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Regeneration and tree diversity in natural and planted forests in a Terai - Bhabhar forest in Katarniaghat Wildlife Sanctuary, India

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Abstract: We compared regeneration, tree diversity and floristic diversity of natural and planted tropical deciduous forests (dominated by *Shorea robusta* and *Tectona grandis; Acacia catechu* and *Syzygium cumini,* respectively) in western Uttar Pradesh, India. Species diversity (70 species in natural and 59 species in planted forests) as well as species evenness was higher in natural forests than in planted forests. Natural forest sites also had higher mature tree, pole, sapling and seedling densities compared with planted forests. In spite of differences in diversity, natural and planted forests did not differ strongly in species composition, fifty-six species occurred in both sites. This may reflect similar soil types but differences in soil moisture, organic carbon, available nitrogen, phosphorus, potassium and soil pH in natural and planted forests. Dominant families in both forest types are Fabaceae, Euphorbiaceae, Verbenaceae, Rubiaceae and Caesalpiniaceae (5 species each), followed by Moraceae, Mimosaceae and Combretaceae. Of the 126 species found in both sites, 32.5% showed good regeneration, 19.8% fair, 24.6% poor and 11.1% lacked regeneration. The remaining 11.9% of species were present as seedlings but not as adult individuals. Good quality timber species are not regenerating, with the exception of *Shorea robusta,* although mortality at seedling stage of this species is high. In all, our results suggest that species richness and diversity differed between natural forest and planted forest and regeneration of some important tree species also varied in natural and planted forests because of variation in their microclimate and edaphic characteristics. Moreover, these conditions indicate succession pattern and a potential for forestry plantations in dry forests. This study will help in the formulation of effective forest management and conservation strategies.

Resumen: Comparamos la regeneración, la diversidad arbórea y la diversidad florística de bosques tropicales caducifolios naturales y plantados (dominados por *Shorea robusta* y *Tectona grandis*; y por *Acacia catechu* y *Syzygium cumini*, respectivamente) en el occidente de Uttar Pradesh, India. La diversidad de especies (70 especies en bosques naturales y 59 especies en bosques plantados), así como la equitatividad de las especies, fueron más altas en los bosques naturales que los bosques plantados. Los sitios de bosques naturales también tuvieron densidades más altas de árboles maduros, jóvenes, juveniles y de plántulas en comparación con los bosques plantados. A pesar de las diferencias en su diversidad, los bosques plantados y naturales no difirieron grandemente en su composición de especies, ya que 56 especies estuvieron presentes en ambos sitios. Esto puede reflejar tipos de suelos similares pero también diferencias en humedad edáfica, carbono orgánico, nitrógeno, fósforo y potasio

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disponibles, y pH del suelo en los bosque naturales y plantados. Las familias dominantes en ambos tipos de bosque son Fabaceae, Euphorbiaceae, Verbenaceae, Rubiaceae y Caesalpiniaceae (5 especies cada una), seguida de Moraceae, Mimosaceae y Combretaceae. De las 126 species registradas en ambos sitios, 32.5% mostraron una buena regeneración, 19.8% suficiente, 24.6% pobre y 11.1% carecieron de regeneración. El restante 11.9% de las especies estuvieron presentes como plántulas pero no como individuos adultos. Las especies maderables de buena calidad no se están regenerando, con excepción de *Shorea robusta,* si bien la mortalidad en la etapa de plántula de esta especie es alta. En conjunto, nuestros resultados sugieren que la riqueza de especies y la diversidad difirieron entre el bosque natural y el bosque plantado, y que la regeneración de algunas especies arbóreas importantes también varió en los bosques naturales y plantados debido a la variación en sus características microclimáticas y edáficas. Además, estas condiciones indican un patrón sucesional y un potencial para plantaciones forestales en bosques secos. Este estudio ayudará a la formulación de un manejo forestal efectivo y de estrategias de conservación.

Resumo: Comparou-se a regeneração, a diversidade arbórea e a diversidade florística de florestas tropicais decíduas, natural e plantada (dominada pela *Shorea robusta* e *Tectona grandis; Acacia catechu* e *Syzygium cumini*, respectivamente) na região ocidental de Uttar Pradesh, Índia. A diversidade específica (70 espécies na floresta natural e 59 espécies na floresta plantada), bem como a uniformidade específica, foi mais elevada na floresta natural do que na plantada. As estações na floresta natural têm também maiores densidades de árvores maduras, novedio, nascedio e plântulas do quando comparadas com as florestas plantadas. Não obstante as diferenças na diversidade, as florestas naturais e as plantadas não diferem significativamente quanto à composição específica pois que nos dois estratos ocorrem cinquenta e seis espécies. Isto pode reflectir similitudes nos tipos de solos mas diferenças no teor de humidade, carbono orgânico, azoto disponível, fósforo, potássio e pH do solo nas florestas naturais e plantadas. As famílias dominantes nos dois tipos florestais eram as Fabaceae, Euphorbiaceaea, Verbenaceae, Rubiaceae e Caesalpiniaceae (cada uma com 5 espécies), seguida pelas Moraceae, Mimosaceae e Combretaceae. Das 126 espécies encontradas em ambos os estratos, 32,5% mostravam boa regeneração, 19,8% razoável, 24,6% pobre e 11,1% não apresentavam regeneração. Os 11,9% das espécies remanescentes encontravam-se presentes no estádio de plântulas mas não no estádio adulto. Com excepção da *Shorea robusta*, as espécies de boa qualidade madeireira não se estão regenerando, embora a mortalidade neste estádio de plântulas nesta espécie seja alta. No seu conjunto, os nossos resultados sugerem que a riqueza específica e a diversidade diferem bastante entre a floresta natural e a plantada e que a regeneração de algumas espécies arbóreas importantes também variam entre a floresta natural e a plantada por causa da variação do seu microclima e características edáficas. Alem disso, estas condições indicam padrões de sucessão e um potencial para as florestas plantadas nas florestas secas. Este estudo ajudará a formulação de estratégias efectivas de gestão e de conservação.

Key words: Density, diversity, mature tree, natural, planted, pole, regeneration, sapling and seedling.

Introduction

Tropical dry deciduous forests are not considered species - rich (Gentry 1995) compared with tropical moist deciduous forests, but do have a good diversity of life-forms (Medina 1995). These forests occur under varied climatic conditions with alternating wet and dry periods. However, the structure, composition and functioning of deciduous forests undergo changes with the length of wet period, amount of rainfall, latitude, longitude, and altitude (Uma Shankar 2001) as well as human and livestock effects (Bhat *et al.* 2000). As a result, there is a lot of spatial and temporal variation in species richness, composition, and productivity across these dry forests. Tropical deciduous forests assume unusual significance for conservation since they are the most used and threatened ecosystems (Janzen 1998) especially in India (Uma Shankar 2001).

Plantations in the Sanctuary forest are mostly run according to the Taungya system, using mechanized or manual labor in clear-cut and gap areas. Clear-cutting of sal forest is currently banned in India in favor of less-intensive forestry methods (e.g., selective harvesting). However, timber production is a key element in the sustainable management of sal forests, whether by industry or communities (Shah 2000). Plantations are considered to hold potential for timber production and in some cases site amelioration (Jackson 1994). Planting is also important to afforest the productive gaps and wastelands and to convert areas of low density to well stocked forests of valuable species and enrich depleted sal area with valuable species.

In many tropical dry forests of India, *Tectona grandis, Eucalyptus* spp., *Acacia catechu, Dalbergia sissoo* & *Albizia lebbeck* were planted between 1925 and 1982 over areas as large as 21 116.33 ha in the Murtiha, Dharmapur, Katarniaghat and Nishangara ranges (Joshi & Johari 1995). Within our study site the first teak plantation was planted as early as 1914-18 in Rampurwa (Nishangara range) and Nishangara (Dharmapur range) (Joshi & Johari 1995). Before 1951 species such as *Dalbergia sissoo, Shorea robusta, Madhuca indica, Acacia catechu* and *Emblica officinalis* were planted mixed with teak. Later these planted areas were clear-felled and pure teak has been planted since 1965. Teak mixed with other species was also introduced in other clear-felled areas, such as under planting in the gaps in sal forests and some grassland areas and other areas of the Sanctuary, Nishangara, Katarniagahat and Dharmapur. In some areas of the Sanctuary it has grown very well. In short, tropical dry forests in this region have seen varied disturbance due to logging.

The present study is an attempt to record and compare the regeneration, diversity status, and general community attributes in natural and planted forest in Terai - Bhabhar forests of Katarniaghat Wildlife Sanctuary. We wished to examine how species diversity, demography of different life - forms (e.g., shrubs, vines, trees) and soil parameters differed in planted forests vs. natural forests due to differences in their history leading to differences in community composition, microclimate, and edaphic characteristics. We hypothesized that regeneration patterns may differ in natural and planted forests and that natural species may also automatically come up in planted forests. This is important because such information may be useful for formulating conservation strategy for natural and planted forests.

Material and methods

Study area

We carried out our study in the Katarniaghat Wildlife Sanctuary, located in Nanpara Tehsil of district Bahraich, U.P. The Indo-Nepal border constitutes the northern boundary of the wildlife sanctuary. It is situated between 28° 6' and 28° 24' N and 81° 24' and 81° 19' E. The area falls under the Terai – Bhabar biogeography sub-division of the upper Gangetic plain (7A), as per the biogeograhic classification of Rodgers & Panwar (1988). Consequent upon Govt. of UP's notification no. 388/14-3-32/1976 dated 31 May, 1976, these forests came to be constituted as a wildlife sanctuary. It is one of the few remnants of the rich and diverse tarai ecosystems, having connections with the Royal Bardai National Park in Nepal which lies to the north, and Dudhwa National Park, which lies to the west of the Sanctuary.

The Sanctuary is unique in that, along with Dudhwa National Park, it is the only place which houses five species of deer, including the highly endangered 'Barasingha' or swamp deer (C*ervus duvancelii*). The rich biological diversity (flora and fauna) helps in maintaining the ecosystem stability in the Sanctuary. The area of the Sanctuary is 409 km^2 (40 009.35 ha), including 13 499.64 ha of eastern buffer and 1503.11 ha of western buffer zone (the total buffer zone of the Sanctuary is 15 002.75 ha or 150 km^2) (Jha 2000).

Katarniaghat Wildlife Sanctuary is one of the most significant representatives of highly rich, diverse, and fragile tarai ecosystems, presently under threat if not zealously guarded against anthropogenic pressures.

The rich soils of tarai coupled with an annual precipitation of over 1300 mm result in great diversity of vegetation in the Sanctuary which also gives rise to a mosaic of diverse habitats. The forests of the wild life sanctuary extend from dense moist tarai sal forests to large open grasslands and dense canebrakes in the riverine tracts. These forests boast of some of the finest stands of sal in this bio-geographic zone (Rodgers & Panwar 1988).

As per Champion & Seth's (1968) revised classification of forest types of India, the Katarniaghat Wildlife Sanctuary falls under various forest types (i) The sal forests - moist bhabhar sal (3C/C2b, moist bhabhar sal 5B/ CIB), dry plain sal (3C/C2b, dry plains sal 5B/CIB), (ii) The miscellaneous forests *Terminalia alata or T. tomentosa* forests ($3/E_1$), cane brake ($1/E_1$). Katarniaghat Wildlife Sanctuary is one of the strongholds of the tiger. Across the international border lies the Royal Bardia National Park in Nepal and the two areas have the potential to hold a viable population of this highly endangered animal (Jha 2000).

The forests of the present study are located in the Tarai - Bhabhar region of Western U.P. adjacent to foothills of Central Himalaya. The forest is tropical dry deciduous, generally dominated by sal (*Shorea robusta*) natural forests (Champion & Seth 1968). Planted forest species included teak (*Tectona grandis)*, followed by *Acacia catechu* and *Syzygium cumini*. There were a few stands of fast-growing trees like *Trewia nudiflora*, *Terminalia* spp., *Albizia lebbeck*, *Bauhinia* spp. The leafless period of sal is only 1-2 weeks. Most evergreen species are confined to lower strata, thus keeping the forest floor moist and cool (Uma Shankar 2001). Generally in the dry deciduous forests, due to a lengthy leaf-drop period, the canopy almost becomes naked and the forest floor gets dry and hot during summer (Sukumar *et al.* 1997; Uma Shankar 2001). In the Tarai-Bhabhar of Kumaun Central Himalaya, the long dry period (5-6 months) and relatively lower rainfall (< 2000 m) and humidity (50-60%) alter floristic diversity (Agni *et al.* 2000).

Field inventory

We conducted our studies during 2001-2002 in four forest sites (Katarniaghat, Nishangara, Murtiha and Dharmapur). At each site, we surveyed both natural and planted forests using a stratified random sampling technique. About 1% of each forest site was sampled. Within each forest, we sampled plots of 0.2 ha (50 m x 40 m) for a total of 138 sample plots (28+25 in Katarniaghat, 21+4 in Dharmapur, 18+10 in Nishangara and 19+13 in Murtiha). Within each sample plot, we surveyed 20 (10 x 10 m = 100 m^2) for mature trees & poles (identity of all stems and size) and 80 (5 x 5 m = 25 m^2) for shrubs, saplings and seedlings (density and identity). We define mature trees as stems with >30 cm girth at breast height (1.3 m) and >13 m height, poles as individuals >10 cm to < 30 cm girth and > 2 m height, saplings are individuals > 1 cm to < 10 cm collar girth and > 0.5 m to < 2 m heights and seedlings >1 cm collar girth and up to 0.5 m height. All plants were enumerated and analyzed in each sample plot.

The species sampled in the four layers of vegetation were classified into the four growth forms, namely large tree, undertree, shrub, and climber. All the emergent species were grouped under large trees. Undertrees included species that were found in sub-canopy, were shade-loving, prevalent in understory, and did not exceed 13 m in height. The species that were characterized by short stature, including annual or biennial herbs and with spiny structures (thorns and spines), were classified as shrubs. Climbers included shade-loving, annual, biennial or perennial, herbaceous, and woody climbing species.

The canopy cover of the trees was measured by recording the percentage overlap between adjacent tree crowns directly above several points in the forest. The canopy closure involved selecting a representative point in the forest to start, stopping every 5 m along a compass line to directly look above and observe the tree canopy, and recording 30 observation points for the sample to obtain a mean score and percentage for canopy closure (Poffenberger *et al.* 1992). Light intensity was measured using a Lux meter directly in the field.

Soil pH and soil moisture were measured by Kelway Soil Tester directly in the field. In each plot four soil samples were taken for laboratory studies. Available nitrogen, phosphorus, potash and organic carbon were analyzed in the laboratory adopting the standard method of "Tropical Soil Biology and Fertility (TSBF) (Anderson & Ingram 1993).

Data analyses

Frequency, density, basal area and importance value index (IVI) were determined for each species following Mueller–Dombois & Ellenberg (1974).

Species diversity (Shannon's diversity index) was calculated using a formula given by Margalef (1968).

$$H' = -\sum_{i=1}^{s} [(n_i/N)\log_2 (n_i/N)]$$

where, H' = Shannon index of general diversity, n_i = density of i^{th} species, N = density of all the species across all classes.

The index of dominance (C) of the community was calculated by Simpson's index (Simpson 1949):

$$\lambda = [(n_i/N)^2]$$

where, λ = Index of dominance, n_i and N being the same as in Shannon index of general diversity.

Species richness (Margalef index) was calculated using a formula given by Margalef (1958):

$$SR = s - 1/\log n$$

where, s is the no. of species, n is the no. of individuals

The evenness index of the community was calculated following Pielou (1966):

$$P = Hi / \log S.$$

where, Hi is the Shannon - Wiener index of diversity and S is the no. of species.

Hill diversity (Hill 1973) index was calculated by the following formulae:

Number 0: N0 = S,

where, S is the total number of species; Number 1: N1 = In H', where, H' is the Shannon's index; Number 2: N2 = $1/\lambda$, where, λ is the Simpson's index.

The regeneration status of sampled species was assessed based on phytosociological data (Uma Shankar 2001) in the following categories: (a) 'good', if present in seedling > sapling > mature strata; (b) 'fair', if present in seedling > sapling < mature strata; (c) 'poor', if a species survives only in the sapling stage, but not as seedlings (even though saplings may be less than, more than, or equal to mature); (d) 'none', if a species is absent both in sapling and seedling stages, but present as mature; and (e) 'new', if a species has no mature, but only sapling and/or seedling stages.

The data were analyzed statistically. In all comparisons between tree and seedling density between natural and planted forest sites the t-test was used. A multivariate regression model of species richness, and six explanatory variables such as soil characters in 138 plots in natural and planted forest sites, were used. Linear regression analysis of seedling density vs. adult density among all the plots was also made. Multiple regression analysis is widely used and considered one of the most efficient parametric tests (Hader & Grandage 1958).

Results

Floristic composition, species richness, and diversity

We found one hundred and twenty-nine species in our plots (62 trees, 31 undertrees, 27 shrubs and 9 climbers); with 70 (34 trees, 16 undertrees, 15 shrubs and 6 climbers) species in natural forest, 59 (29 trees, 15 undertrees, 12 shrubs and 3 climbers) in planted forest, 56 species (27 trees, 14 undertrees, 12 shrubs and 3 climbers) common to both natural and planted forest (Table 1). There were 61 genera: 58 in natural forest, 49 in planted forest, 48 genera were common to natural and planted forest. A total 31 families were recorded: 30 in natural, 27 in planted forests, and 27 families were common to both forests. Stem density was greater in planted forests compared with natural forests (Table 1).

The best-represented families in these forests were Fabaceae, Caesalpiniaceae Euphorbiaceae, Verbenaceae and Rubiaceae (5 species each), Moraceae (4), Mimosaceae and Combretaceae (3 species each), Ehretiaceae, Rutaceae, Ulmaceae, Myrtaceae, Tiliaceae, Apocynaceae, Anacardiaceae, Annonaceae and Lamiaceae (2 species each), and rest of the families had single species. Fabaceae, Euphorbiaceae, Verbenaceae, Rubiaceae and Caesalpiniaceae constituted 16.1% of the total number of species, followed by Moraceae, Mimosaceae and Combretaceae with 15.5% species. Diversity was higher in natural forest than in planted forest (Table 1) and species richness (Margalef index) was also higher in natural forest. Similarly evenness (Pielou index) showed a higher value (2.64) in natural forest and

Table 1. Consolidated details of regeneration (tree, pole, sapling and seedlings density ha^{-1}), basal area (m^2 ha^{-1}), soil (pH, moisture, organic carbon, available N, P, K,) (mean ± S.D.), tree structure (number, canopy) and diversity Index (Shannon, Simpson, species richness, evenness and Hill) from the six study areas of Katarniaghat Wildlife Sanctuary.

Parameters	Natural forests	Planted forests
No. of plots	86	52
Tree density ha^{-1}	515.0 ± 71.7	484.7 ± 35.1
Pole density ha^{-1}	238.1 ± 56.4	248.9 ± 23.0
Sapling density ha^{-1}	197.6 ± 25.2	501.6 ± 11.0
Seedling density ha^{-1}	722.6 ± 151.0	13.0 ± 8.5
No. of species	70	59
No. of genera	45	38
No. of families	30	27
Population density	9602.9	12913.4
Diversity indices		
Shannon (H)	4.85	4.27
Simpson (C)	0.3395	0.3031
Species richness (Margalef index)	17.33	14.11
Evenness (Pielou index)	2.64	2.44
Hill diversity		
N0	70.0	59.0
N1	14.23	13.12
N2	2.95	3.29
Canopy cover (%)	60-75	50-60
Light penetration (Lux100)	6050-1008	8600-11100
Soil moisture (%)	38.0 ± 1.5	21.0 ± 9.8
Soil organic carbon (%)	1.9 ± 0.6	0.9 ± 2.4
Soil pH	6.8 ± 0.5	6.9 ± 0.8
Available soil nitrogen (kg ha^{-1})	169.1 ± 21.7	94.2 ± 17.3
Available soil P (kg ha^{-1})	9.2 ± 7.6	6.6 ± 3.6
Available soil K (kg ha^{-1})	328.0 ± 26.2	313.9 ± 18.0

the Hill diversity index was also relatively higher in natural forest (Table 1).

Stand structure, density, basal area, and soil characteristics

Tree density was greater in natural (515.0 ± 71.6 stems ha^{-1}) than in planted forests (484.7 ± 35.1 stems ha^{-1}, significant at $P < 0.05$). The average pole density in natural and planted forests was respectively 238.1 ± 56.4 and 248.9 ± 23.0 plants ha^{-1}, while 197.6 ± 25.2 and 501.6 ± 11.0 plants ha^{-1} sapling density was recorded for natural and planted forest. Seedling density of 722.6 ± 151.0 plants ha^{-1} and 13.0 ± 8.5 plants ha^{-1}, significant at $P< 0.05$, was recorded in natural and planted forests respectively (Table 1). The average canopy cover ranged over 60- 75% in natural forest and 50-60% in planted forests. Average light penetration in planted forests was similar to natural forests. Soil moisture, organic carbon, available nitrogen, phosphorus and potash, however, were high in natural forests compared with planted forests, while soil pH was higher in the planted forest area in Katarniaghat Wildlife Sanctuary (Table 1).

Large tree density

There were 33 and 29 tree species (>13 m height), with a combined mature stage and pole density of 1349.9 and 1940.9 individuals, in natural and planted forests respectively. Combined sapling and seedling density of 2987.1 and 4479.4 individuals respectively was recorded in natural and planted forests. In natural forests, the genera *Terminalia* and *Ficus* were represented by three and two species respectively and the remaining 23 by one species each (Table 2). However, in planted forests all genera were recorded as single species (Table 2). The density of *Shorea robusta* (Dipterocarpaceae) in mature and pole strata was highest (232.2 ± 120.8 stems ha^{-1}) in natural forests, followed by *Schleichera oleosa* (226.6 ± 112.0), *Acacia catechu* (151.8 ± 81.3) and *Dalbergia sissoo* (72.0 ± 38.3 stems ha^{-1}). The lowest (2.0 ± 0.9 stems ha^{-1}) density was recorded for *Semecarpus anacardium* followed by *Dillenia pentagyna* (6.3 ± 3.2 stems ha^{-1}) in natural forests. However, *Eucalyptus* species (Myrtaceae) density for mature trees and poles was highest (278.7 ± 96.0 stems ha^{-1}) in planted forests, followed by 165.8 ± 79.6 for *Acacia catechu* and 153.7 ± 106.1 stems ha^{-1} for *Bombax ceiba*. Minimum mature stage and pole density (2.5 ± 1.0 stems ha^{-1}) was recorded for *Semecarpus anacardium* (Anacardiaceae), followed by 5.8 ± 2.8 for *Aegle marmelos* and 11.3 ± 5.0 for *Ougenia oojeinensis* in planted forests (Table 2).

Sapling and seedling density of *Shorea robusta* was also highest (1610.2 ± 834.5 plants ha^{-1}) in natural forests, followed by 137.6 ± 74.7 for *Schleichera oleosa* and 120.3 ± 34.0 for *Diospyros tomentosa*. However, lowest sapling and seedling density (9.0 ± 0.0 and 9.0 ± 2.8 plants ha^{-1}) was recorded for *Cordia dichotoma* and *Lannea grandis* respectively, followed by 9.5 ± 3.5 plants ha^{-1} for *Drypetes roxburghii* in natural forests. In planted forests, maximum sapling and seedling density (2011.0 ± 511.6 plants ha^{-1}) was also recorded for *Shorea robusta*, followed by 792.1 ± 302.6 for *Schleichera oleosa,* while minimum density (8.5 ± 0.0 plant ha^{-1}) was observed for *Cordia dichotoma*, followed by 9.0 ± 4.2 plants ha^{-1} for *Adina cordiafolia* (Table 2).

Undertrees density

Sixteen and 15 undertree species (<13 m height) contributed to a total of 194.9 and 321.4 individuals in mature tree and pole density in natural and planted forests respectively, while a total sapling and seedling density of 1796.7 and 1292.1 individuals was recorded in natural and planted forests. The genus *Bauhinia* had three species, *Miliusa* two and the remaining eight were represented by one species each in natural forests. In planted forests, *Cassia* (two species) and the rest of the 10 genera were represented by one species each (Table 2). *Premna integrifoia* was recorded as commonest in mature tree and pole density (37.2 ± 28.2 stems ha^{-1}) in natural forests, followed by 27.5 ± 3.5 for *Randia dumentrum,* and the lowest density (7.0 ± 0.0 stems ha^{-1}) was recorded for *Azadirachta indica,* while maximum mature tree and pole density (217.3 ± 298.4 stems ha^{-1}) was recorded for *Mallotus philippensis* in planted forests and minimum density (2.0 ± 0.0) was recorded for *Ficus hipsida* (Table 2).

In sapling and seedling strata highest density (580.0 ± 235.1 plants ha^{-1}) was also recorded for *Premna integrifolia* in natural forests, followed by 380.5 ± 85.4 plant ha^{-1} for *Tamarindus indica* and 325.4 ± 0.0 plants ha^{-1} for *Mallotus philippensis*. Lowest density (7.3 ± 3.8 plants ha^{-1}) was recorded for C*assia fistula*, followed by 10.0 ± 9.8 for *Azadirachta indica* in natural forests. Maximum sapling and seedling density (571.0 ± 390.5 plants ha^{-1}) was observed for *Litsea glutinosa,* followed by 471.1 ± 128.9 for *Mallotus philippensis,* while minimum density (14.3 ± 8.1 plants ha^{-1}) was recorded for *Miliusa velutina* in planted forests (Table 2).

Shrub and climber density

The shrub species that are characterized by short stature, including annual or biennial herbs with spiny structures (thorns and spines), and climbers included species that were shade-loving, have been mentioned in Table 2 only in sapling and seedling categories.

Shrub layers

There were 15 and 12 species with a pole density of 1371.3 and 83.0 plants ha^{-1} in natural and planted forests respectively, while seedling and sapling density was 2806.8 and 4570.8 plants ha^{-1} individuals in natural and planted forests respectively. In the shrub layer all the genera were represented by single species in both forests (natural and planted). The highest density (1028.9 ± 671.6 plants ha^{-1}) was recorded for *Tiliacora acuminata* in natural forests, and the lowest (7.8 ± 3.0) was recorded for *Grewia asiatica*. In planted forests maximum density (47.0 ±9.9 plants ha^{1}) was recorded for *Ziziphus mauritiana,* and minimum density (12.8 ± 8.7) for *Casearia tomentosa* (Table 2).

Table 2. Floristic composition and density ha^{-1} (seedling, sapling, pole and mature tree) (mean ± S.D.) in natural and planted forests of Katarniaghat Wildlife sanctuary.

Species	Family	Mature tree and pole density ha^{-1}		Sapling and seedling density ha^{-1}	
		Natural	Planted	Natural	Planted
TREES					
Shorea robusta	Dipterocarpaceae	232.2±120.8	111.7±68.0	1610.2±834.5 ^{G}	2011.0±511.6^{G}
Schleichera oleosa	Sapindaceae	226.6±112.0	18.4±13.4	137.6±74.7 ^{P}	792.2±302.7^{G}
Acacia catechu	Mimosaceae	151.8±81.3	165.8±79.6	66.8±28.6 ^{F}	104.5±50.1 ^{P}
Syzygium cumini	Myrtaceae	72.9±46.8	122.8±92.3	106.6±75.4^{G}	407.6±143.0^{G}
Dalbergia sissoo	Fabaceae	72.0±38.3	143.5±57.6	35.6±21.4 ^{F}.	0.0 ^{N}
Bombax ceiba	Bombaceae	58.4±18.2	153.7±106.1	51.3±36.8 ^{F}	67.0±0.0 ^{P}
Terminalia tomentosa	Combretaceae	56.0±35.2	20.8±12.1	40.9±13.6 ^{P}	6.3±1.1 ^{P}
Tectona grandis	Verbenaceae	47.8±18.1	178.7±72.9	56.5±42.6 ^{F}	0.0 ^{N}
Aegle marmelos	Rutaceae	47.6±20.9	9.8±2.8	16.2±9.0 ^{F}	133.0±112.6 ^{G}
Trewia nudiflora	Euphorbiaceae	44.4±23.4	120.5±77.8	25.8±12.8 ^{P}	141.8±107.0^{F}
Ficus glomerata	Moraceae	39.7±16.6	35.7±20.3	49.0±43.6 ^{F}	126.2±92.1^{G}
Lagerstroemia parviflora	Lythraceae	39.5±22.0	38.8±18.9	43.2±30.4 ^{F}	43.5±24.6 ^{F}
Terminalia arjuna	Combretaceae	33.0±15.6	61.3±38.3	16.3±11.6 ^{P}	28.7±12.2 ^{P}
Ehretia laevis	Ehretiaceae	30.4±12.8	34.3±13.7	10.0±4.6 ^{P}	0.0 ^{N}
Terminalia bellerica	Combretaceae	23.5±21.3	10.8±7.6	201.0±2.8 ^{G}	37.7±22.9 ^{G}
Ficus ramphii	Moraceae	20.0±0.0	--	0.0 ^{N}	--
Lannea grandis	Anacardiaceae	20.0±4.2	--	9.0±2.8 ^{P}	--
Diospyros tomentosa	Ebenaceae	19.9±9.3	--	120.3±94.0 ^{G}	241.6±109.7 ^{I}
Holarrhena antidysenterica	Apocynaceae	18.6±9.9	41.0±25.7	36.9±25.2 ^{G}	89.0±55.3 ^{P}
Streblus asper	Moraceae	15.0±2.8	73.3±38.8	11.0±0.0 ^{P}	31.0±0.0 ^{P}
Ougeinia oojeinensis	Fabaceae	14.7±5.7	11.3±5.0	30.5±13.4 ^{G}	46.3±16.9 ^{G}
Butea monosperma	Fabaceae	14.0±4.2	--	50.5±9.2 ^{G}	--
Kydia calycina	Malvaceae	14.0±7.1	--	25.0±14.5 ^{G}	--
Adina cordifolia	Rubiaceae	13.8±7.7	--	19.5±0.7 ^{G}	9.0±4.2 ^{I}
Madhuca indica	Sapotaceae	9.0±3.2	32.3±27.7	30.0±0.0 ^{G}	0.0 ^{N}
Drypetes roxburghii	Euphorbiaceae	7.0±1.4	37.6±14.7	9.5±3.5 ^{F}	58.5±38.5 ^{F}
Dillenia pentagyna	Dilleniaceae	6.3±3.2	18.3±17.5	50.0±23.7 ^{G}	0.0 ^{N}
Semecarpus anacardium	Anacardiaceae	2.0±0.9	2.5±1.0	0.0 ^{N}	0.0 ^{N}
Albizia lebbeck	Mimosaceae	--	24.0±14.5	--	32.3±12.5 ^{F}
Eucalyptus spp.	Myrtaceae	--	278.7±96.0	--	0.0 ^{N}
Grewia subinaequalis	Tiliaceae	--	--	84.5±43.3 ^{I}	159.0±90.9 ^{G}
Holoptelea integrifolia	Ulmaceae	--	--	24.00±17.0 ^{I}	45.60±22.5^{I}
Cordia dichotoma	Ehretiaceae	--	16.7±3.4	9.0±0.0 ^{I}	8.5±0.0 ^{P}
Celtis tetrandra	Ulmaceae	--	--	10.5±2.1 ^{I}	--
UNDERTREES					
Premna integrifolia	Verbenaceae	37.2±28.2	--	580.0±235.1 ^{G}	--
Randia dumetorum	Rubiaceae	27.5±3.5	20.3±12.3	67.0±43.6 ^{G}	98.5±55.6 ^{G}
Miliusa velutina	Annonaceae	19.2±11.7	--	69.2±35.4 ^{G}	14.3±8.1 ^{I}
Litsea glutinosa	Lauraceae	18.9±9.8	6.5±2.7	32.6±18.5 ^{F}	571.0±390.6 ^{G}
Bauhinia racemosa	Caesalpiniaceae	16.5±8.3	--	155.9±92.8 ^{G}	29.3±15.2 ^{I}
Ficus hipsida	Moraceae	14.8±13.2	2.0±0.0	18.0±7.4 ^{F}	37.5±26.1 ^{G}
Mitragyna parvifolia	Rubiaceae	14.2±5.8	10.3±8.3	10.5±2.1 ^{P}	31.0±0.0 ^{F}

Contd...

Table 2. Continued.

Species	Family	Mature tree and pole density ha^{-1}		Sapling and Seedling density ha^{-1}	
		Natural	Planted	Natural	Planted
Miliusa tomentosa	Annonaceae	13.5±7.5	42.8±16.9	69.7±43.7 ^{G}	0.0 ^{N}
Cassia fistula	Caesalpiniaceae	11.1±5.7	5.5±2.1	7.3±3.8 ^{P}	23.0±11.8 ^{F}
Azadirachta indica	Meliaceae	7.0±0.0	8.4±6.3	10.0±9.8 ^{F}	0.0 ^{N}
Mallotus philippensis	Euphorbiaceae	--	217.3±118.4	325.4±0.0 ^{I}	471.1±128.9 ^{G}
Bridelia retusa	Euphorbiaceae	--	36.4±20.7	19.6±9.5 ^{I}	75.0±0.0 ^{G}
Stereospermum suaveolens	Bignoniaceae	--	33.3±26.3	6.6±3.5 ^{I}	0.0 ^{N}
Wendlandia exserta	Rubiaceae	--	31.0±16.9	9.5±0.0 ^{I}	0.0 ^{N}
Tamarindus indica	Caesalpiniaceae	--	28.5±13.4	380.5±85.4 ^{I}	0.0^{N}
Cassia siamea	Caesalpiniaceae	--	18.0±7.2	30.5±9.0 ^{I}	9.0±0.0 ^{P}
SHRUBS					
Ziziphus mauritiana	Rhamnaceae	1260.7±3.5	47.0±9.9	100.0±90.0 ^{P}	86.7±47.5 ^{F}
Glycosmis pentaphylla	Rutaceae	61.2±28.0	--	758.4±388.1^{G}	394.8±205.1 ^{G}
Helicteres isora	Sterculiaceae	20.0±0.0	--	29.6±18.6 ^{P}	10.0±1.4 ^{P}
Casearia tomentosa	Flacourtiaceae	12.3±8.9	12.8±8.7	8.0±5.2^{P}	50.0±23.7 ^{F}
Hymenodictyon excelsum	Rubiaceae	9.5±0.0	--	10.0±0.0 ^{P}	50.0±0.0 ^{P}
Grewia asiatica	Tiliaceae	7.8±3.0	--	--	--
Murraya koenigii	Rutaceae	--	23.2±29.1	199.1±86.9 ^{G}	312.1±218.3 ^{G}
Tiliacora acuminata	Menispermaceae	--	--	1028.9±671.6 ^{G}	1851.5±1053.3 ^{G}
Clerodendrum viscosum	Verbenaceae	--	--	362.2±137.9^{G}	710.8±474.7 ^{G}
Callicarpa macrophylla	Verbenaceae	--	--	106.5±70.4^{G}	763.3±394.2^{G}
Ardisia solanacea	Myrsinaceae	--	--	73.6±35.1^{F}	50.0±0.0 ^{F}
Colebrookia oppositifolia	Lamiaceae	--	--	66.3±43.0^{F}	--
Lantana camara	Verbenaceae	--	--	40.0±0.0 ^{P}	112.0±63.2 ^{F}
Moghania brevipes	Fabaceae	--	--	18.2±12.12 ^{P}	179.25±95.11 ^{G}
Rauvolfia serpentine	Apocynaceae	--	--	6.0±0.00 ^{P}	--
CLIMBERS					
Acacia concinna	Mimosaceae	27.0±0.0	17.5±2.0	158.7±74.8 ^{G}	--
Breynia rhamnoides	Euphorbiaceae	10.5±1.5	--	9.5±0.7 ^{P}	--
Bauhinia vahlii	Caesalpiniaceae	8.3±6.4	--	15.3±6.0 ^{P}	40.3±28.7 ^{P}
Calamus tenuis	Arecaceae	--	--	137.0±17.0 ^{F}	--
Milletia auriculata	Fabaceae	--	--	6.9±4.1 ^{P}	9.0±5.6 ^{P}
Pogostemon plectranthoides	Lamiaceae	--	--	3.0±1.0 ^{P}	--

Superscripts for sapling and seedling density denote good (G), fair (F), poor (P), no regeneration (N) and new or immigration (I); see text for details.

Climbers

There were six and three species with a total density of 17.5 and 39.5 plants ha^{-1} in natural and planted forests respectively. In natural and planted forests all the genera were represented by one species each (Table 2). The highest density (27.0 ± 0.0 plants ha^{-1}) was recorded for *Acacia concinna*. However, the lowest density (8.3 ± 6.4 plants ha^{-1}) was recorded for *Bauhinia vahlli* in natural forests. *Acacia concinna* was the only species found in planted forests, which had the density of 17.5 ± 2.0 plants ha^{-1}. The maximum (158.7 ± 74.8 plants ha^{-1}) for *Acacia concinna* sapling and seedling density was recorded in natural forests, and minimum (3.0 ± 1.0) for *Pogostemon plectranthoides* in natural forests (Table 2).

Regeneration

In natural forests, in addition to 68 species with >10 cm girth, 10 more species were recorded regenerating in the sapling and seedling layers

(Fig. 1); four large trees (*Celtis tetranda, Cordia dichotoma*, *Grewia subinaequalis* and *Holoptelia integrifolia*) and six undertrees (*Bridelia retusa, Cassia siamea, Mallotus philippensis, Tamarindus indica, Stereospermum suaveolens* and *Wendlandia exserta*). Similarly in planted forests, of 58 species, five new species were also regenerating in the sapling and seedling layers (Fig. 1); three large trees (*Adina cordifolia, Diospyros tomentosa* and *Holoptelea integrifolia*) and two undertrees (*Bauhinia racemosa* and *Miliusa velutina*). Of the 68 species in natural forest, 32.4% showed good regeneration, 22.1% fair, and 27.9% poor, while 2.9% lacked regeneration (Fig. 1). The remaining 14.7% seem to be either reappearing or immigrating in natural forests. While in planted forests, out of a total of 58 species, 32.8% showed good regeneration, 17.2% fair, 20.7% poor, and 20.7% species were not found regenerating, while the remaining 8.6% seem to be either re-appearing or immigrating (Fig. 1). In natural forests only eleven to eight large trees species showed good - to - fair regeneration, while eight to four large trees recorded good - to - fair regeneration in planted forests. In the undertree layer, less species were either poorly regenerating or failing and abundant species exhibited good - to - fair regeneration in natural forests. Similarly, in planted forests in the undertree layer less species exhibited poor regeneration and in five species there was no regeneration. In natural forests abundant shrub species also showed good - to - fair and poor regeneration. Climbers showed less regeneration in natural forests as well as in planted forests. In the tree and undertree layers a total of ten to five species were regenerating, either re-appearing or immigrating (Fig. 1).

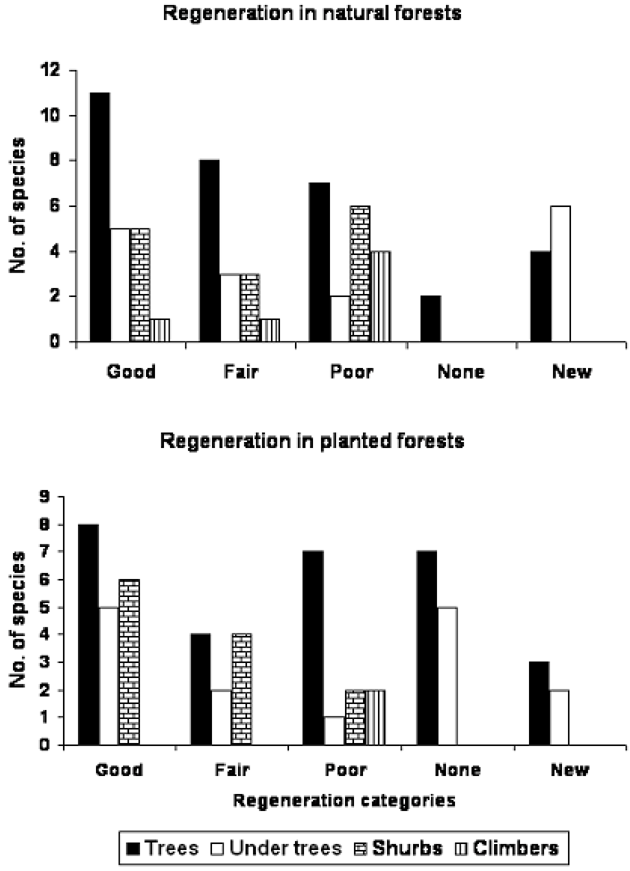

Fig 1. Regeneration of species in four growth forms of Katarniaghat Wildlife Sanctuary.

Discussion

The flora of Katarniaghat Wildlife Sanctuary forests is characterized by an overwhelming dominance of tree species (49 tree species including undertrees). Of all individuals, 70% belong to trees. The dominance of tree and shrub species appears to be the characteristic feature of dry deciduous forests (Seetharam *et al.* 2000). The Sanctuary forest appears unusually rich in species, with 70 and 59 species in natural and planted forests respectively across all the study sites. The total number of species in four categories (large tree, undertree, shrub and climber) was significantly greater in natural forests. However, similarities were found among species in both types of forests. Similarities in species richness and diversity indices are reflected in 56 species common to both sites, the similarity index indicating less variation in the species composition. This could also be attributed to no major variations in soil type and available soil nutrients between natural and planted forests of the present study sites. The richness was greater than that of sal forests of Eastern Himalaya (Uma Shankar 2001), Central Himalaya (Singh & Singh 1992) and deciduous forest in Western Ghats (Sukumar *et al.* 1997).

Shannon's diversity index (H′) was higher in the study area (4.27 for planted forests and 4.85 for natural forests) which is greater than the 1.58-3.53 recorded for old sal plantations in Gorakhpur (Pandey & Shukla 1999; Shukla & Pandey 2000), 3.59 for sal forests in Eastern Himalaya (Uma

Shankar 2001), 2.65 & 2.94 for Western Ghats (Arunachalam 2002), and a tropical dry evergreen forest (2.28) of south India (Parthasarathy & Sethi 1997). Knight (1975) reported an average value of 0.06 in Simpson's index for tropical forests, while that of sal plantation in Gorkhapur ranged between 0.042 and 0.211 (Pandey & Shukla 1999). In the present study, the values are comparable with the Simpson value of 0.3395 for natural forests and 0.3031 for planted forests. The Pielou's evenness indices were 2.64 and 2.44 for natural and planted forests respectively (Table 1), which were higher than the 0.9 on average reported for Western Ghats (Arunachalam 2002), indicating high dominance and a more or less regular distribution of plant species in the study sites. Hill diversity numbers were relatively low in planted forests and significant variation was observed between the two study areas, while in Western Ghats no significant variation was observed (Arunachalam 2002). This indicates that the sal forests in Eastern Himalaya are similar to the present study sites in terms of species richness, but less diverse than the present study sites in terms of different life - forms. It is perhaps due to availability of moisture and the rich transported soil of Tarai - Bhabhar. Historically the Tarai - Bhabhar forest area is mainly composed of gangetic alluvium with a succession of beds of sands and loam of varying depths. The surface soil in the low alluvium is very recent, but that in the high alluvium is mostly loamy sand varying in depth and composition. However, these comparisons convey limited meaning since the sample area is variable across study sites and forests are mostly restricted to the protected area network. However, the high index values could be a result of sample size variation.

The greater number of saplings in the stands indicate the composition of future vegetation (Swaine & Hall 1988). According to Jones *et al.* (1994), seedling layers differ in composition from their respective overstories. Regeneration of species is dependent on internal community processes and exogenic disturbance (Barker & Patrik 1994). In the study site seedlings of three dominant overstory species (*Shorea robusta, Syzygium cumini* and *Mallotus philippensis*) were found in great abundance while for some other dominant species such as *Ficus ramphii* and *Semecarpus anacardium* seedling and sampling were absent. Some of the species were found in low density of seedling and sapling strata e.g. *Lannea grandis, Drypetes roxburghii, Cordia dichotoma, Streblus asper, Stereospermum suaveolens, Wendlandia exserta* in natural forest and *Adina cordifolia, Cordia dichotoma, Terminalia tomentosa* and *Cassia siamea* in planted forest. The lack of juveniles of some of the primary species has also been reported from the rain forest of Khade, Ghana (Swaine & Hall 1988).

Few ecological studies are available on the regeneration of species in relation to fire, grazing, light, canopy density, soil moisture and soil nutrients. The multiple regression data computed between a few important tree and seedling densities and six explanatory variables (soil moisture, soil organic carbon, soil pH, N, P and K) for natural and planted forests are given in Tables 3 and 4. The multiple regression model for natural forest indicates that 15% variation of *Acacia catechu* tree density, 19% variation of *Terminalia bellerica* tree density and 13% variation of *Premna integrifolia* seedling density are explained by six variables (soil moisture, soil organic carbon, soil pH, N, P and K). The multiple regression model reveals no significant impact of soil characteristics on tree and seedling density in natural forest (Table 3). The value of the F-ratio is significant at 5% in *Acacia catechu* and *Trewia nudiflora* tree density, and at 1% in *Terminalia bellerica* tree density. The multiple regression model for planted forest indicates 35% variation of *Mallotus philippensis* seedling density, 24% variation of *Syzygium cumini* tree density and *Trewia nudiflora* seedling density, 23% variation of *Terminalia bellerica* seedling density, 22% variation of *Shorea robusta* seedling density, 20% variation of *Litsea glutinosa* seedling, 16% variation of *Acacia catechu* seedling density, *Shorea robusta* and *Trewia nudiflora* tree density, 15% variation of *Schleichera oleosa* tree density are explained by six variables (soil moisture, soil organic carbon, soil pH, N, P and K). The multiple regression model revealed the significant impact of soil characteristics on tree and seedling density in planted forest (Table 4). The value of the F-ratio is significant at 5% in *Trewia nudiflora* and *Terminalia bellerica* seedling density as well as *Syzygium cumini* tree density, and at 1% in *Mallotus philippensis* seedling density. These data show that the systematic variation is considerably

Table 3. Regression equations for the tree species under study using parameters such as soil moisture, soil organic carbon, pH, nitrogen, phosphorus and potassium with tree and seedling density in natural forest of Katarniaghat Wildlife Sanctuary.

Species (sample size)		Regression equation coefficients		
		Intercept (SE)	R^2 (adjusted r^2)	F ratio (F significance)
Acacia catechu (86)	Tree	198.878 (99.099)	0.156 (0.092)	2.436 (0.0326)
	Seedling	114.404 (38.075)	0.055 (-0.017)	0.762 (0.602)
Aegle marmelos (86)	Tree	80.494 (28.724)	0.068 (-0.002)	0.967 (0.453)
	Seedling	22.458 (8.339)	0.102 (0.033)	1.489 (0.192)
Bauhinia racemosa (86)	Tree	24.262 (14.371)	0.094 (0.025)	1.361 (0.241)
	Seedling	102.214 (136.939)	0.049 (-0.023)	0.687 (0.661)
Diospyros tomentosa (86)	Tree	20.516 (12.580)	0.038 (-0.036)	0.514 (0.796)
	Seedling	54.775 (81.102)	0.075 (0.005)	1.068 (0.388)
Ficus glomerata (86)	Tree	32.012 (18.293)	0.028 (-0.046)	0.376 (0.892)
	Seedling	0.398 (42.115	0.058 (-0.013)	0.813 (0.563)
Litsea glutinosa (86)	Tree	-14.472 (22.218)	0.105 (0.037)	1.539 (0.176)
	Seedling	19.107 (19.811)	0.092 (0.023)	1.331 (0.253)
Premna integrifolia (86)	Tree	-32.037 (25.291)	0.099 (0.031)	1.451 (0.206)
	Seedling	900.358 (426.611)	0.133 (0.068)	2.026 (0.071)
Shorea robusta (86)	Tree	276.508 (96.680)	0.079 (0.009)	1.136 (0.349)
	Seedling	2030.36 (1663.101)	0.042 (-0.031)	0.579 (0.745)
Schleichera oleosa (86)	Tree	243.789 (108.817)	0.119 (0.053)	1.794 (0.111)
	Seedling	174.410 (75.311)	0.041 (-0.032)	0.557 (0.763)
Syzygium cumini (86)	Tree	117.677 (41.237)	0.065 (-0.006)	0.916 (0.488)
	Seedling	69.174 (102.425)	0.015 (-0.059)	0.204 (0.974)
Terminalia bellerica (86)	Tree	34.101 (21.904)	0.198 (0.137)	3.241 (0.007)
	Seedling	197.833 (7.578)	0.073 (0.003)	1.041 (0.405)
Trewia nudiflora (86)	Tree	79.170 (23.677)	0.147 (0.082)	2.261 (0.046)
	Seedling	36.693 (14.489)	0.113 (0.045)	1.669 (0.139)

greater than should be explained by chance in natural and planted forests.

There is no linear relationship between seedling density per species and adult density in natural and planted forests. Therefore, this is an indication that regeneration does not be account for adult density. Chapman & Chapman (1997) reported lower sampling density in the heavily logged tropical forests at Kibale National Park, Uganda, resulting in lower recruitment into the sapling class in logged forests. The low-grade timber species such as *Diospyros tomentosa* and *Schleichera oleosa*, *Syzygium cumini,* shrubs such as *Tiliacora acuminata*, *Clerodendrum viscosum* and *Gylcosmis pentaphylla,* and climbers like *Acacia concinna* was regenerating well. *Shorea robusta* had good population of seedlings, but these were not maturing in good numbers to young stages.

It has been recorded that regeneration of species is affected by fire (Murthy *et al.* 2002; Sukumar *et al.* 1997), grazing, light, canopy density, soil moisture, soil nutrients and anthropogenic pressure. In general, the regeneration of species is also affected by natural phenomena such as light gaps (Teketay 1997). Similar observations were recorded in this study, where planted forests sites showed low species density and diversity as well as low soil characteristics and high light penetration (Table 1) compared with the natural forest sites. Some of the natural species such as *Grewia subinaequalis, Lagerstroemia parviflora, Miliusa tomentosa, Shorea robusta, Syzygium cumini,* and *Mallotus philippensis* were also found regenerating in the planted forests. Similar findings were also reported by other workers, indicating that natural species have regenerated automatically under

Table 4. Regression equations for the tree species under study using parameters such as soil moisture, soil organic carbon, pH, nitrogen, phosphorus and potassium with tree and seedling density in planted forest of Katarniaghat Wildlife Sanctuary.

Species (sample size)		Regression equation coefficients		
		Intercept (SE)	R^2 (adjusted r^2)	F ratio (F significance)
Acacia catechu (52)	Tree	206.299 (107.958)	0.076 (-0.047)	0.619 (0.713)
	Seedling	175.367 (62.918)	0.165 (0.053)	1.479 (0.207)
Aegle marmelos (52)	Tree	7.427 (5.978)	0.029 (-0.099)	0.228 (0.962)
	Seedling	162.910 (96.998)	0.137 (0.022)	1.193 (0.327)
Ficus glomerata (52)	Tree	29.750 (24.156)	0.043 (-0.084)	0.339 (0.912)
	Seedling	260.264 (94.873)	0.104 (-0.016)	0.867 (0.526)
Litsea glutinosa (52)	Tree	1.868 (4.642)	0.146 (0.032)	1.282 (0.285)
	Seedling	216.134 (539.884)	0.202 (0.096)	1.903 (0.101)
Mallotus philippensis (52)	Tree	60.806 (230.363)	0.048 (-0.079)	0.377 (0.889)
	Seedling	479.598 (330.650)	0.358 (0.273)	4.190 (0.002)
Shorea robusta (52)	Tree	21.504 (84.228)	0.162 (0.051)	1.446 (0.218)
	Seedling	2059.192 (2356.826)	0.222 (0.119)	2.142 (0.067)
Schleichera oleosa (52)	Tree	36.421 (14.033)	0.158 (0.045)	1.402 (0.234)
	Seedling	1037.782 (304.911)	0.048 (-0.079)	0.376 (0.889)
Syzygium cumini (52)	Tree	50.046 (85.766)	0.242 (0.141)	2.392 (0.043)
	Seedling	467.608 (287.322)	0.103 (-0.016)	0.863 (0.529)
Terminalia bellerica (52)	Tree	12.867 (10.951)	0.094 (-0.027)	0.776 (0.593)
	Seedling	-31.943 (25.309)	0.235 (0.133)	2.302 (0.050)
Trewia nudiflora (52)	Tree	34.138 (80.006)	0.160 (0.049)	1.433 (0.223)
	Seedling	-81.877 (87.125)	0.248 (0.147)	2.468 (0.037)

plantations (Shah 1996). This is an indication that the protection carried out by the Sanctuary authority has been enhancing natural species regeneration in plantations.

Tree density and seedling density in natural forest are not influenced much by soil characteristics, while the same parameters are significantly influenced by soil characteristics in planted forest, as revealed by multiple regression analysis. The planted forest is still in the growing stage. Interestingly, some natural species have been regenerating automatically in planted forest, thereby indicating that good management has been carried out for regeneration of natural species.

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