A community analysis of sal (*Shorea robusta*) forests in the western Terai of Nepal

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Abstract

Sal (*Shorea robusta*) forest is found in an extensive array of conditions in lowland Nepal, and has been heavily used by both government and local people. Thus, we did a study to provide information on sal forests occupying a broad range of historical and environmental influences across an extensive range in the western Terai of Nepal and explore factors – both environmental and anthropogenic – that may be responsible for variation of forest structure.

Trees, saplings, seedlings and shrubs were sampled along transects (2 km long) in two protected areas and two proposed community forests. The protected areas had three transects each, and a single transect covered two proposed community forests. Samplings were done every 200 m along the transects, a plotless technique sampled trees (>5 cm dbh). With tree sampling point as the center, shrubs and saplings (1–5 cm dbh and >1 m height) were sampled in 5 m radius circular plots and herbs and seedlings (<1 m height) were sampled in 1 m^2 circular plots nested within shrub plots. Altogether 131 species were recorded: 28 trees, 10 shrubs, 6 climbers and 87 herbs. The mean density across all plots was 220 trees/ha and the average basal area was 13.2 m^2/ha. Three different associations of sal forest were identified by cluster analysis. Community types distinguished in the classification analysis were clearly separated in the site ordination. None of the environmental variables measured (pH, percent organic matter, total nitrogen, available phosphorous, available potassium and soil texture) explained the distribution of plots in the site ordination. We concluded that rainfall and past disturbances (fire and anthropogenic use) are mainly responsible for different community types. Community types were different in structure and composition, thereby representing unique entities. The protection and maintenance of each of the different communities through forest management is important for biodiversity conservation.
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1. Introduction

As recently as the 1950s, forests covered almost 75% of the Terai (the subtropical lowlands) in central and western Nepal (Joshi, 2002). Due to the importance of these forests for both commercial and subsistence purposes (Webb and Sah, 2003), however, heavy human pressures reduced forested area to less than 50% of the total land area in Terai by 1988, resulting in degradation and fragmentation of historically contiguous land-scapes, and posing threats to biodiversity conservation and local livelihoods. In such a human dominated environment, baseline

ecological information on the remaining forests is necessary in order to develop effective management and planning strategies.

Subtropical lowlands affected by monsoonal climatic regimes typically support seasonal broad-leaved forest (Wesche, 1997). More than half of the Terai in Nepal is under such forest cover, dominated by *Shorea robusta* (locally known as sal) (Webb and Sah, 2003). *S. robusta* (Dipterocarpaceae) is a light-demanding tree that grows to 45 m in height and frequently forms a nearly monospecific canopy (Rautiainen and Suoheimo, 1997). *S. robusta* is semi-deciduous species (Pandey and Shukla, 2001) and grows in a broad range of well-drained soils (Dinerstein, 1979; Banerjee et al., 1992). Due to the low ground water table and porous soils in the region the soil surface is rarely inundated during the monsoon period (Bolton, 1976).

In Nepal, sal is considered the most valuable tree species. It is used in construction and carpentry work, and is the main

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source of fuelwood in the Terai. Sal leaves are valuable as fodder and for making disposable plates (Jackson, 1994). Most of Nepal's rural communities, which constitute 80% of the total population of the country (World Resources Institute, 1996), depend on sal forest for subsistence needs. Local people collect fodder, firewood, poles, timber and wild vegetables (ferns, mushrooms, medicinal plants, etc.) from these forests. Sal forests are also important for the landscape level conservation in the Nepalese terai because they occupy a larger percentage of area outside protected areas that are proposed wildlife corridors of Terai Arc Landscape program (HMGN, 2004).

Vast tracts of *S. robusta* forest in Nepal remained unutilized before the 1950s. Conditions changed once migration into the fertile Terai began, spurred on by the eradication of malaria in the late 1950s, establishment of resettlement offices in the districts, construction of the east–west highway (fully completed in the 1990) and political disturbances in the mountains more recently (HMGN, 1996, 1998). Sal forests, since then and until now are subjected to extensive logging, used heavily for fodder, fuelwood and firewood, and burned frequently to promote grassy undergrowth for livestock grazing. Realizing the importance of conserving natural areas, the government established protected areas during 1970s. Some sal forest after this came under strict protection thereby changing the nature of disturbances. Even after the establishment of protected areas, some kind of consumptive uses are allowed (Heinen, 1993). In most of the Terai protected areas, park authorities permit local people to collect thatch twice a year. In addition to this, people have collected fodder and fuelwood illegally (Heinen, 1993), however, illegal activities have been limited after the protection.

Despite their widespread occurrence and importance from both economic and ecological points of view, little information exists on ecological aspects of sal forest. Past studies on the forests and flora of Nepal (Stainton, 1972; Dobremez, 1976), a few floristic studies conducted inside protected areas (Dinerstein, 1979; Shrestha and Jha, 1997; Sharma, 1999) and a study in central Nepal (Wesche, 1997) provide information on sal forest, but there is a dearth of information regarding their condition in the western Terai, which receives lower rainfall than other parts of lowland Nepal.

Structure, composition and function are the three important attributes of forest ecosystems. These attributes change in response to climate, topography, soil and disturbances—human induced and natural. The above-mentioned factors along with forest succession are also responsible for both local (within stand) and landscape level variation in forest attributes, thereby producing spatial heterogeneity. In the western Terai of Nepal, the length of monsoon, total rainfall, seasonal flooding and soil conditions, and other factors such as grazing, clearing for cultivation, burning, selective cutting, logging and lopping have been considered as factors modifying vegetational composition and succession (Dinerstein, 1979).

The present study provides important information on the structure, composition, and dynamics of sal forests with alternative management histories, some that have undergone almost three decades of protection and others that have experienced constant human influence. Both are crucial for
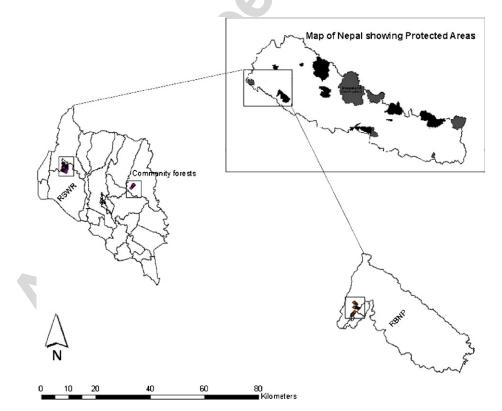

Fig. 1. Map of the study area showing Royal Bardia National Park (RBNP) and Kanchanpur District which includes Royal Suklaphanta Wildlife Reserve (RSWR) and proposed community forests (PCFs) sampled. Study sites are shown in boxes.

landscape level conservation of forest-dependent biodiversity in the Nepal Terai. Our objective is to report on the floristic composition and structure of sal forests of the western Terai region and to explore factors both anthropogenic and environmental that may responsible for variation among forest stands.

2. Study area

To encompass forests under different management regimes, we selected three sites in western Nepal: two inside protected areas and a third that included two proposed community forests (PCFs). The protected area sites were in Royal Bardia National Park (RBNP) in Bardia District and Royal Suklaphanta Wildlife Reserve (RSWR) in Kanchanpur District of far western Nepal, while the PCFs were the Birendra and Mayur Jagdamba forests, also in Kanchanpur District (Fig. 1). The two protected areas were approximately 150 km apart and the PCFs were about 10 km east of RSWR and more than 130 km west of RBNP. All three areas were at similar elevation (range 150–220 m) and on alluvial flat land, commonly referred to as Terai.

Royal Bardia National Park (28°35′N, 81°20′E; Fig. 1) is currently 968 km² in size, and is the largest park in the Terai. The physiography of the park consists of Bhabar, Terai and Riverine Flood Plains. Most of the park lies in the Bhabar zone, consisting of rocks, boulders and sand interbedded with clay and silt driven down from Churia hills to the north. Soils in this zone are young, shallow, and very prone to erosion while the Terai zone is composed of deep alluvial soils. The vegetation of the park ranges from early successional grasslands on alluvial flood plains to climax sal community in the relatively dry flatlands. The climate of the area is subtropical monsoonal. Four distinct seasons occur: winter, spring, summer and rainy. Rainfall recorded in 1987–2001 at Chisapani Station adjacent to RBNP is highly seasonal, the mean total annual rainfall between the periods was 2100 mm. Most rain occurs between the months of June and September followed by 7–8 months of dry season.

Royal Suklaphanta Wildlife Reserve (28°45′–28°57′N, 80°07′–80°21′E) covers an area of 305 km² near the western border of Nepal. Most of the reserve is classified as Terai, although some areas lie in the Bhabar zone. Its vegetation includes forests, grasslands and wetlands. Sal forest is the dominant forest type in the reserve. The climate of the region is much like that of RBNP, except that it receives only about 75% of the annual precipitation as the latter.

The proposed community forests sampled were located in Bank, Kanchanpur District. Birendra and Mayur Jagdamba community forests lie north of the east–west highway and slightly east of RSWR (28°52′N, 80°25′E). The forest types present are sal forest dominated by *S. robusta* and *Terminalia tomentosa*. It has similar climate as Royal Suklaphanta Wildlife Reserve.

3. Methods

A total of seven transects were used for sampling vegetation and each transect was 2 km long. Three transects each were established in RBNP and RSWR, and a single transect was established that encompassed both PCFs. Sampling locations were established every 200 m along each transect; thus, 30 locations were sampled in RBNP, 30 in RSWR and 10 in the PCFs. Starting points of the transects were selected randomly along fire lines in the protected areas and along the east–west highway adjacent to the community forests. Sampling was conducted between February and April 2004. Tree species were sampled in three stata: trees (>5 cm DBH), saplings (1–5 cm DBH and >1 m height) and seedlings (<1 m height). Shrubs and herbs were also sampled.

Sampling of trees employed a plotless technique (variable plot cruising: Grosenbaugh, 1952). With the sampling point as center, all nearby trees were observed through a prism of known diopter. A tree was counted "In" if its diameter at breast height was large enough to subtend the fixed critical angle of the prism, or "Out" if it was not. Each "In" tree was identified to species and diameter at breast height (DBH; 1.3 m above the ground) was measured. The height of the three tallest trees was also measured with a clinometer. Using the diameter of "In" trees, basal area and density were estimated for each sampling point and later converted to an areal basis (per ha). Since further analysis of tree data was done on per ha basis, plots instead of points are used when referring to trees. Tree height was measured for the three tallest trees in each sampling point. For saplings and shrubs, 5 m radius circular plots were established with the tree sampling point as the center. Within each plot, saplings and shrubs were identified to species and the number of individuals of each species was counted. Herbs and seedlings were sampled in two 1 m² circular plots nested within shrub plots. Herbs and seedlings were also identified to species and their numbers within each plot were estimated.

Soils collected from 0 to 15 cm depth at four fixed locations in each plot were bulked in a polyvinyl bag and analyzed at the laboratory of Department of Agriculture, Lalitpur, Nepal. pH, texture, organic matter (%), total nitrogen (%), available phosphorous (kg/ha) and available potassium (kg/ha) were determined for each sample following methods described in Bray and Kurtz (1945), Jackson (1958) and Hesse (1994).

4. Data analysis

Density and basal area per ha were calculated for all tree species. Relative values of frequency, density and dominance of trees were calculated by dividing individual values for frequency, density and basal area by the sum of frequencies, densities and basal areas of all species in a plot, then multiplying by 100. An importance value index (IVI) was calculated for all the tree species by summing its relative frequency, density and dominance values. Densities of shrubs, saplings, seedlings and herbs were also calculated on a per ha basis.

Species richness, evenness and Shannon's diversity index (H') were calculated for each plot following methods described in PC-ORD statistical package (McCune and Mefford, 1999). The diversity measures were calculated separately for different life forms: trees, saplings, shrubs, seedlings and herbs. Numbers of species per plot was taken as a measure of species richness.

Hierarchical agglomerative cluster analysis (McCune and Grace, 2002) was applied to define groups among the 70 plots sampled. Cluster analysis was performed using the importance value of tree species, and the results were presented in a dendrogram. In the classification process, Sorensen (Bray-Curtis) dissimilarity was the distance measure and the flexible beta method was used to determine relatedness among groups (McCune and Grace, 2002). Species that occurred in less than 5% of the samples were eliminated from the analysis. Two sites/plots were also determined to be outliers on the basis of very low importance value of *S. robusta* for the first plot, and absence of Shorea along with several other species for the second. Theses plots did not sort with any of the major groups in the classification analysis and appeared as outliers in the NMS ordination (described below). To prevent distortion of the structure of the classification and ordination analyses, these sites were removed from further analysis. Removing the outliers left 68 plots and 18 species for analysis. The final groupings were those defined in the dendrogram when approximately 40% of information was unexplained, according to the Wishart objective function.

We analyzed the interrelationships between plant communities by ordinating sample plots using non-metric multidimensional scaling (NMS). The advantages of NMS over other ordination techniques are: (1) it is not based on the assumption of multivariate normality, and (2) it is robust to large numbers of zero values (Minchin, 1987). The ordination with low stress value, which measures the relationship of distance in original *p*-dimensional space with distance in reduced *k*-dimensional ordination space, was used for final analysis. Lower the stress value, the better the ordination. We examined relationships between plant communities and environmental variables by overlaying and contouring environmental variables on the NMS ordination of plots. Correlations between ordination scores and environmental variables were calculated with Pearson's *r* (Peterson and McCune, 2001). The PC-ORD statistical package was used for both cluster analysis and ordination. Differences in environmental variables among groups were tested with one-way analysis of variance if the data were normal. If the data were not normal and the assumption of equal variance was violated, we used the Kruskal–Wallis test statistic (Sokal and Rohlf, 1995). We also used Kruskal–Wallis to test the difference among associations identified by ordination in parameters related to trees, saplings, shrubs, seedlings and the ground layer. A

one-tailed Mann–Whitney *U*-test was used for multiple comparisons when the overall tests proved significant.

5. Results

5.1. Average forest structure and composition

Altogether, 131 species were recorded: 28 trees, 10 shrubs, 6 climbers and 87 herb species. The forest canopy was dominated by *S. robusta* and *T. tomentosa*. Occasionally *Adina cordifolia* and *Terminalia bellirica* were present in the canopy. The subcanopy was dominated by *Buchanania latifolia*, *Dillenia pentagyna*, *Cleistocalyx operculatus* and *Lagerstroemia parviflora*. The understory was quite sparse and dominated by *S. robusta* saplings and shrubs such as *Flemingia strobilifera*, *Clerodendrum viscosum* and *Indigofera pulchella*. The mean density across all plots was 220 trees/ha (Table 1). The highest tree density was recorded for *S. robusta* (64 stems ha^{-1}), followed by *B. latifolia* (50 stems ha^{-1}), *C. operculatus* (25 stems ha^{-1}), *L. parviflora* (22 stems ha^{-1}), *T. tomentosa* (16 stems ha^{-1}) and *D. pentagyna* (11 stems ha^{-1}). The average basal area across all plots was 13.2 m^2/ha (Table 1), the minimum was 3.4 m^2/ha (RSWR) and the maximum was 22 m^2 (PCFs). The species with the highest overall basal area was *S. robusta* (9 m^2/ha) followed by *T. tomentosa* (2 m^2/ha) and other species covered less than 1 m^2/ha. The minimum tree height for the tallest trees was 20.7 m and the maximum was 42 m, with a mean tree height of 28.5 m. More than 80% of the tallest trees were *S. robusta* and *T. tomentosa*. Other trees that were present in this category were *A. cordifolia*, *T. bellirica*, and *Syzygium cumini*. Altogether, there were 3.6 tree species per sample point and the Shannon's diversity index (*H'*) for trees was 0.82.

5.2. Classification

The hierarchical agglomerative cluster analysis distinguished three groups/associations (Fig. 2) among the 70 plots sampled (68 plots used for the analysis). These associations are described below.

5.3. S. robusta–B. latifolia association

Group 1, the *S. robusta–B. latifolia* association, was represented by 18 sites/plots (Table 1). Five sites in this

Table 1
Summary of forest structure across all plots and different associations of sal forest

	Tree				Sapling		Seedling	
	No. of sites	Density (trees/ha)	Basal area (m²/ha)	No. of species	Density (plants/ha)	No. of species	Density (plants/ha)	No. of species
Across all plots	68	220 (13–993)[a]	13.2 (3.4–22)[a]	28	1798	17	79,072	25
Group 1	18	289 (21–948)	12.8 (5.7–18.3)	21	2851	14	57,778	11
Group 2	13	297 (13–938)	13.5 (6.8–18.3)	19	2753	13	70,769	7
Group 3	37	163 (13–993)	13.7 (3.4–22)	18	1019	11	94,189	14

Group 1 (*Shorea robusta–Buchanania latifolia*), Group 2 (*Terminalia tomentosa–S. robusta*) and Group 3 (*S. robusta–C. operculatus*).
[a] Numbers in parentheses indicate range of density (trees/ha) and basal area (m²/ha).
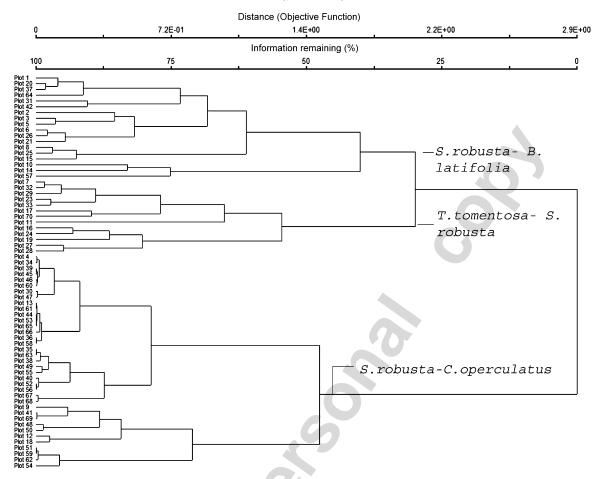
Fig. 2. Dendrogram showing the different associations identified by the hierarchical agglomerative cluster analysis based on importance value of trees.

association were from the RSWR and one site was from the PCFs. Twenty-one species of trees were present in this association (Tables 3 and 4). Ten were relatively abundant and the remaining 11 species had frequencies less than 11%. *Engelhardtia spicata*, *Ficus benghalensis*, *Holarrhena pubescens*, and *Acacia catechu* were present exclusively in this association. Mean tree density in this association was 289 trees/ha (minimum, 21 trees/ha; maximum, 948 trees/ha), while mean basal area was 12.8 m^2/ha (minimum, 5.7 m^2/ha; maximum, 18.3 m^2/ha) (Table 1). *B. latifolia* had the highest density followed by *S. robusta*, while *S. robusta* (mean basal area, 6.2 m^2/ha) was the dominant species in terms of basal area (Tables 3 and 4).

5.4. T. tomentosa–S. robusta association

Group 2, the *T. tomentosa–S. robusta* association, was present at 13 sites. Two sites in this association were from the RSWR and a site was from the PCFs. *Anogeissus latifolius*, which was present in Group 1, was absent in this group. Nineteen species of trees were present in the *T. tomentosa–S. robusta* association (Tables 3 and 4); seven were abundant and the rest had frequencies <15%. Species such as *Picrasama javanica*, *Desmodium oojeinense* and Paruli (local name) were present exclusively in this group. Mean tree density in this

association was 297 ha^{-1} (minimum, 13 trees/ha; maximum, 938 trees/ha), while mean basal area was 13.5 m^2/ha (minimum, 6.8 m^2/ha; maximum, 18.3 m^2/ha) (Table 1). *S. robusta* and *T. tomentosa* were the dominant species in terms of basal area, representing 5.1 and 4.5 m^2/ha, respectively (Table 4). Other species comprised less than 1 m^2/ha basal area.

5.5. S. robusta–C. operculatus association

Group 3, the *S. robusta–C. operculatus* (*Eugenia operculata*) association, was found at 37 sampling locations. Six sites in this association were from the RBNP and the remaining sites were from the RSWR and the PCFs. *S. robusta* was highly dominant in the group (Table 2), which included a total of 19 species (Tables 3 and 4). Four species were abundant and the remaining 14 species had frequencies of less than 9%. Jingar (local name) was present exclusively in this group. *Semecarpus anacardium*, which was present in the other two groups, was completely absent from Group 3. Mean density of trees was 163 trees/ha (minimum, 13 trees/ha; maximum, 993 trees/ha), while mean basal area was 13.7 m^2/ha (minimum, 3.4 m^2/ha; maximum, 22 m^2/ha) (Table 1). *S. robusta* (94 trees/ha) had the highest density of trees followed by *C. operculatus* (31 trees/ha). Other species had densities of less than 6 trees/ha. *S. robusta* was the dominant species

Table 2

Importance value of trees for the three different groups (associations) identified by cluster analysis

Species	Group 1	Group 2	Group 3
S. robusta	81.7	74.2	178.69
Dillenia pentagyna	24.46	19.62	9.76
T. tomentosa	28.07	81.44	22.56
B. latifolia	37.55	32.53	4.81
Anogeissus latifolius	3.56	0	1.22
Myrsine semiserrata	16.88	20.08	1.21
Mallotus philippensis	4.63	9.24	6.92
Largerstroemia parviflora	19.84	13.68	4.74
Schleichera oleosa	4.86	2.05	1.39
C. operculatus	29.39	2.42	27.32
Adina cordifolia	1.58	5.07	4.52
Syzygium cumini	2.67	3.3	3.61
Anthocephalus chinensis	2.2	4.09	0.28
Semecarpus anacardium	8.25	4.41	5.77
Terminalia bellirica	1.4	4.49	3.23

Group 1 (*S. robusta–B. latifolia*), Group 2 (*T. tomentosa–S. robusta*) and Group 3 (*S. robusta–C. operculatus*).

Table 3

List of trees species and their density (stems ha^{-1}) in different groups (associations)

Species	Density (stems ha^{-1})		
	Group 1	Group 2	Group 3
S. robusta	33	24	94
D. pentagyna	20	16	4
T. tomentosa	8	46	3
B. latifolia	110	96	5
A. latifolius	0.5	–	0.1
M. semiserrata	21	46	0.45
M. philippensis	5	2	4
L. parviflora	31	42	11
S. oleosa	1.3	0.17	0.11
C. operculatus	30	3	31
A. cordifolia	0.15	0.23	0.84
S. cumini	1.58	0.59	0.46
A. chinensis	–	1.09	0.076
S. anacardium	20	6	–
T. bellirica	0.85	0.81	0.94
Picrasama javanica	–	0.28	–
Engelhardia spicata	0.43	–	–
Desmodium oojeinense	–	0.62	–
Paruli[a]	–	1.96	–
Careya arborea	1.05	6	5
Ficus beghalensis	0.4	–	–
Butea monosperma	1.02	–	0.58
Holarrhena pubescens	2.09	–	–
Acacia catechu	1.07	–	–
Zizyphus sps.	0.46	0.58	2.01
Ban ritha[a]	–	–	0.05
Jingar[a]	–	–	0.20
Spatholobus parviflorus[b]	0.35	2.58	–

Group 1 (*S. robusta–B. latifolia*), Group 2 (*T. tomentosa–S. robusta*) and Group 3 (*S. robusta–C. operculatus*).

[a] Local name.

[b] Climber.

Table 4

List of trees species and their basal area (m^2/ha) in different groups

Species	Basal area (m^2/ha)		
	Group 1	Group 2	Group 3
S. robusta	6.25	5.12	10.89
D. pentagyna	0.83	0.53	0.25
T. tomentosa	1.47	4.50	0.81
B. latifolia	0.89	0.79	0.12
A. latifolius	0.13	–	0.03
M. semiserrata	0.32	0.53	0.03
M. philippensis	0.13	0.18	0.13
L. parviflora	0.45	0.35	0.06
S. oleosa	0.19	0.09	0.03
C. operculatus	1.02	0.09	0.40
A. cordifolia	0.06	0.18	0.09
S. cumini	0.06	0.09	0.12
A. chinensis	–	0.09	0.03
S. anacardium	0.13	0.09	–
T. bellirica	0.13	0.18	0.22
P. javanica	–	0.09	–
E. spicata	0.06	–	–
D. oojeinense	–	0.09	–
Paruli[a]	–	0.18	–
C. arborea	0.13	0.09	0.25
F. beghalensis	0.06	–	–
B. monosperma	0.13	–	0.09
H. pubescens	0.06	–	–
A. catechu	0.13	–	–
Zizyphus sps.	0.06	0.09	0.09
Ban ritha[a]	–	–	0.03
Jingar[a]	–	–	0.03
S. parviflorus[b]	0.13	0.18	–

Group 1 (*S. robusta–B. latifolia*), Group 2 (*T. tomentosa–S. robusta*) and Group 3 (*S. robusta–C. operculatus*).

[a] Local name.

[b] Climber.

(mean basal area 10.89 m^2/ha; Table 4) with the basal area ranging from 2.2 to 19.5 m^2/ha. All the other species had basal area less than 1 m^2/ha.

5.6. Forest–environment relationships

The NMS ordination of the tree data yielded a two-dimensional solution with a low stress value of 10.2 (Fig. 3). Community types distinguished in the classification analysis were clearly separated in the site ordination. Axis 1 separated the *T. tomentosa–S. robusta* association from the *S. robusta–B. latifolia* and *S. robusta–C. operculatus* association. The *S. robusta–C. operculatus* association was distinguished from the other two groups on Axis 2. Contour plots of environmental factors (pH, percent organic matter, total nitrogen, available phosphorous, available potassium and soil texture) superimposed on the NMS site ordination did not suggest a strong relationship between any of the measured variables and forest composition. Pearson's correlation showed that Axis 1 was significantly correlated with pH and available phosphorous ($p < 0.05$), but the correlation was weak ($r = -0.26$ and 0.28, respectively). None of the environmental variables was significantly correlated with Axis 2. One-way ANOVA and Kruskal–Wallis tests likewise indicated no statistically
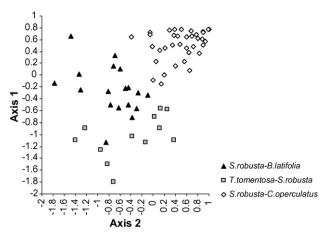
Fig. 3. Site scores from two axis non-metric multidimensional scaling (NMS) ordination, based on importance value of trees.

Fig. 5. Diameter distribution of trees (>5 cm DBH) for *Shorea robusta–Buchanania latifolia* association (Group 1).

significant differences in the measured environmental variables among groups ($p > 0.05$).

5.7. Structure and composition

The diameter distribution of trees across all 70 plots is presented in Fig. 4. The pooled diameter distributions show an uneven size structure, with monotonically decreasing density with increasing tree size up to the largest DBH class, which comprised a secondary peak in density. The peak in the largest DBH class resulted in part from inclusion in that class of all the trees greater than 40 cm. *S. robusta* was present in all DBH classes but was especially well represented in very small (5–10 cm) and very large (>30 cm) DBH classes. Its highest density was in the >40 cm DBH class. *T. tomentosa* was completely absent from the lowest DBH class, but was present in other DBH classes in low numbers. The most abundant species in the 5–10 cm DBH class was *B. latifolia* (47%) followed by *L. parviflora* and *C. operculatus*. Species such as *B. latifolia*, *C. operculatus*, *L. parviflora* and *D. pentagyna* were more abundant in the <30 cm DBH classes and rare in classes
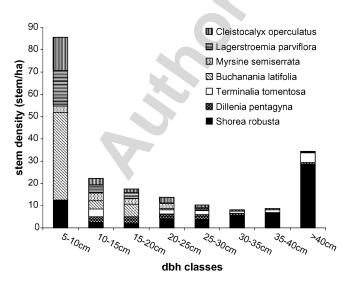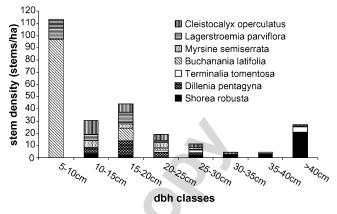
above 30 cm—across all plots, these species exhibited a stable population size structure indicated by a reverse *J* or negative exponential distribution.

The relative abundance of large trees is an important feature of these forests. The largest DBH classes were represented by *S. robusta* and *T. tomentosa*. Density of *S. robusta* in >50 cm DBH was 16 trees/ha, among which 2 trees/ha exceeded >80 cm DBH. On average, the density of very large (>50 cm DBH) *T. tomentosa* was 3 individuals/ha, and *A. cordifolia*, *T. bellirica* and *S. cumini* occasionally reached these sizes.

All three of the forest associations exhibited a multimodal size structure, with concentrations of trees in the smallest and largest size classes (Figs. 5–7). Nearly 40% of the trees in each community represented the lower diameter classes (<10 cm), while the 30–40 cm trees were sparse in each. In the *S. robusta–B. latifolia* and *T. tomentosa–S. robusta* association common in RBNP, *S. robusta* was absent in the lower DBH classes, and very few in number (<5 trees/ha) in the middle DBH classes, but in the *S. robusta–C. operculatus* association it was well represented in all the DBH classes.

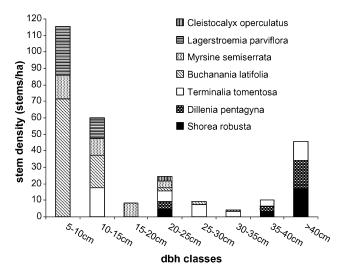Fig. 4. Diameter distribution of trees (>5 cm DBH) across all plots.

Fig. 6. Diameter distribution of trees (>5 cm DBH) for *Terminalia tomentosa–S. robusta* association (Group 2).
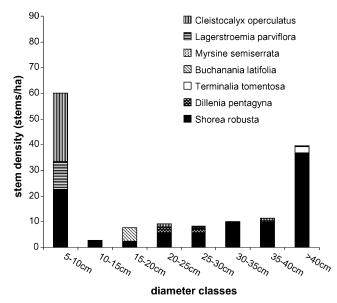
Fig. 7. Diameter distribution of trees (>5 cm DBH) for *S. robusta–Cleistocalyx operculatus* association (Group 3).

We recorded saplings of 16 tree species. *Grewia* sp., *Cassia fistula* and Kaphale (local name) were absent in the tree layer but present as saplings, and *Mallotus philippensis* was abundant as a sapling compared to its abundance in the tree layer (Table 5). Across all plots, mean sapling density was 1798 plants/ha (Table 1). Mean sapling density per ha for *S. robusta–B. latifolia* and *T. tomentosa–S. robusta* forests were similar (2851 and 2753 stems ha^{-1}, respectively), but mean sapling density in *S. robusta–C. operculatus* was less than half as much (1019 stems ha^{-1}). The Kruskal–Wallis test showed a significant difference in sapling density between groups ($\chi_2^2 = 12.53$, $p < 0.01$), but pairwise comparisons showed that only *S. robusta–B. latifolia* and *S. robusta–C. operculatus*

differed significantly ($z = 3.48$, $p < 0.01$). These community level results were largely attributable to *S. robusta* saplings, which were most abundant in *S. robusta–B. latifolia* and *T. tomentosa–S. robusta* forests (Table 5). Like sapling density, sapling species richness also exhibited significant differences among forest types ($F = 5.58$, $p < 0.01$). Again, species richness was higher in *S. robusta–B. latifolia* than *S. robusta–C. operculatus*, but other pairwise differences were non-significant. Among important tree species, we did not observe significant difference in sapling density between the forest types except for *S. robusta*. Another interesting finding was the absence of *B. latifolia* saplings in *S. robusta–C. operculatus* community.

Seedlings of 21 tree species were recorded. Mean seedling density was 79,072 ha^{-1} (Table 1), with the vast majority *S. robusta* (70,462 ha^{-1}). Among other important canopy and subcanopy species, *M. philippensis* (1500 ha^{-1}), *B. latifolia* (1071 ha^{-1}), *C. operculatus* (571 ha^{-1}), *T. tomentosa* (574 ha^{-1}), *L. parviflora* (357 ha^{-1}) and *D. pentagyna* (214 ha^{-1}) were well represented as seedlings. *Aegle marmelos*, a species which we did not observe in the tree or sapling stage, was present as seedlings in *T. tomentosa–S. robusta* forests. *S. robusta* seedlings were present in high densities in all forest types, but were maximum in *S. robusta–C. operculatus* forests (Table 6). The total number of species recorded in the seedling layer was also highest in these forests (12 species), with the fewest species (7) found in *T. tomentosa–S. robusta* forests. In the latter forest type, *Shorea*, *Cleistocalyx* and *Buchanania* were the most common species in the seedling layer; no seedlings of *T. tomentosa*, the dominant tree species, were present.

Table 5
List of saplings and density (stems ha^{-1}) in different groups (associations)

Species	Density (stems ha^{-1})		
	Group 1	Group 2	Group 3
S. robusta	2045.16	1969.49	278.86
L. parviflora	56.61	78.39	24.10
B. latifolia	77.84	137.18	–
C. operculatus	99.07	107.78	79.18
P. javanica	14.15	29.40	6.89
M. philippensis	134.46	205.77	82.62
H. pubescens	56.61	–	210.00
Zizyphus sps.	120.30	88.19	89.51
E. spicata	113.23	29.40	–
S. anacardium	21.23	–	–
Grewia sps.	92.00	9.80	213.45
S. oleosa	7.08	9.80	3.44
S. cumini	–	–	3.44
Cassia fistula	7.08	29.40	–
D. pentagyna	–	9.80	–
Kaphale[a]	7.08	29.40	27.54

Group 1 (*S. robusta–B. latifolia*), Group 2 (*T. tomentosa–S. robusta*) and Group 3 (*S. robusta–C. operculatus*).
[a] Local name.

Table 6
List of seedlings and their density (plants/ha) in different groups (associations)

Species	Density (plants/ha)		
	Group 1	Group 2	Group 3
S. robusta	49166.67	61538.46	87432.43
P. javanica	2222.22	–	–
S. oleosa	555.56	769.23	405.41
M. philippensis	555.56	1923.08	1891.89
Aegle marmelos	–	384.62	–
S. cumini	–	–	270.27
T. tomentosa	277.78	–	945.95
B. latifolia	1111.11	2692.31	–
Unidentified	–	384.62	–
C. operculatus	–	3076.92	405.41
S. anacardium	1111.11	–	–
D. oojeinense	555.56	–	–
E. spicata	1388.89	–	–
D. pentagyna	–	–	135.14
L. parviflora	277.78	–	540.54
Unidentified	–	–	135.14
Careya aroborea	–	–	270.27
Unidentified	–	–	675.68
Zizyphus sps.	555.56	–	810.81
Ficus benghalensis	–	–	135.14
H. pubescens	–	–	135.14

Group 1 (*S. robusta–B. latifolia*), Group 2 (*T. tomentosa–S. robusta*) and Group 3 (*S. robusta–C. operculatus*).

Table 7
Mean sapling and shrub species richness per plot (S) and Shannon's diversity index (H′) and mean shrub density (plants/ha)

Groups	Sapling		Shrub		
	S	H′	S	H′	Density
All sampled forests	2.4	0.56	0.69	0.11	338
Group 1	3.2	0.69	0.83	0.346	467
Group 2	2.3	0.52	0.80	0.085	363
Group 3	2.0	0.52	0.60	0.082	265

Table 8
List of shrubs and shrub density (plants/ha) in the different groups (associations)

Species	Density (plants/ha)		
	Group 1	Group 2	Group 3
Flemingia strobilifera	254.76	215.57	82.62
Callicarpa macrophylla	14.15	–	0.00
Indigofera pulchella	35.38	117.58	20.66
Phyllanthus sp.	148.61	–	–
Flemingia chappar	–	29.40	6.89
Clerodendrum viscosum	7.08	–	86.07
Hedyotis sp.	7.08	–	–
Elsholtzia blanda	–	–	37.87
Pogostemon benghalensis	–	–	27.54
Grewia sp.	–	–	3.44

Group 1 (*S. robusta–B. latifolia*), Group 2 (*T. tomentosa–S. robusta*) and Group 3 (*S. robusta–C. operculatus*).

Altogether, we recorded 10 species of shrub (Table 8). Shrub cover was sparse, and density was only 338 plants/ha. Species richness and Shannon's diversity index were both low in all three forest types (Table 7). *F. strobilifera* was the most abundant shrub species in the *S. robusta–B latifolia* and *T. tomentosa–S. robusta* forest types, but *C. viscosum* was the most abundant shrub in the *S. robusta–C. operculatus* type (Table 8).

We recorded 87 different species in the ground layer. There were 65 forbs, 20 grasses, 2 sedges, 1 orchid and 1 pteridophyta. Species richness averaged 4.38 taxa per plot, and Shannon's diversity index was 0.98. Plots in the *S. robusta–C. operculatus* type were richest in terms of species in the ground layer (Table 9), but we found no significant difference in per plot species richness ($\chi^2 = 3.27$, $p = 0.19$) or Shannon's diversity index ($\chi^2 = 1.25$, $p = 0.53$) among types. *Imperata cylindrica* was the most abundant species in the herb layer in all groups. Other species of grass such as *Desmostachya bipinnata* and

Table 9
Different life forms in the ground layer for different groups (associations)

Life forms	Group 1	Group 2	Group 3
Forbs	39	22	43
Grass	14	13	19
Sedge	2	1	1
Orchid	1	1	1
Pteridophyta	1	1	1

Group 1 (*S. robusta–B. latifolia*), Group 2 (*T. tomentosa–S. robusta*) and Group 3 (*S. robusta–C. operculatus*).

Vetiveria zizanoides were also abundant. Among forbs, *Evolvulus nummularis*, *Justicia procumbens* and *Ageratum houstoniaum* were abundant. Twenty-eight percent of the total recorded species were present in all three forest types.

6. Discussion

Stainton (1972) described sal forests as species-poor. The low Shannon's diversity index and per plot species richness we observed for different life forms support this characterization. Likewise, our observations of relatively low stem density (220 trees/ha) are consistent with other studies that show sal forest to be a relatively open assemblage. Densities reported by Shrestha and Jha (1997) (348 trees/ha) in RBNP and Pandey and Shukla (2003) (408 trees/ha) in Gorakhpur India somewhat exceeded our overall mean, but Rautiainen (1999) measured similar densities (152–264 trees/ha) in pure, >80 year old sal forest in the Bhabar–Terai zone of Nepal. Based on the low overall density and large height and diameter of dominant trees, our stands are considered mature forest.

Average basal area of 13 m²/ha was low compared to Terai *S. robusta* forest (36 m²/ha) of RBNP (Shrestha and Jha, 1997). The upper limit for basal area in our study (22 m²/ha) was within the range 16.0–61.1 m²/ha reported by Singh et al. (1995) in Corbett National Park, India. The low basal area observed in our study area resulted from very low stocking among the mid-size classes (i.e., 10–40 cm DBH) despite the presence of some very large trees. The absence of mid-size trees was unlikely to have resulted from suppression by individuals comprising the canopy, which was itself relatively open. Instead, such a diameter structure points in this case to human disturbance as a root cause. The widespread human use of the forests before the 1970s prevented regeneration and establishment and trees reaching the mid-size class during the sampling period will be the ones that regenerated before the 1970s.

Results from the cluster analysis indicated that three different associations of sal forest occur in the western Terai of Nepal. Among these groups, plots from Bardia District (RBNP) and Kanchanpur District (RSWR) were clearly separated, and two different associations were identified in the former. The ordination of species composition among plots confirmed these relationships (Fig. 4). However, the environmental variables measured in the present study, soil texture and selected soil chemical properties, did not explain the distribution of plots in ordination space. What then is responsible for the differences in species composition among sites? Several authors (Hubbell and Foster, 1986; Barnes et al., 1998; Clark et al., 1999) have suggested that the distribution of plant communities is determined together by soil moisture, soil nutrients, rainfall, past disturbances, mass effects and chance. In western Nepal, higher rainfall in Bardia District in comparison to Kanchapur District, with its subsequent effect on soil moisture conditions, may have been one important factor. In addition, the forests of the two districts were exposed to different intensities of disturbance, especially fire and selective logging in the past. Not very long ago, most of the Terai that extends between the Bhabar and the Indian border

were covered with homogenous forest dominated by *S. robusta* (Stainton, 1972). However, due to selective logging, burning, overgrazing and indiscriminate cutting of firewood and building timbers, old growth *S. robusta* forests have been reduced, leaving a mixed type of sal forest with heavy admixtures of other tree species, especially *T. tomentosa* (Dinerstein, 1979; Shrestha and Jha, 1997). In most stands, the largest *S. robusta* trees were felled, resulting in a change in the proportion of *S. robusta* to other species. *Terminalia* dominance is also an indication of moisture-retentive, heavy soils (Lal, 1992), and high soil moisture condition could be the reason for the separation of two groups from RBNP. Within Kanchapur District, the common grouping of the PCFs plots and those from RSWR is characterized by high dominance of sal, relatively low tree density, and more open canopy.

Across all stands, the diameter distribution may be described as uneven-sized in structure, with a peak in the largest DBH class comprised of trees left after selective logging in the past. When analyzed by forest type, however, a gap among pole-size stems, especially in the 10–20 cm DBH classes, is evident in the *S. robusta–C. operculatus* type. This gap is less evident in the *S. robusta–B. latifolia* and *T. tomentosa–S. robusta* types in RBNP, where it is filled by relatively high densities of species other than *Shorea* and *Terminalia*. Multimodal size distributions are usually indicative of disturbance (Spies, 1998). Typically, old growth forests that are approaching an equilibrium condition exhibit an uneven size structure (Leak, 1996), but human disturbance such as logging removes trees and opens up the canopy, allowing new individuals to emerge and creating unimodal, bimodal and multimodal distributions such as those we observed.

The absence of *Shorea* in pole-size DBH classes in forests of RBNP, but its abundance in sapling and seedling classes, indicates a time lag in recruitment. One possible reason for this lag is reduction in fire frequency immediately after forest protection was instituted. Previously, local residents burned these forests annually to initiate the growth of grasses for livestock grazing (Dinerstein, 1979). Frequent burning promotes the dominance of *Shorea*, which is notably tolerant of fire (Troup, 1921). Regeneration of *Shorea* is also best in high light environments (Tewari, 1995). Higher canopy closure (Timilsina, 2005) associated with the development of shade tolerant, fire-sensitive species such as *Buchanania*, *Largerstroemia*, *Cleistocalyx*, and *Dillenia* which populate the current subcanopy layers, may also have served to prevent *Shorea* establishment.

Sal forests in western Nepal were heavily logged because of their proximity to India and their accessibility (HMGN, 1998). Especially in the *S. robusta–C. operculatus* forest common in Kanchanpur District, this logging history may be responsible for the higher percentage of trees in lower DBH classes, and the abundance of trees in >40 cm DBH class. Selective logging created gaps, increased light penetration and reduced competition from mature *Shorea* and *Terminalia*, and allowed other species to regenerate. The absence of *Terminalia* in seedling, sapling, and pole size categories, and the abundance of *Buchanania* suggests that the *T. tomentosa–S. robusta* type in

RBNP may be a successional stage that will eventually lead to *S. robusta–B. latifolia* forest. Within a single stand, one frequently finds small patches characteristic of each of these assemblages, which creates great spatial heterogeneity in the Bardia.

The overall shrub diversity in the study area is very low, as expressed by Shannon's diversity index (Table 7). *S. robusta–C. operculatus* forests of Kanchanpur had the highest shrub species richness, but shrub density was higher in the forest types common in RBNP where the tree density was higher. This reflects the positive association of canopy closure and understory cover within the study area (Timilsina, 2005). The positive correlation between the canopy closure and understory is unexpected, as these structural elements are often negatively correlated (Berger and Puettmann, 2000), and suggest that the saplings and shrubs common to these forests are relatively tolerant to shade. In Kanchanpur forests, frequent fire may be responsible for the relatively high herb richness we observed. Surface fire of low intensity destroys new sal recruits and its associates, allowing herbs to dominate (Maithani et al., 1986). The increase in herbaceous cover attracts herbivores such as Sambar (*Cervus unicolor*), Cheetal (*Axis axis*) and Blue Bull (*Boselaphus tragocamelus*), and in turn, this browsing pressure further exacerbates problems in the establishment of sal (Tewari, 1995).

7. Conservation implications

Forest development is a continuous process starting from disturbance and legacy creation to pioneer cohort loss (Franklin et al., 2002). Small patches within a forest stand exhibit various stages of development, thereby creating spatial heterogeneity that provides habitat for a variety of wild animals. The three different association of sal forests observed in the present study are the result of a variety of forces, both environmental and human induced, and may represent different stages of sal forest development. For instance, in RBNP, *Shorea*- and *Terminalia*-dominated stands alternate along transects within the broad sal forest. These are unique communities that should be a priority for conservation.

Sal forest covers almost 70% of the area of the southern Nepal, provides habitat for rich floral and faunal assemblages, and timber and non-timber forest products for local communities. Past human disturbances have significantly reduced natural sal cover. Protected forests provide important information on forest structure and composition prior to human alteration, and for that reason are important for the management of biodiversity. In addition, they allow for the study of floral restoration after their establishment, compared to actively used community and district forests. The present study sites in RBNP and RSWR have been protected since the 1970s and are among the best examples of mature sal forests in Nepal. Our results provide an account of sal forest under natural and anthropogenic disturbance regimes for periods ranging up to four decades, and could be used to manage similar forest type outside protected areas. These include forests within the Terai Arc Landscape—a landscape level conservation effort designed

to connect several protected areas of lowland Nepal through forest corridors. Sal forest in RBNP and RSWR provides habitat for wild animals such as tigers, wild elephants, several species of deer and a variety of birds. The information of the current study about these forests is useful for the design and management of outside forests as wildlife corridors.

Our data suggest that fire and past disturbances are the important determinants of structure and composition of sal forest. The high degree of disturbance that some of our forests, especially those in Kanchanpur District, currently receive poses serious problems for sal regeneration. Too frequent burning allows encroachment of the forest by herbs and grasses that compete with sal seedlings, thereby reducing sal regeneration. Removal of overstory cover through logging opens up the canopy and allows encroachment of other species, thereby changing the composition of sal dominated forest. Periodic fire is necessary for sal dominance, but too much burning adversely affects seedlings. For the long-term management of forests for both local livelihoods and biodiversity conservation it is de rigueur to initiate studies addressing the effects of fire in the sal forest. Adequate fire management policy addressing intensity, duration and timing should be developed and implemented.

Acknowledgements

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