Species diversity and forest structure of pine plantations in the middle hills of Nepal

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There is substantial debate on the potential benefits and drawbacks of pine plantations to communities and the environment in the Middle Hills. Within this context, we compared species richness and stem density of colonizing woody species in pine plantations with nearby natural forests in Roshi watershed area of Kabhrepalanchok district in the Middle Hills of Nepal. Effects of plantation size, aspect, and canopy closure on species richness and stem density were analyzed. The results showed that 1) natural forests had greater species richness and stem density compared to plantations; 2) northern aspect plantations had greater species richness and stem density than southern aspect plantations; 3) plantation size had no significant effect on diversity or stem density; and 4) canopy closure of planted trees and species richness were negatively related. High variability in species richness across plantations suggests that the diversity of regeneration in pine plantations should not be generalized. Further investigation is necessary on how biophysical parameters affect forest characteristics. Some implications for community forest management are discussed.

Key words: Community forestry, conservation, forest management, silviculture, pine, plantation

Forestation with fast-growing native or exotic tree species started in the Middle Hills in the 1960s, in response to problems of deforestation, environmental degradation, and the difficulties of farmers in meeting their daily requirements of forest products. Since the inception of forestation programmes, pines have been among the first choice in the selection of species for plantations because of a number of silvicultural and biological characteristics that allow them to establish, grow and succeed on poor sites.

In the two districts of Kabhrepalanchok and Sindhupalchok, approximately 16,000 hectares of pine plantations were established from 1978 until 1992, with the support from successive Australian Aid (Ladley, 1995). Plantations had been established on degraded forest land, formerly sustaining natural broadleaf forests, grasslands, and abandoned agricultural land (Ingles, 1995; Collet *et al.*, 1996). Plantations had been initially established as community forests, or had been established as government plantations but later handed-over to local communities.

The widespread establishment of pine plantations has been a subject of criticism by some sections of the society in recent years (e.g. Himalayan Times, Feb. 9, 1999). Moreover, local users and recent research have raised further issues. Local forest users in Kabhrepalanchok widely believe that fallen pine needles prevent the growth of other plants, that includes the establishment and growth of native broadleaf species. Pine has no value for fodder, is a poor fuelwood and provides base-poor litter which is not desirable for composting (Jackson, 1994; Schmidt *et al.*, 1995). Livestock raising, which is a major source of cash income to the rural households, has been affected in many places due to the unavailability of fodder and quality litter for animal bedding. Gautam (1999) found that community forestry programme in Roshi watershed did not improve the availability of fodder to the beneficiaries, despite substantial increase in high forest cover during 1978-92. Based on the perceived negative effects of pines, many Forest User Groups (FUGs) have a plan of successive reductions in the number of pine trees and promotion of broadleaf species in their community forests (FUG leaders, pers. comm.).

On the positive side, research has shown that the establishment of pine plantations is an important achievement, because these plantations represent a large growing forest resource, which is economically important for the communities (Ladley, 1995; Collet *et al.*, 1996). Pine timber, along with other conifers, is the main source of building timber in Europe and North America. In Nepal other timbers have been preferred for building construction, but pine can be used for making inexpensive furniture, and can be used as a general utility timber for packing cases and boxes (Jackson, 1994).

There are some documents that inform the secondary successional processes of native flora under pine plantation in Nepal (Gilmour and Fisher, 1991; Gautam, 1999; Webb and Gautam 2001) and other parts of the world (Geldenhuys, 1997; Keenan, *et al.*, 1997). Past research in Kabhrepalanchok and Sindhupalchok districts has shown that most of the pine plantations in these districts could be converted to natural broadleaf

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forests in the long term if the communities manage them to promote the development of naturally regenerated species (Ingles, 1995). Generally, however, our understanding of the factors and processes affecting recolonization of natural species under pine plantations is limited.

Improved understanding of successional factors and processes may allow us to develop plantation management systems that benefit biodiversity conservation, while improving the availability of required forest products to the forest-dependent communities. Furthermore, as plantations in the hills await scientific management to commence, it is an appropriate time to consider this issue in the management of community forests. This study compares the species richness between pine plantations and natural forests and investigates major factors affecting diversity and density of woody plants in pine plantations within a typical watershed in the Middle Hills of Nepal.

Methods

Study area

The study was carried out in Roshi watershed area of Kabhrepalanchok district in the Middle Hills. Extending between the elevation range of around 540 m to 2,940 m above sea level, Roshi watershed covers an area of 54,336 hectares and exhibits substantial topography including subtropical river valleys, warm temperate hills (where this study was confined), and cool temperate *Mahabharat* mountains (Gautam, 1999). Microclimate varies widely; northern slopes are cooler and moisture than southern slopes (Schmidt *et al.*, 1995).

As in other parts of the Middle Hills, forests in Roshi watershed are generally fragmented except on the higher *Mahabharat* slopes where continuous tracts of forest can be found (Gautam *et al.*, in review). The natural vegetation in most part of the watershed (i.e. warm temperate hills) consists of a mixed broadleaf forest dominated by *Schima wallichi* and *Castanopis* spp. Some *Shorea robusta* forests are found in lower river valleys. Patches of *Pinus roxburghii* occur in southern slopes in lower elevations and *Quercus* spp. forms the dominant vegetation above 1700 m, on the *Mahabharat* mountain (ICIMOD, 1993).

Roshi, is one of the pioneer areas in Nepal to implement community forestry programme. The programme has been receiving continuous support from Australian Agency for International Development since the late 1970s through successive bilateral projects. By the end of 1998, a total of 4,974 hectares public forest in Roshi had been handed over to the 160 Forest User Groups comprising 15,810 households (DFO, 1999a).

Excessive extraction of fuelwood and fodder to meet subsistence needs of the rural households has caused forest degradation (Banskota and Sharma, 1995). The Afforestation Division of the Forest Department in 1960s initiated plantation establishment in these degraded areas but there is hardly any reliable record available about these early plantations. The rate of plantation establishment gained momentum along with the start of bilateral forestry aid project of the Australian government in late 1970s (Ladley, 1995). In between 1976 and 1998, a total 9,481 hectares of plantation had been established in the study area and almost all of these are pine plantations (DFO, 1999b).

The three pine species used in these plantations are *Pinus roxburghii*, *P. patula* and *P. wallichiana;* of these *P. patula* is exotic. Generally planting density for all the species was 1,600 seedling per hectare. Success rate varies widely; the reasons for this have not been determined yet. The size of plantation ranges from less than two hectares up to eighty hectares as a single block (DFO, 1999b). Weeding was done during first 3 or 4 years after planting (DFO staff, pers. comm.); after that there is no evidence of systematic silvicultural treatment in any of these plantations. Most of plantations are now under varying degrees of community protection.

Data collection and analysis

All the field surveys were conducted in January-February, 1999. Plantations were selected for the study principally based on age and size. First, sampling was restricted to plantations in similar climatic conditions. Moreover, since the age of the plantation is an important variable that has an influence on the species richness (Gilmour and Fisher, 1991; Lugo, 1991; Keenan *et al.*, 1997), only mature plantations (≥10 yr. old) were considered. A total of 20 plantation sites were selected and stratified into size (≤5 hectares, i.e. 'small'; ≥10 hectares, i.e. 'large') and aspect (north slope or south slope) groups. Five sites were selected per group: large plantations north (5) and south (5), and small plantation north (5) and south (5). Seven additional plots (five in south and two in north aspects) were established in closed-canopy plantations (canopy closure >75%), in order to investigate the effects of canopy closure on species richness across a wider range of canopy conditions (Table 1). The strategy of selecting equal number of closed canopy plantations in both the aspects, however, was constrained by the unavailability of enough sites in north aspects.

In each site, one belt transect was established in a randomly selected location. The dimensions were 150 m² (50m x 3m), subdivided into ten 5m x 3m quadrats. Within each quadrat, every stem above 1m height was identified to species. Trees, saplings and shrubs ≥5cm dbh were measured for diameter at 1.4 m (dbh). The percent of canopy closure of planted trees was estimated and grouped into quartiles (<25%, 25-50%, 50-75%, >75%; Table 1). Canopy closure is a function of both the density of planted trees as well as the crown size of individual trees. In the absence of baseline information on forest biodiversity in the Middle Hills (Ingles, 1995), nearby natural forests (the least disturbed available) with similar topographic and site conditions were used as control sites, assuming that they represented the original diversity of mixed natural forests for that particular site. Ten belt transects were established in natural forest (five in north and five in south aspects), using the same protocol as in the plantations.

Species-area relationships for plantations and natural forest are calculated. Simple factorial Analysis of Variance and t-tests were run to analyze the effects of plantation size, aspect, and canopy-closure of planted trees on species diversity and density of woody plants, and also to compare the average number of species between plantation and natural forest plots. To avoid the error arising from unequal sample sizes, the seven closed canopy plantation plots were excluded from the t-test comparisons. Rarefaction (Hurlbert, 1971) was used to calculate the number of species expected under different canopy closure if all samples were reduced to a standard size. All analyses were undertaken using SPSS, except for rarefaction, which used the BASIC programme RAREFRAC.BAS of Ludwig and Reynolds (1988).

Results and discussion

Species in pine plantations and natural forests

The number of species per 150 m^2 transect ranged from 2 to 24 plantations, and 15 to 25 in natural forest plots. Overall, natural forest plots exhibited higher richness per unit area than plantations. Among the twenty most common natural regenerating species found in plantations, almost all had some ethnobotanical use to the local communities (Table 2).

A t-test between the richness of plantation and natural forest plots revealed that pine plantations exhibited significantly lower species richness and stem densities than natural forests (Table 3). This difference was attributable to the significant difference on southern plots; northern aspect showed no significance influence on those parameters (Table 4).

These findings support the speculations that the plant diversity found in pine plantations would probably be insufficient to meet diverse needs of the rural community user group members. Moreover, the differences between north and south plots suggest a necessity of further investigation that considers other environmental, technological, socioeconomic, and institutional factors in the analysis, before making firm conclusion regarding the effects of pine plantations on species diversity. As the difference in site condition prior to plantation has influence on regeneration (Gilmour and Fisher, 1991), the history of land use and level of site degradation at the time of planting could be other important variables to consider in future analysis. Such research should be aimed at defining the circumstances under which community forests can be managed for the maximum benefit of the human communities as well as to the supporting ecosystem.

Effect of plantation size, aspect and canopy closure on species richness and stem density

The effect of plantation size, aspect and canopy closure on the species richness and stem density was tested and results are summarized in Table 5. The test shows that aspect and canopy closure of planted trees has significant effect on the number of species per plot. Aspect also has significantly affected the total number of stems. The combined effect was significant for number of species and total number of stems.

For a more in-depth investigation into the effect of plantation-size, aspect and canopy closure on these parameters, t-tests were run between north and south aspect plots, as well as small and large plantation plots separately. Results showed no significant difference in any parameters between small and large size plantations (Table 6), whereas aspect significantly contributed to differences in species richness and stem density in the plantations (Table 7). This shows that aspect significantly affects the successional processes in pine plantations.

Community forest plantations are generally situated as 'islands' within the cultivated agricultural landscape and are of different sizes. The theory of island biogeography suggests that a small forest in the form of island should be poorer in species diversity due to reduced habitat variability, a high extinction rate, barriers to dispersal and altered climatic variability (Mac Arthur and Wilson, 1967). Results of this study, however, do not confirm to the expected result, since species richness and stem densities were not significantly different between small and large plantations. This may be because of high heterogeneity in the shape of the plantation sites in the study area. For example, a plantation in the form of strip over long distance with adjoining natural forest may have higher chances of getting seed and higher habitat variety than a circular plot of the same size.

Alternatively, the arbitrary stratification of "small" and "large" forests (islands) for this study may not have sufficiently spanned the biologically relevant "island" size range or time element in order to reveal this phenomenon. Long term research across a wider size range is probably necessary to test the theory of island biogeography to reforested land in the middle hills.

The difference in diversity between southern and northern aspects is due to the variation in physical condition between these two aspects, which has created two distinct types of habitats each being favorable for certain plant species. Southern slopes are generally exposed to the solar radiation for longer period of the day, and are therefore hotter and drier than northern slopes (Schmidt *et al.*, 1995). Plant species, which can not withstand long dry period, cannot grow in southern aspect, but they can in northern aspect. As the colonization of tree and shrub species is more evident on the moister slopes (Gilmour and Fisher, 1991), northern aspect plantations were found richer in species diversity than southern.

Relationship between species richness and canopy closure of planted trees

To overcome the incompatibility of unequal sample sizes under different canopy closure, rarefaction was used to measure the species richness for plantation plots with different canopy closure. This method calculates the number of species expected from different communities if all samples were reduced to a standard size (Ludwig and Reynolds, 1988). Results of the rarefaction presented in Table 8 show that the expected number of species in a plot, for a given sample size, decreases with an increase in canopy closure of planted trees. The difference, however, gets smaller when the canopy closure crosses 50%. This is most likely due to reduced availability of light in the understorey, and increased competition for nutrition among plants in closed canopy forests. Furthermore, the thick layer of fallen pine needles in a dense pine forest may have prevented the growth of other plants in these sites.

Implications for community forest management

This research is an initial step to evaluate the influence of some of the major factors on the species diversity and stem density of colonizing woody plants under pine plantations in the Middle Hills of Nepal. The findings are expected to be useful in choosing the best management model for community forests that can meet the dual goals of achieving conservation of biological diversity, while at the same time, optimizing economic benefits to the local people managing them. The results suggest that community forest management should take into consideration the following:

- Careful consideration needs to be given while setting management objectives of plantations in the mid hills. Northern aspects are more prone to recolonization of natural broadleaf species, which provides opportunity to establish a more diverse forest on these sites. South slopes, on the other hand, could be more suitable for commercial timber and resin production from pine plantations. This is, however, difficult to generalize without investigating the influence of other biophysical factors (site condition, elevation and choice of species) for the success or failure of pine plantations.
- Except situations, where users wish to manage pine plantations for timber production, silvicultural treatments for pine plantations should be designed to encourage species diversity, especially of indigenous broadleaf species, to meet the diverse needs of the rural households. One way to do this, could be through enrichment planting of broadleaf seedlings, so that when pines are harvested, the seedlings can contribute to the forest regrowth.
- Considering the fact that almost all of the twenty most common woody species found in plantations had some ethnobotanical use, there is the possibility of using wider spacing in pine plantations to favour secondary successional processes of useful native species. Canopy manipulation through appropriate thinning and pruning could be another alternative for enhancement of regeneration.
- Wide variability in species richness between similar sites suggests that the use of *Pinus* species in community forest planting programme should not be viewed from a single perspective. Some pine plantations maintained low species diversity, while others exhibited high species richness, indicating that they help improve the site condition, and thus pave the way for the regeneration of other broadleaf species. This suggests the need to consider users' needs along with the site condition before establishing on handing over plantations as community forests.

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Table 1: Characteristics of 27 plantations surveyed for the species richness and density of recolonizing woody species in Roshi Watershed, Kabhrepalanchok

Site Name	Plantation species	Aspect	Area (ha.)	Est. canopy closure (%)	Est. distance to natural forest (km)	Number of recoloriging species in 150m² transect
Large Plantations						
Amaldol B	*Pinus roxburghii*	N	30.5	25-50	0.10	17
Chindu	*P. patula, P. wallichiana, P. roxburghii*	N	38.1	0-25	0.10	18
Jyalachitti B	*Pinus patula*	N	24.0	0-25	0.10	17
Sharadadevi	*Pinus patula*	N	14.0	50-75	0.10	15
Thalpu	*Pinus roxburghii*	N	52.5	25-50	1.00	18
Amaldol A	*Pinus roxburghii*	S	30.5	25-50	0.10	17
Basuki	*Pinus roxburghii*	S	30.5	50-75	1.00	7
Dhobikhola	*P. patula, P. roxburghii*	S	16.0	0-25	0.02	11
Panauti	*Pinus roxburghii*	S	80.0	25-50	2.00	15
Sanipokhari	*Pinus roxburghii*	S	46.2	0-25	3.00	9
Small Plantations						
Baikiba	*P. patula, P. wallichiana*	N	2.0	0-25	0.10	19
Byankhot B	*Pinus roxburghii*	N	3.2	25-50	0.10	17
Mayaltar	*P. patula, P. wallichiana, P. roxburghii*	N	2.0	0-25	0.10	24
SanoAmaldol	*Pinus roxburghii*	N	2.0	25-50	1.00	19
Sapneswori	*Pinus roxburghii*	N	1.7	25-50	0.07	14
Bhasmebhir	*Pinus roxburghii*	S	3.7	0-25	0.10	4
Byankhot A	*Pinus roxburghii*	S	3.2	25-50	0.10	16
Dhakalpaha	*Pinus roxburghii*	S	2.5	0-25	0.10	17
Kunechaur	*Pinus roxburghii*	S	4.8	0-25	0.30	8
Sallenipakha	*P. patula, P. wallichiana*	S	2.0	0-25	0.10	10
Closed Canopy Plantations						
Thuloban, Tukucha A	*Pinus roxburghii*	N	54.0	>75	0.10	9
Thuloban, Tukucha B	*Pinus roxburghii*	S	54.0	>75	2.00	2
Bause	*Pinus patula*	S	42.0	>75	0.50	5
Gosaikunda	*Pinus roxburghii*	S	39.3	>75	0.10	5
Jyalachitti A	*Pinus patula*	S	24.0	>75	0.05	11
Faskot	*Pinus patula*	N	8.5	>75	1.00	8
Om dada	*Pinus roxburghii*	S	4.5	>75	5.00	4

Table 2: The twenty most common regenerating woody species encountered in pine plantations in Roshi Watershed, Kabhrepalanchok.

Botanical name	Local name	Growth form	Family	Ethnobotanical use	Occurrence (% of plots)
Phyllanthus parvifolius	Khareto	Shrub	Euphorbiaceae		59
Rubus ellipticus	Ainselu	Shrub	Rosaceae	Fruit	55
Schima wallichii	Chilaune	Large tree	Theaceae	Timber, fuel, fodder	55
Pieris ovalifolia	Angeri	Small tree	Ericaceae	Fuel, medicine	37
Myrsine semiserrata	Kalikath	Medium tree	Myrsinaceae	Fuel, medicine, fodder	33
Symplocos pyrifolia	Setikath	Small tree	Symplocaceae	Agricultural implements	30
Myrica esculenta	Kafal	Medium tree	Myricaceae	Fruit, fuel, charcoal	26
Berberis asiatica	Chutro	Shrub	Berberidaceae	Berry, medicine, live hedge	22
Melastoma normale	Chuleshi	Shrub	Melastomaceae	Medicine	22
Lonicera ligustrina	Masino kanike	Shrub	Caprifoliaceae		22
Castanopsis tribuloides	Musure katus	Medium tree	Fagaceae	Timber, fodder, fuel	22
Xylosma controversum	Phalame kada	Small tree	Flacourtiaceae	Charcoal	18
Rhododendron arboreum	Lali gurans	Small tree	Ericaceae	Fuel, charcoal, medicine	18
Eurya acuminata	Jhigaine	Small tree	Theaceae	Fodder, fuel	15
Smilax menispermoides	Kukurdaino	Climbing shrub	Smilaceaceae		15
Rhus parviflora	Pithauli	Shrub	Anacardiaceae	Fruit, medicine, fuel	15
Wendlandia coriacea	Rato kainyo	Small tree	Rubiaceae	Fuel, poles, fodder	15
Cornus oblonga	Lati kath	Medium tree	Cornaceae	Fuel, poles, fodder	11
Syzygium cumini	Jamun	Medium to large tree	Myrtaceae	Timber, dye, fruit	11
Inula cappa	Gaitihare	Shrub	Compositae	Fodder	11

Table 3: Average species richness and density of woody plants between plantation and natural forests in Roshi watershed, Kabhrepalanchok. (Numbers in parentheses refer to standard deviations.)

	Plantation (n=20)	Natural forest (n=10)	t-test significance (equal variances not assumed)
Number of species	14.6 (4.92)	18.6 (3.47)	0.017
Total number of stems	115.2 (63.19)	204.0 (97.59)	0.021
Number of stems ≥5cm dbh	5.5 (5.17)	25.4 (14.32)	0.002

Table 4: Average species richness and density of woody plants between plantation and natural forests in north and south aspect in Roshi Watershed, Kabhrepalanchok. (Number in parentheses refer to standard deviation.)

	Plantation (n=10)	Natural forest (n=5)	t-test significance (equal variances not assumed)
North aspect:			
Number of species	17.8 (2.70)	21.0 (3.16)	0.094
Total number of stems	145.1 (40.78)	249.6 (124.46)	0.134
Number of stems ≥5cm dbh	7.2 (5.31)	24.2 (14.31)	0.055
South aspect:			
Number of species	11.4 (4.6)	16.2 (1.64)	0.012
Total number of stems	85.3 (69.13)	158.4 (27.19)	0.012
Number of stems ≥5cm dbh	3.8 (4.66)	26.6 (15.9)	0.031

Table 5: Effect of plantation size, aspect and canopy closure on the species richness and stem density of woody plants in plantations (n= 27).

	Probability at 95% cc			
	Size of plantation	Aspect	Canopy closure	Combined effect
Number of species	0.165	0.000	0.008	0.000
Total stems	0.232	0.005	0.160	0.020
Stems ≥5 cm dbh	0.263	0.054	0.227	0.115

Table 6: Average number of species and stem density in small and large plantation plots. (Number in parentheses refer to standard deviation).

	Small plots (n=10)	Large plots (n=10)	t-test significance (equal variances not assumed)
Number of species	14.8 (5.9)	14.4 (4.0)	0.862
Total number of stems	118.2 (71.6)	112.2 (57.3)	0.839
Number of stems ≥5cm dbh	6.1 (5.1)	4.9 (5.4)	0.617

Table 7: Average number of species and stem density in north and south aspect plantations. (Number in parentheses refer to standard deviation.)

	North aspect (n=10)	South aspect (n=10)	t-test significance (equal variances not assumed)
Number of species	17.8 (2.7)	11.4 (4.6)	0.002
Total number of stems	145.1 (40.8)	85.3 (69.1)	0.033
Number of stems ≥5cm dbh	7.2 (5.3)	3.8 (4.7)	0.146

Table 8: Results of rarefaction among four canopy closure classes of planted pine trees in Roshi watershed, Kabhrepalanchok (n=27).

No. of individuals	Expected number of species under different canopy closure			
	0-25%	25-50%	50-75%	>75%
10	8	7	6	5
20	12	11	9	7
30	15	13	10	9
40	18	15	11	10
50	20	17	12	11
60	21	18	13	12
70	22	19	14	13
80	24	20	14	14
90	25	21	15	15
100	25	21	15	16
110	26	22	16	16
120	27	23	16	17