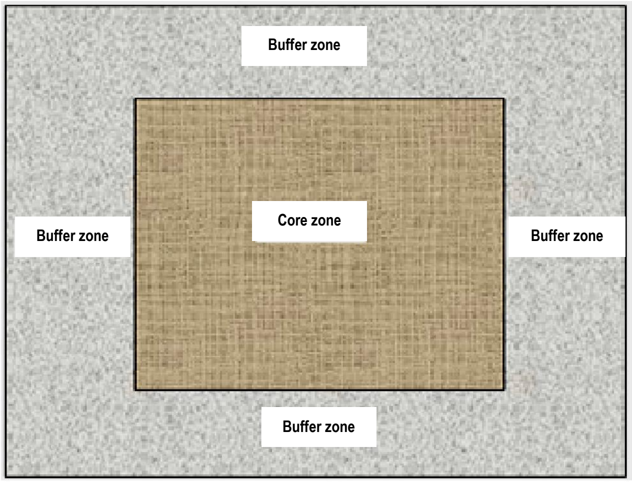

Fig. 1. Thematic diagram of the protected area management in Lawachara National Park, Moulvibazar District, Bangladesh, indicating the delineating boundary of core and buffer zones.

Materials and methods

Study site

The study was conducted in LNP, one of the largest protected areas in Bangladesh (24° 30'-24° 32' N and 91° 37'- 91° 39' E) (Fig. 2). The total

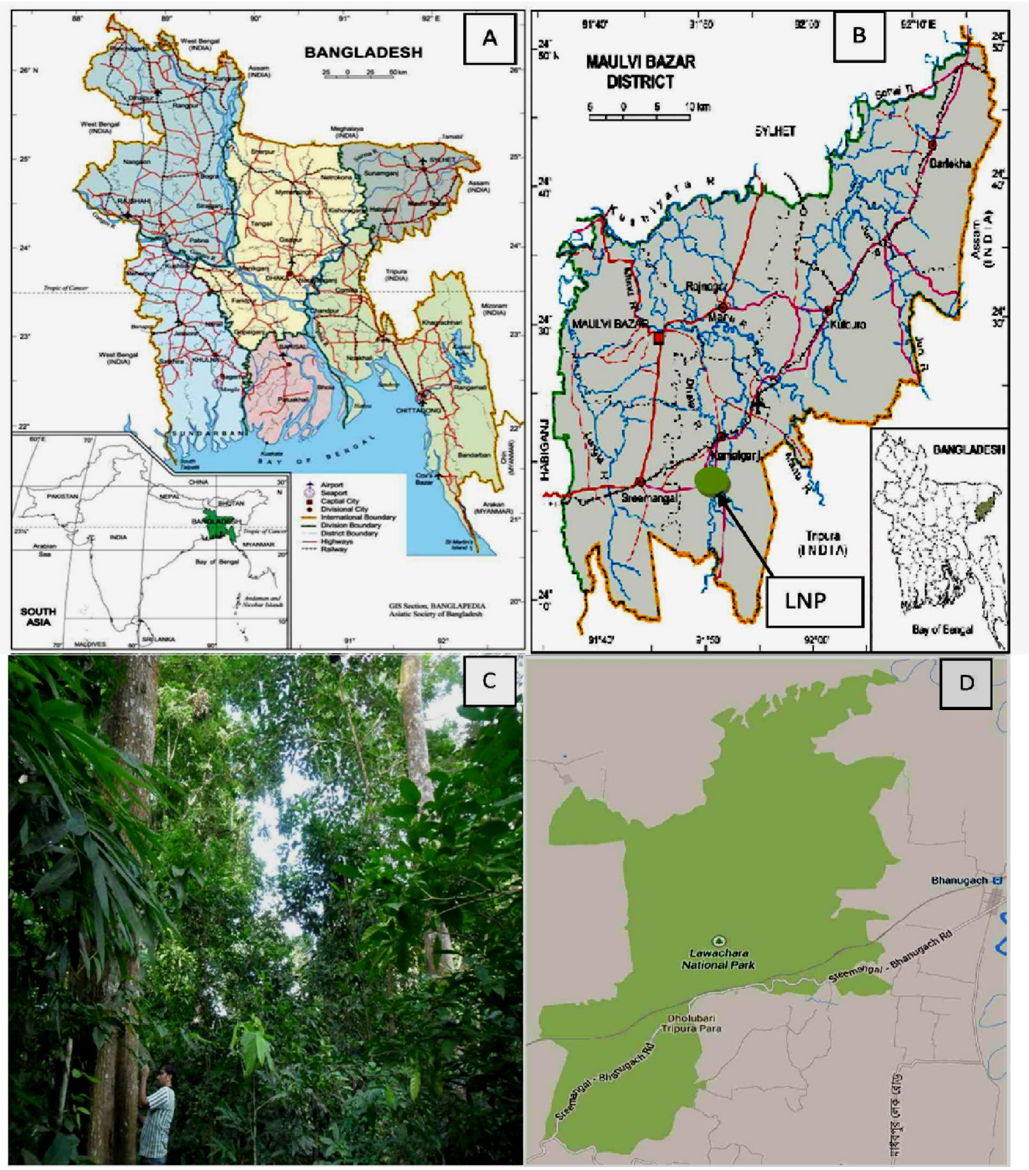

Fig. 2. Maps of the study site: A = Map of Bangladesh, including map of South Asia; B = Map of Bangladesh showing Moulvibazar District; C = Forest interior; and D = Map of Lawachara National Park in Moulvibazar District.

area of the national park is 1,250 ha and located within the 2,740 ha West Bhanugach Reserved Forest under Moulvibazar Forest Division (FSP 2000). LNP was declared as a national park by the Bangladesh government on July 7, 1996 under the Wildlife Amendment Act of 1974 (Canonizado & Rahman 1998; Riadh 2007). It is reported that the park has been subjected to a large scale logging in 1920 and, then, replanted with both native and exotic species (Feeroz & Islam 2000), making it a mixture of old growth natural and secondary forests. Vegetation types include semi-evergreen forest containing both deciduous canopy and evergreen understory (Ahsan 2000). Topography is undulating with hillocks of 10 - 50 m (Riadh 2007) that interspersed with numerous streams flowing through the forest. The soils range from alluvial brown sandy clay loam to clay loam dating from the Pliocene epoch (Ahmad 1970; Hossain *et al.* 1989).

The site experienced a moist tropical climate (Uddin & Hassan 2010) with long wet (April-October) and relatively short dry (November-March) seasons (Fig. 3). The rainfall and temperature data of nearby weather station (24° 30' N

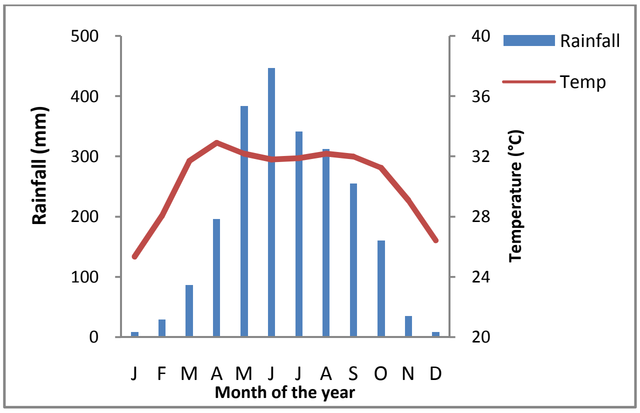

Fig. 3. Climate diagram based on data recorded at nearby weather station (9 km away from study site) during 1950 to 2011 and 1948 to 2010 for rainfall and temperature, respectively.

and 91° 39' E) were obtained from South Asian Association for Regional Cooperation Meteorological Research Centre (SMRC).

Study species

We studied the effect of two physical factors on the establishment of *D. turbinatus* saplings in the core and buffer zones of LNP under protected area management. *Dipterocarpus turbinatus* is a slow-growing, lofty, ever-green hardwood tree attaining upto 50 m in height and 159 cm in diameter at breast height (DBH) with a clean, cylindrical bole and elevated crown. The species prefers clay to clayey loam soils on plain land and sandy loam to coarse sand on hillyground. This species cannot tolerate extreme soil pH. Preferred soil pH varied from 4.9 to 5.8. In Bangladesh, *D. turbinatus* is found scattered in the tropical wet evergreen forests and tropical semi-evergreen forests of Chittagong, Chittagong Hill Tracts, Cox's Bazar and Sylhet (Champion 1936) in association with *D. gracilis, Chukrassia tabularis* A. Juss., *Hopea odorata* Roxb., *Salmalia insignis* Schott & Endl., etc. At the early stages, the species behave as a shade tolerant species, but with the subsequent development it prefers strong light like a pioneer species (Zabala 1989). Flowers appear from January through March and occasionally up to April. Fruiting occurs in May and June (Gamble 1922; Troup 1921). Fruits ripen and fall from the tree around the middle of May to the middle of June. Seeds have a hygroscopic, spongy, thick, dome-shaped part of the pericarp located just above the embryo (Banik 1980).

Sampling procedure

A total of 50 quadrat sample plots (plot size = 20 × 20 m) were established in the Garjan stands of LNP. Most of the *D. turbinatus* stands were established in 1920 throughout the forest after a large scale felling (Feeroz & Islam 2000), making this forest an intimate mixture of old growth natural and secondary forest stands of valuable species. After declaring as protected areas in 1996, *D. turbinatus* stands were distributed both in the buffer and core zones. Although there was no well-defined boundary between buffer and core zones, we considered up to 400 m from the edge of the forest towards the interior of the forest as buffer zone. We randomly sampled 25 stands from the buffer zone (outer part) and 25 stands from the core zone (inner part) of the forest. The number of *D. turbinatus* saplings was counted in each plot. The number of saplings counted in each plot was converted to number of saplings ha^{-1} by multiplying the plot size (400 m^2) by 250. An individual, which attained a height of > 1 - 2 m and a diameter at breast height (DBH) of < 5 cm was considered as a sapling.

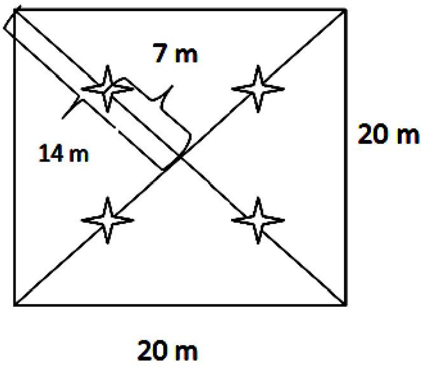

Fig. 4. Layout of a sample plot. The four point stars indicate the locations of soil sampling and measurement of canopy openness.

Measurement of canopy openness

Canopy openness was measured by using a canopy densiometer (Paul E. Lemon, Forest Densiometers, 2413 N. Kenmore St., Arlington, Virginia, USA). In each 20 × 20 m plot, the canopy openness was measured at four locations on the ground (Fig. 4). At each location, four measurements were taken at four directions. Therefore, a total of 16 measurements were taken in each plot and then averaged to get the final canopy openness of each plot.

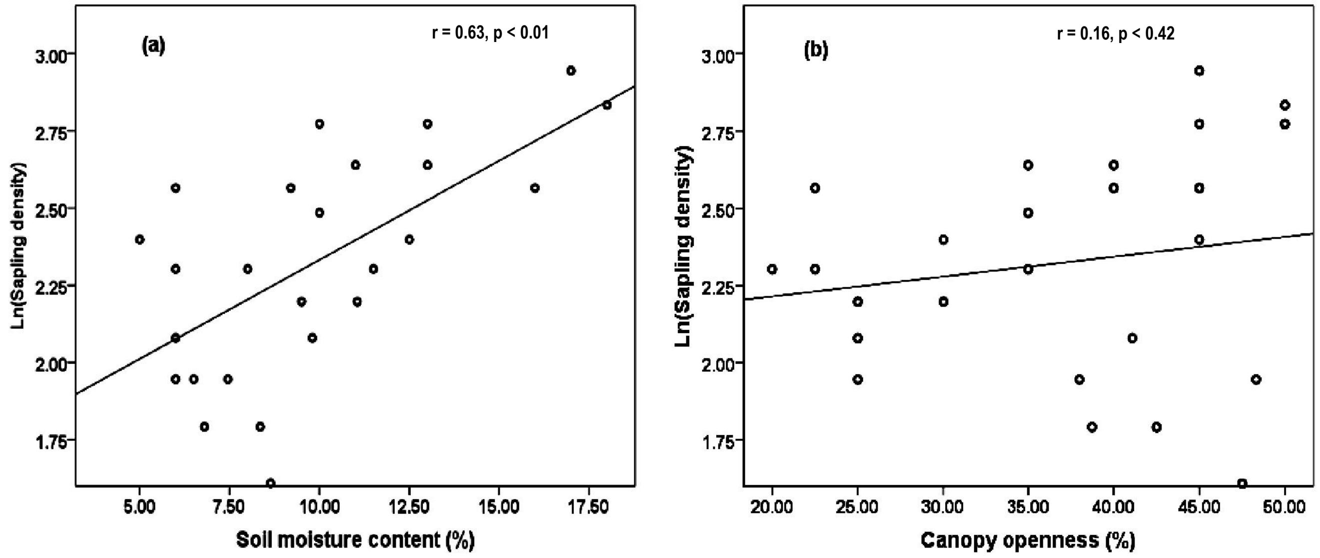

Fig. 5. Relationship between sapling density of *D. turbinatus* and the physical factors: (a) soil moisture content; and (b) canopy openness in the buffer zone of Lawachara National Park, Bangladesh.

Soil sampling and measurement of soil moisture content

Soil samples were taken from four locations of each plot (Fig. 4) at 30 cm depth by using a soil auger (2.5 cm diameter). Four soil sub-samples were, then, thoroughly mixed up to make a composite soil sample for each plot. The moist soil samples were first sieved through 10 mm mesh sieve to remove gravel, small stones and coarse roots and, then, passed through 2 mm sieve. The samples were weighed before air-drying and transported to the Laboratory of Forestry and Environmental Science, Shahjalal University of Science and Technology, Bangladesh, for determination of soil moisture content. Soil moisture content was measured following the method developed by SAA (1977). Soil samples were oven dried at 105 °C for 24 h. Moisture content of the soil was determined from the difference of initial and final readings. These results were then multiplied by 100 and divided by the weight of dried soil to get the moisture content in percentage. The following formula was used:

$$\text{Soil moisture content (\%)}=\{(W2-W3)/(W3-W1)\}\times 100$$

where, W1 = Weight of Petri dish (g); W2 = Weight of moist soil + Petri dish (g); and W3 = Weight of dried soil + Petri dish (g).

The major advantage of this method over digital moisture meter is the accuracy of the measurement since it involves direct measurement of soil moisture content.

Statistical analyses

We performed an independent sample t-test to compare the soil moisture content, canopy openness and sapling density of *D. turbinatus* between core and buffer zones. A simple Pearson correlation test was performed to show the relationship between each ecological parameter and the sapling density in either forest zone. Soil moisture content and the canopy openness data were square root-transformed and the sapling density was log transformed to normalize the distribution of residuals. All the analyses were performed by using SPSS version 19.0 (IBM Corporation 2010).

Results

Density of saplings

A total of 440 saplings were recorded from overall 50 sample plots in the buffer and core zones. The number of saplings in each plot ranged from 5 to 19 in the buffer and 0 to 13 in the core zones. The average sapling density of *D. turbinatus* was 271 ha^{-1} and 169 ha^{-1} in the buffer and core zones, respectively.

Variation between buffer and core zones in three ecological parameters

There was a significant difference in canopy openness, soil moisture content and sapling density

Table 1. Comparison of parameters used to compare the buffer and core zones of Lawachara National Park, Bangladesh.

Parameters	Forest zone	N	Mean	Standard Error of the Mean	t-value	Degrees of freedom	Level of significance
Canopy openness (%)	Buffer zone	25	36.84	1.894	14.97	48	$P < 0.001$
	Core zone	25	6.73	0.6777			
Soil moisture content (%)	Buffer zone	25	9.85	0.712	-12.86	48	$P < 0.001$
	Core zone	25	22.71	0.338			
Sapling density ha^{-1}	Buffer zone	25	10.84	0.756	4.08	48	$P < 0.001$
	Core zone	25	6.76	0.686			

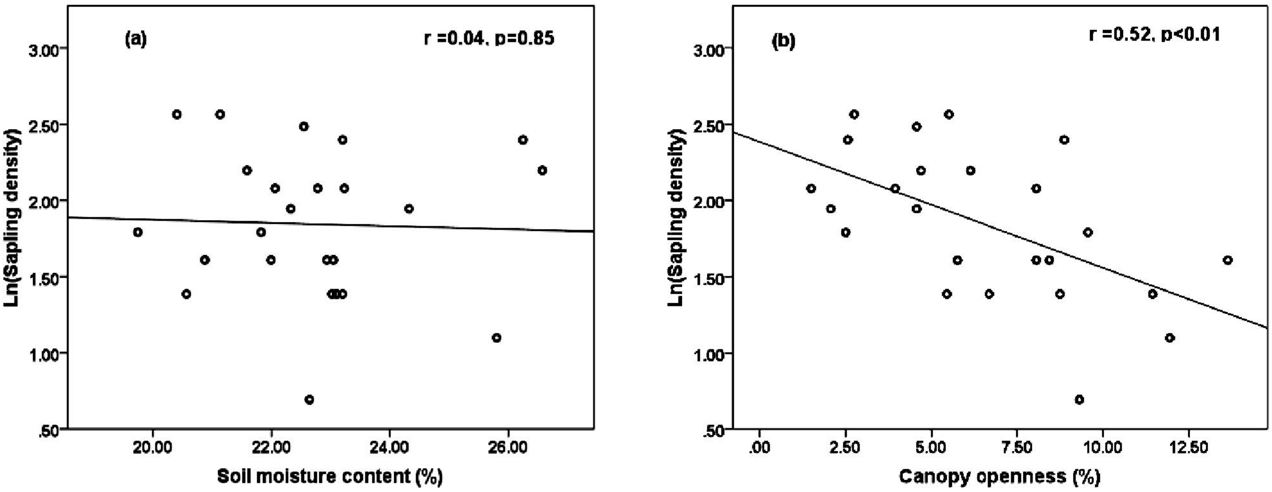

Fig. 6. Relationship between sapling density of *D. turbinatus* and the physical factors (a) soil moisture content and (b) canopy openness in the core zone of Lawachara National Park, Bangladesh.

of *D. turbinatus* between the buffer and core zones of the forests (Table 1). In the core zone, the canopy was much denser than that of the buffer zone (t = 14.97, $P < 0.001$). On the other hand, the core zone contained relatively higher soil moisture content than the buffer zone (t = -12.86, $P < 0.001$ and the variation was highly significant (t = 4.08, $P < 0.001$). The mean percentage of canopy openness and soil moisture content in the core zone were 6.73 ± 0.68 and 22.71 ± 0.39, respectively. In contrast, the average canopy openness and soil moisture content in the buffer zone were 36.85 ± 1.89 and 9.85 ± 0.71, respectively (Table 1).

Effects of soil moisture and canopy openness in the buffer and core zones

Soil moisture content in the buffer zone ranged from 5 to 18 % whereas forest canopy openness ranged from 20 to 50 % along the plots. Soil moisture content was significantly related to the natural regeneration of *D. turbinatus* at LNP (N = 25, r = 0.63, $P < 0.01$). The number of saplings increased with increasing soil moisture content in the buffer zone. On the other hand, forest canopy openness was not significantly related to natural regeneration of *D. turbinatus* in the buffer zone (N = 25, r = 0.17, $P = 0.42$) (Fig. 5).

In the core zone, soil moisture content ranged from 19.7 to 26.6 % whereas forest canopy openness varied from 1.5 to 13.6 % along the plots. No relationship was found between soil moisture content and sapling density of *D. turbinatus* in the core zone (N = 25, r = 0.04, $P = 0.85$). However, canopy openness was significantly related to the sapling density of *D. turbinatus* (N = 25, r = 0.52, $P < 0.01$). The number of saplings decreased with increasing canopy openness in the core zone (Fig. 6).

Discussion

A wide range of variation was found in the three parameters (soil moisture content, forest canopy openness and sapling density of *D. turbinatus*) in LNP. Soil moisture content was higher in the core than buffer zones. Because soil moisture content is highly correlated to the soil organic matter content in the arid environment (Wang *et al.* 2013), the higher moisture content in the core zone reported here might be attributed to the higher water holding capacity of its soil resulting from the continuous and undisturbed litter layer and, consequently, higher organic matter content in the soil. On the other hand, a continuous litter layer is apparently absent in the buffer zone due to mainly high magnitude of anthropogenic disturbances.

Forest canopy openness differed in the two forest zones of the study site. Higher vegetation density and presence of dominant trees result in lower canopy openness in the core zone. In contrast, vegetation density in the buffer zone is lower than the core zone, making the buffer zone a relatively open area (Biswal *et al.* 2013; Mehring & Stoll-Kleemann 2013; Sahoo & Davidar 2013). However, lower sapling density of *D. turbinatus* was observed in the core zone. The likely drivers of this result might be the increased competition from both larger trees and denser undergrowth vegetation. The allelopathic impact of undergrowth may also be attributed to this lower sapling density because there is experimental evidence in favor of allelopathic inhibition of woody plant seedlings by herbaceous growth (Ahmed *et al.* 2007).

Soil moisture content affected *D. turbinatus* regeneration in the buffer zone, whereas the canopy openness was not significantly related to the sapling density of *D. turbinatus*. Because *D. turbinatus* shows different light preference traits throughout its life cycle and can tolerate partial shade at the early stage (Zabala 1989), light may not be a determinant of seedling recruitment and survival of its saplings, particularly in the buffer zone where there is adequate light on the forest floor. This theory is reflected in our result suggesting that canopy openness is not a critical factor for the survival of saplings of *D. turbinatus.* Soil moisture content might influence the natural regeneration of dipterocarp species in tropical forests (Boyce & Bakshi 1959; Gautam *et al.* 2007; Hole 1914, 1921; Seth & Bhatnagar 1960). Relatively low soil moisture content and the positive association between sapling density of *D. turbinatus* and soil moisture content in the buffer zone of our study sites entails that soil moisture content is a critical factor for a viable population of this species.

In the core zone of LNP, soil moisture content did not affect the regeneration of *D. turbinatus*. The likely reason of this result might be the availability of sufficient soil moisture throughout the core zone. Instead, forest canopy openness influenced natural regeneration of *D. turbinatus*. Canopy openness may influence seedling growth and survival either directly (Choudhury *et al.* 2014; Piiroinen *et al.* 2013; Zhang *et al.* 2013) or indirectly through affecting the physical environment (Beckage & Clark 2003; Dey & Macdonald 2001). The negative association between sapling density and canopy openness in our study, however, might be attributed to the colonization of undergrowth species. Tropical forest environment promotes colonization and dominance by perennial shrubs, vines and grasses which are light-demanding, early successional and typical of open habitats (Badruddin *et al.*1990; Chandrasekaran & Swamy 1995; Whitmore 1991). Increased colonization of these aggressive weeds is likely attributed to inhibit seed germination, survival and establishment of *D. turbinatus* seedlings in LNP.

Conclusions

The core zone and the buffer zone were quite different in terms of soil moisture content, canopy openness and sapling density of *D. turbinatus*. The frequency and intensity of anthropogenic disturbances might be the main underlying causes of these differences. The soils are not capable of holding sufficient moisture as a consequence of lower litter content in the buffer zone, making soil moisture content a crucial factor for the establishment of *D. turbinatus* saplings in the buffer zone. On the other hand, increase canopy openness limited the establishment of *D. turbinatus* by stimulating the growth of herbaceous growth and, the subsequent competition for similar resources. These findings demonstrated that different silvicultural practices should be employed in the different forest zones depending on the ecological requirements of species in a particular zone of a protected forest area. Future research should include more environmental parameters, including soil nutrients to infer firm conclusions about the responses of *D. turbinatus* seedlings in the protected areas.

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References

Ahmed, F. U. 2008. Participatory management of protected Areas of Bangladesh: paradigm shift. pp. 132-142. *In*: S. B. Bajracharya & N. Dahal (eds.) *Shifting Paradigm in PA Management*. NTNC, Kathmandu.

Ahmad, N. 1970. *Working Plan for the Forests of the Sylhet Division for the Period 1963-64 to 1982-83*. Working plan division 2, CTG. E.P. Dacca, East Pakistan Govt. Press.

Ahmed, R., M. B. Uddin, M. A. S. A. Khan, S. A. Mukul & M. K. Hossain. 2007. Allelopathic effects of *Lantana camara* on germination and growth behavior of some agricultural crops in Bangladesh. *Journal of Forestry Research* **18**: 301-304.

Ahsan, M. F. 2000. Socio-ecology of the hoolock gibbon (*Hylobates hoolock*) in two forests of Bangladesh. pp. 286-299. *In: Proceedings from 'The Apes: Challenges for the 21st Century' (Ed. by rookfield Zoo)*. Chicago: Brookfield Zoo.

Ashton, P. 1998. *Dipterocarpus turbinatus*. *In:* IUCN 2013. *IUCN Red List of Threatened Species*. Version 2013.2. <www.iucnredlist.org>. Downloaded on 20 February 2014.

Banik, R. L. 1980. Studies on sowing position of Garjan seeds on their germination and seedling behavior. *Bano Biggyan Patrika* **9**: 43-52.

Beckage, B. & J. S. Clark. 2003. Seedling survival and growth of three forest tree species: the role of spatial heterogeneity. *Ecology* **84:** 1849-1861.

Badruddin, A. Z. M., M. Al-Amin, M. K. Bhuiyan & K. R. Islam. 1990. Natural regeneration of vegetation in the forest lands of the Chittagong University Campus, Bangladesh. *Journal of the Asiatic Society of Bangladesh (Science)* **16**: 87-90.

Biswal, A., A. Jeyaram, S. Mukherjee & U. Kumar. 2013. Ecological significance of core, buffer and transition boundaries in biosphere reserve: A remote sensing study in Similipal, Odisha, India. *Computational Ecology and Software* **3**: 126-137.

Boyce, J. S. & B. K. Bakshi. 1959. Dying of sal. *Indian Forester* **85**: 585-588.

Canonizado, J. A. & S. M. Rahman. 1998. *GOB/WB Forest Resources Management Project Technical Asistance Component: Integrated Forest Management Plan for the Sylhet Forest Division*. Mandala Agricultural Development Corporation and Forest Department, Ministry of Environment and Forest, Dhaka, Bangladesh.

Champion, H. G. 1936. A preliminary survey of the forest types of India and Bangladesh. *Indian Forest Records* (New series) **1:** 1-286.

Chandrasekaran, S. & P. S. Swamy. 1995. Changes in herbaceous vegetation following disturbance due to biotic interference in natural and manmade ecosystems in Western Ghats. *Tropical Ecology* **36:** 213-220.

Choudhury, B. A., M. L. Khan & A. K. Das. 2014. Seedling dynamics of the critically endangered tree legume *Gymnocladus assamicus* in northeast India. *Tropical Ecology* **55**: 375-384.

Cremer, K. W. 1990. *Trees for Rural Australia.* Inkata Press. Australia.

Dey, D. C. & G. B. Macdonald. 2001. Over storey manipulation. pp. 157-175. *In:* R. G. Wagner & S. J. Colombo (eds.) *Regenerating the Canadian Forest: Principles and Practice for Ontario*. Fitzhenry & Whiteside Limited, Markham, Ontario.

Feeroz, M. M. & M. A. Islam. 2000. Primates of the West Bhanugach Forest Reserve: major threats and management plan. pp. 239-253. *In*: *Bangladesh Environment*. 2000. BAPA Bangladesh Poribesh Andolon, Dhaka. Bangladesh.

Fischer, J. & D. B. Lindenmayer. 2007. Landscape modification and habitat fragmentation: a synthesis. *Global Ecology and Biogeography* **16**: 265-280.

FSP (Forestry Sector Project). 2000. *First Five Year Management Plan for Lawachara National Park*. Vol. 1: Management Plan. Forest Department, Ministry of Environment and Forests, Dhaka.

Gamble, J. S. 1922. *A Manual of Indian Timber. An Accaunt of the Growth, Distribution and Uses of the Trees and Shrubs of India and Ceylon with Descripton of Their Wood Structure*. Sampson Low, Marston and Company Limited, London.

Gautam, M. K., A. K. Tripathi & R. K. Manhas. 2007. Indicator species for the natural regeneration of *Shorea robusta* Gaertn. f. (sal). *Current Science* **93**: 1359-1361.

Gehlhausen, S. M., M. W. Schwartz, C. K. Augspurger. 2000. Vegetation and microclimatic edge effects in two mixed-mesophytic forest fragments. *Plant Ecology* **147**: 21-35.

Hole, R. S. 1914. Ecology of sal (*shorea robusta*). *Indian Forest Records* **5**: 87-102.

Hole, R. S. 1921. Regeneration of sal *(Shorea robusta)* forests - A study in economic ecology. *Ind. Forest*

Rec. (Old series). Silviculture **8:** 163-228.

Hossain, M. K., Q. N. Islam, S. A. Islam, M. A. Tarafdar, M. Zashimuddin & A. Ahmed. 1989. *Assistance to the Second Agricultural Project- Bangladesh, Status Report on the Activities of the Silviculture Research Division.* BFRI, Chittagong. FO:DP/BGD/83/010, Working Paper No.6

Hosseini, N. M., K. H. M. Siddique, J. A. Palta & J. D. Berger. 2009. Effect of soil moisture on seedling emergence and early growth of some chickpea (*Cicer arietinum* L.) genotypes. *Journal of Agriculture and Science Technology* **11**: 401-411.

IBM. 2010. IBM Corp. Released 2010. IBM SPSS Statistics for Windows, Version 19.0. Armonk, NY: IBM Corp.

Khan, M. S., M. M. Rahman & M. A. Ali (eds.). 2001. *Red Data Book of Vascular Plants of Bangladesh.* Bangladesh National Herbarium. Dhaka.

Lieberman, D & M. G. Li. 1992. Seedling recruitment patterns in a tropical dry forest in Ghana. *Journal of Vegetation Science* **3**: 375-382.

Marod, D., U. Kutintara, H. Tanaka & T. Nakashizuka. 2002. The effects of drought and fire on seed and seedling dynamics in a tropical seasonal forest in Thailand. *Plant Ecology* **161**: 41-57.

McLaren, K. P. & M. A. McDonald. 2003a. Seedling dynamics after different intensities of human disturbance in a tropical dry limestone forest in Jamaica. *Journal of Tropical Ecology* **19**: 567-578.

McLaren, K. P. & M. A. McDonald. 2003b. The effects of moisture and shade on seed germination and seedling survival in a tropical dry forest in Jamaica. *Forest Ecology and Management* **183**: 61-75.

Mehring, M. & S. Stoll-Kleemann. 2011. How effective is the buffer zone? Linking institutional processes with satellite images from a case study in the Lore Lindu Forest Biosphere Reserve, Indonesia. *Ecology and Society* **16**: 3.

Nair, C. T. **S.** 1986. Management of the tropical wet evergreen forests in India: a comparative account of the silvicultural practices in Kerala, Andaman Islands and Assam. Paper read at the Symposium on *Rain Forest Regeneration and Management*, Guri, Venezuela, 1986.

Nair, P. N. 1961. *Regeneration of moist Tropical Forests with Special Reference to Kerala.* DAIFC Dissertation, Indian For. Coll., Dehra Dun.

Piiroinen, T., P. Nyeko & H. Roininen. 2013. Canopy openness in gaps determines the influence of herbaceous climbers and insect folivory on the survival of a tropical pioneer tree, Neoboutonia macrocalyx Pax. *African Journal of Ecology* **52**: 41-49.

Riadh, S. M. 2007. Assessing the role of non-timber forest products in the livelihoods of communities living inside and outside of Lawachara Forest. pp. 36-49. *In:* J. Fox, B. R. Bushley, S. Dutt & S. A. Quazi (eds.) *Making Conservation Work: Linking Rural Livelihoods and Protected Areas Management in Bangladesh.* East-West Centre and Nishorgo Program of the Bangladesh Forest Department, Dhaka.

SAA. 1977. *Determination of the Moisture Content of a Soil: Oven Drying Method (standard method).* Standards Association of Australia. AS 1289 B1. 1-1977. Australia.

Sahoo, S. & P. Davidar. 2013. Effect of harvesting pressure on plant diversity and vegetation structure of sal forests of Similipal Tiger Reserve, Odisha. *Tropical Ecology* **54**: 97-107.

Schütz, W., P. Milberg, B. B. Lamont. 2002. Germination requirements and seedling responses to water availability and soil type in four eucalypt species, *Acta Oecologia* **23**: 23-30.

Seth, S. K. & H. P. Bhatnagar. 1960. Inter-relation between mineral constituents of foliage, soil properties, site quality and regeneration status in some *Shorea robusta* forests. *Indian Forester* **86**: 590-601.

Singh, S. P., Y. S. Ravat & S. C. Garkoti. 1997. Failure of brown oak (*Quercus semecarpifolia*) to regenerate in Central Himalya: A case of environmetal semi-surprise. *Current Science* **73**: 371-374.

Swarupanandan, K. & N. Sasidharan 1992. *Rege-neration Studies on Some Important Trees in a Natural Moist Deciduous Forest Ecosystem.* KFRI Research Report 83, Kerala Forest Research Institute Peechi, Thrissur.

Troup, R. **S.** 1921. *The Silviculture of Indian Trees.* Vol. 1. Clarendon Press, Oxford.

Tyagi, J. V., N. Qazi, S. P. Rai & M. P. Singh. 2013. Analysis of soil moisture variation by forest cover structure in lower western Himalayas. *Journal of Forestry Research* **24**: 1-8.

Uddin, M. Z. & M. A. Hassan. 2010. Angiosperm diversity of Lawachara National Park (Bangladesh): A preliminary assessment. *Bangladesh Journal of Plant Taxonomy* **17**: 9-22.

Wang, C., C. Zhao, Z. Xu, Y. Wang & H. Peng. 2013. Effect of vegetation on soil water retention and storage in a semi-arid alpine forest catchment. *Journal of Arid Land* **5:** 207-219.

Whitmore, T. C. 1991. Tropical rain forest dynamics and its implications for management. pp. 67-90. *In:* A. Gomez-Pompa, T. C. Whitmore & M. Hadley (eds.) *Rain Forest Regeneration and Management.* UNESCO: Paris.

Zabala, N. Q. 1989. *Silviculture of Species.* Field document no. UNDP/ FAO/BGD/85/001. Institute of Forestry, Chittagong University, Chittagong, Bangladesh.

Zhang, M., J. Zhu, M. Li, G. Zhang & Q. Yan. 2013. Different light acclimation strategies of two coexisting tree species seedlings in a temperate secondary forest along five natural light levels. *Forest Ecology and Management* **306**: 234-242.

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