# Tree diversity and regeneration of community-managed Bhabar lowland and Hill Sal forests in central region of Nepal

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A view over Nepal’s Terai Bhabar landscape.
Photograph I. P. Sapkota.

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## RÉSUMÉ

**DIVERSITÉ DES ESSENCES ET RÉGÉNÉRATION DE FORÊTS COMMUNAUTAIRES À SAL (*SHOREA ROBUSTA*) DANS LA RÉGION CENTRALE DU NÉPAL**

Cette étude a porté sur la diversité et la régénération d'essences forestières dans deux forêts communautaires à Sal (*Shorea robusta*) au centre du Népal, la forêt de plaine de Bhabar (LEF) et une forêt d'altitude (HEF). Les essences de plus de 30 cm de hauteur ont été dénombrées sur 16 quadrats systématiquement délimités. La densité, la dominance et la fréquence ainsi que l'indice des valeurs d'importance (IVI) des essences ont été calculés afin de caractériser la composition floristique. La densité des peuplements, la surface terrière et des mesures de diversité ont été calculées afin d'analyser la structure et l'hétérogénéité des peuplements de chaque communauté forestière. Au total, 17 familles, 19 genres et 21 espèces étaient représentées dans la LEF. Pour la HEF, le total recensé est de 13, 18 et 21, respectivement. Les résultats de l'étude indiquent que *Shorea robusta* est l'essence la plus abondante aussi bien pour la LEF (IVI = 174,4 %) que la HEF (IVI = 206,9 %). Il ressort nettement de l'étude une association de *Shorea robusta*, *Schima wallichi* et *Syzygium operculatum* dans la forêt LEF et de *Shorea robusta, Pinus roxburghii* et *Eugenia jambolana* dans la HEF. La densité des peuplements et la surface terrière de la LEF (13 231 tiges/ha, 34,30 m²/ha) est plus élevée que pour la HEF (7 787 tiges/ha, 20,69 m²/ha). Les indices de Shannon-Weiner et Simpson ont tout deux fait ressortir une densité plus importante pour la HEF (H'= 2,42, 1 D = 0,64) que pour la LEF (H'= 1,38, 1 D = 0,35). L'état de régénération des deux forêts à Sal semble globalement satisfaisant, avec 38 % et 33 % de l'ensemble des espèces de la LEF et la HEF, respectivement, représentées aux stades du plant et de la régénération avancée. L'étude conclut que les variations en termes de composition spécifique, de diversité et de régénération s'expliquent en partie par l'altitude.

**Mots-clés :** diversité biologique, foresterie communautaire, structure forestière, *Shorea robusta*, composition spécifique.

## ABSTRACT

**TREE DIVERSITY AND REGENERATION OF COMMUNITY-MANAGED BHABAR LOWLAND AND HILL SAL FORESTS IN CENTRAL REGION OF NEPAL**

Diversity and regeneration of tree species were studied in two community-managed Sal forests, Bhabar lowland (LEF) and Hill (HEF), in the central region of Nepal. Tree species ›30 cm in height were enumerated in 16 systematically laid quadrats. Density, dominance and frequency as well as the Importance Value Index (IVI) of species were computed to characterize the floristic composition. Stand density, basal area, and diversity measures were calculated to examine stand structure and heterogeneity in each forest community. A total of 17 families, 19 genera and 21 species were represented in the LEF. In the HEF, the number of families, genera and species recorded was 13, 18 and 21, respectively. Results showed *Shorea robusta* as the single most abundant species in both LEF (IVI = 174.4%) and HEF (IVI = 206.9%). A clear site-specific association of *Shorea robusta*, *Schima wallichi* and *Syzygium operculatum* in LEF and *Shorea robusta, Pinus roxburghii* and *Eugenia jambolana* in HEF were found. The stand density and basal area in the LEF (13,231 stems $ha^{-1}$, 34.30 m² $ha^{-1}$) was higher than in the HEF (7 787 stems $ha^{-1}$, 20.69 m² $ha^{-1}$). Both Shannon-Weiner and Simpson´s indices identified the HEF (H'= 2.42, 1-D = 0.64) as more diverse than the LEF (H'= 1.38, 1 D = 0.35). The overall regeneration status of both Sal forests was satisfactory, as 38% and 33% of the total species in the LEF and HEF, respectively, were represented in both seedling and advance regeneration stages. In conclusion, variations in species composition, diversity and regeneration status between the forests studied is partly explained by their altitude.

**Keywords:** biodiversity, community forestry, forest structure, *Shorea robusta*, species composition.

## RESUMEN

**DIVERSIDAD DE ESPECIES Y REGENERACIÓN DE BOSQUES COMUNITARIOS DE SAL (*SHOREA ROBUSTA*) EN EL CENTRO DE NEPAL**

Este estudio aborda la diversidad y la regeneración de especies forestales en dos bosques comunitarios de sal (*Shorea robusta*) en el centro de Nepal: el bosque de llanura de Bhabar (LEF) y un bosque de altura (HEF). Se enumeraron las especies de más de 30 cm de altura en 16 cuadrados. La densidad, dominancia, frecuencia e índice de valores de importancia (IVI) de las especies se calcularon para caracterizar la composición florística. Se procedió al cálculo de densidad de los rodales, área basal y medidas de diversidad para analizar la estructura y heterogeneidad de los rodales de cada comunidad forestal. En total, había 17 familias, 19 géneros y 21 especies representadas en el LEF. En el HEF, el número total registrado fue, respectivamente, de 13, 18 y 21. Los resultados muestran que *Shorea robusta* es la especie más abundante, tanto en el LEF (IVI = 174,4%) como en el HEF (IVI = 206,9%). Se desprende claramente de este estudio la existencia de una asociación de *Shorea robusta*, *Schima wallichi* y *Syzygium operculatum* en el LEF y de *Shorea robusta, Pinus roxburghii* y *Eugenia jambolana* en el HEF. La densidad de los rodales y el área basal del LEF (13.231 tallos/ha, 34,30 m²/ha) es más alta que en el HEF (7 787 tallos/$ha^{-1}$, 20,69 m²/ha). Los índices de Shannon-Weiner y Simpson arrojaron ambos una densidad mayor en el HEF (H'= 2,42, 1-D = 0,64) que en el LEF (H'= 1,38, 1-D = 0,35). El estado de regeneración de los dos bosques de sal parece globalmente satisfactorio, ya que el 38 y el 33% del total de especies del LEF y el HEF, respectivamente, estaban representados en las etapas de plántula y de regeneración avanzada. En conclusión, las variaciones en la composición específica, la diversidad y la regeneración se explican, en parte, por la altitud.

**Palabras clave:** diversidad biológica, silvicultura comunitaria, estructura forestal, *Shorea robusta*, composición específica.

## Introduction

Regeneration in mature Bhabar Sal forests.
Photograph I. P. Sapkota.

*Shorea robusta* Gaertn. f. (commonly known as Sal) forests are the dominant forest types in the tropical region of Nepal, covering ca. 1.4 million ha (Rautiainen, 1999). Sal forests cover most of the flat Terai (lowland) Bhabar zones (gravelly band of fans), Siwalik dunes and hills and the foothills of mountains. Stainton (1972) has broadly classified the Sal forests of Nepal into lowland and hill Sal forests, which stretch across the mid mountain range to the far north along river slopes and valleys. These forest types extend from a few meters to 1500 m above sea level (Gautam, Devoe, 2006). The Sal forests of Nepal are shrinking, their regeneration status is poor and their species trajectories have changed from the original species composition (Sapkota *et al.*, 2009). The current status of Sal forest structure and species composition is the result of actions and interactions between environmental and biotic factors, and has often been explained from the viewpoint of plant successional theory (see Gautam, Devoe, 2006 for detail).

From the viewpoint of both commercial and subsistence benefits, Sal forests are important resources for Nepal. These forests satisfy many of the subsistence needs of rural communities (ca. 80% of the rural population), providing timber, fuelwood, livestock feed, animal litter and compost (Wagle, 2002; Webb, Sah, 2003). Therefore, selective logging, grazing, browsing, fuelwood, fodder and litter extraction are common phenomena in Sal forests in most parts of India (Pandey, Shukla, 2003) as well as in Nepal. Selective logging of old, inferior, dead and diseased trees has been practiced in Nepal since the emergence of the timber trade (Sapkota *et al.*, 2009). Cutting and lopping for fodder and collection of ground litter for livestock feed and bedding materials were observed in forests close to the settlements (Gautam, Devoe, 2006). Sal forests have also been used for various NTFPs in order to improve the livelihoods of local people (Webb, Sah, 2003). Furthermore, fire has long been considered one of the main factor affecting (beneficially or injuriously) Sal stand development (Gautam, Devoe, 2006). These factors in combination cause disturbances, particularly at a small scale, but they occur frequently and vary in nature (Sapkota *et al.*, 2009). Therefore, these forests are considered as the most disturbed types of forests in Nepal and hence are widely sought conservation needs.

The species assemblages of these forest communities are affected above all by environmental variability, especially due to the altitudinal gradient (Tasfaye *et al.*, 2002; Kharkwal *et al.* 2005; Sanchez-Gonzalez, Lopez-Mata, 2005; Gao, Zhang, 2006). Environmental variability often overrides the frequent and fluctuating disturbances and determines habitat preferences among species (Tasfaye *et al.*, 2002). This phenomenon produces significant impacts on stand structure and species composition (Tasfaye *et al.*, 2002; Anonymous, 2002; Kharkwal *et al.* 2005). Similarly, variations in associated species of Sal (*Shorea robusta*) and their regeneration status, diversity and species composition are determined by altitudinal, climatic and edaphic (environmental) variability, which eventually results in different types of Sal forests (e.g. dry, moist or wet) with varying canopy structures (Uma Shankar, 2001). For example, hill Sal forests are characterized by the predominance of Sal over various broadleaved trees, while lower tropical (Bhabar lowland) Sal forests tend to dominate all terrestrial vegetation. Furthermore, Bhabar lowland Sal forests grow to a considerable size, whereas the hill Sal forests contain much smaller trees (Uma Shankar, 2001).

Information on the vegetational attributes of Nepalese Sal forests, such as stand structure, species composition and diversity, is very scanty (Sapkota *et al.*, 2009). Therefore, there is a need for more knowledge about these attributes of the remaining Sal forests in order to predict future trends in species composition and stand structure and to optimize management strategies, which have not been systematically applied in

Stand structure of mature Bhabar Sal forests with high regeneration of tree species.
Photograph I. P. Sapkota.

forest management in Nepal for a long time. Rather, forest management in Nepal has been practiced with too little awareness of the potential consequences. Furthermore, detailed vegetation analyses in the remaining Sal forests and their documentation are necessary to provide a baseline for future assessments of the effects of community management systems on their structure and species composition. Therefore, the main objective of this study was to assess and document the current status of stand structure, species composition and diversity of two lowland and hill Sal forests now handed over for community management.

We lack specific studies on sites and/or altitude that would elucidate the extent of the impact of frequent and fluctuating disturbances on hill and/or lowland Sal forests. We also lack scientific information of past silvicultural interventions and their impacts on these forests. However, irrespective of the varying altitudes of the sites, we speculate that the impacts on vegetation attributes of past disturbance regimes, management history and the use pattern of all Sal forests are of a similar nature. Therefore, studies made by Uma Shankar (2001), Webb and Sah (2003), Gautam and Devoe (2006) and Sapkota *et al.* (2009) in Sal forests with different climatic characteristics have actually left ample room for a descriptive comparison of the present stand structure and species composition of Sal forests in relation to altitudinal variation. Moreover, the management prescription outlined in the current forest operational plans is identical and does not take altitudinal variations into account, which we believe is not scientifically valid. Therefore, site and/or altitude-specific characterization and rigorous comparison of these two Sal forests and their application in forestry brings new understanding to a country like Nepal, where scientific forest management has been in wide demand for a long time. This may also help to understand the differences or similarities in stand structure, diversity and species composition, which we believe will justify whether or not there is a need to prepare scientific site-specific and/or altitude-based forest management plans in future.

# Materials and Methods

## Study area

The study was carried out in two community-managed Sal forests, which are located in the central region of Nepal (figure 1). The Betkholsi community forest, representing the Bhabar lowland Sal forest (hereafter referred to as LEF), is located in Makawanpur district (85°03' E, 27°25' N), and The Tanke community forest, representing hill Sal forest (hereafter referred to as HEF), is located in Kavre Palanchok district (85°32' E, 27°37' N). The topographic and climatic attributes of these community forests are given in table I. The LEF and HEF correspond respectively to Nepal's upper tropical and sub-tropical ecological zones, (Stainton, 1972; Jackson, 1994; Anonymous, 2002). Both ecological zones have pronounced winter (December-February) and summer (May-September) seasons. The winter season is comparatively cold and dry, although fog, dew and frost are frequent. More than 85% of the annual rainfall is received during May-September (monsoon period), and occasional showers of rain are common during the pre-monsoon season from March onwards.

Until the late 1970s, both forests were well stocked and considered to be in good condition. Considerable destruction of the forests occurred during the democratic movement of 1989. *Shorea robusta*, a prominent timber species (Rautiainen, 1999; Webb, Sah, 2003), was widely used for construction work and almost vanished. Illegal logging and accidental fires during the dry season brought the forests to the verge of extinction. The local people started a conservation movement against illegal logging and fire in 1991. Acknowledging the conservation efforts of the local communities, management rights were formally handed over to the community in 1993 and protective rules were imposed.

**Table I.**
**Topographic and climatic attributes of Bhabar lowland (LEF) and Hill Sal forests (HEF) in Central region of Nepal.**

| Attributes | LEF | HEF |
|---|---|---|
| Area (ha) | 37.5 | 21.5 |
| Altitude (masl) | 450 | 1 200 |
| Slope | Gentle | Gentle |
| Aspect | East, south-west | South-west |
| Predominant soil type | Bauldery red clay | Bauldery red clay |
| Soil pH range | 6.3 – 6.9 | 5.0 – 6.0 |
| Drainage | Well-drained | Well-drained |
| Soil erosion/land slide | Not observed | Not observed |
| Minimum temperature range (°C) | -2.0 – 7.0 | -9.0 – 4.0 |
| Maximum temperature range (°C) | 35 – 45 | 29 – 40 |
| Mean annual temperature (°C) | 24.1 | 17.6 |
| No. of days with > 30 °C (range) | 62 – 215 | 0 – 173 |
| No. of days with < 0 °C (range) | 0 – 10 | 0 – 53 |
| Precipitation extremes (mm) | 947 – 3 867 | 519 – 5 284 |
| Mean annual precipitation (mm) | 1 904 | 1 875 |

Sources: Wagle (2002), Anonymous (2003).

## Inventory and data analysis

The study was based on the inventory data gathered by two District Forest Authorities, Makawanpur and Kavre Palanchok. Detailed inventories of tree species were carried out from January to April 2003 using the quadrat method. Sixteen 10 m x 10 m quadrats were laid systematically at of 138 m intervals along transects in order to assess all tree species with a diameter at breast height (dbh) > 10 cm. 5 m x 5 m nested quadrats were laid to assess individuals with dbh < 10 cm. Each plot was systematically surveyed by identifying the species, counting the number of stems for each species, and measuring the height of all individuals and the dbh of saplings, poles and trees. Based on height and dbh measurements, the life-cycle stages were identified as follows: adult trees (individuals with dbh > 30 cm), poles (individuals with dbh between 10 cm and 30 cm), saplings (individuals with dbh between 4 cm and 10 cm) and seedlings (individuals > 30 cm in height and dbh < 4 cm). Seedlings < 30 cm height were considered as ephemeral and not counted. Density

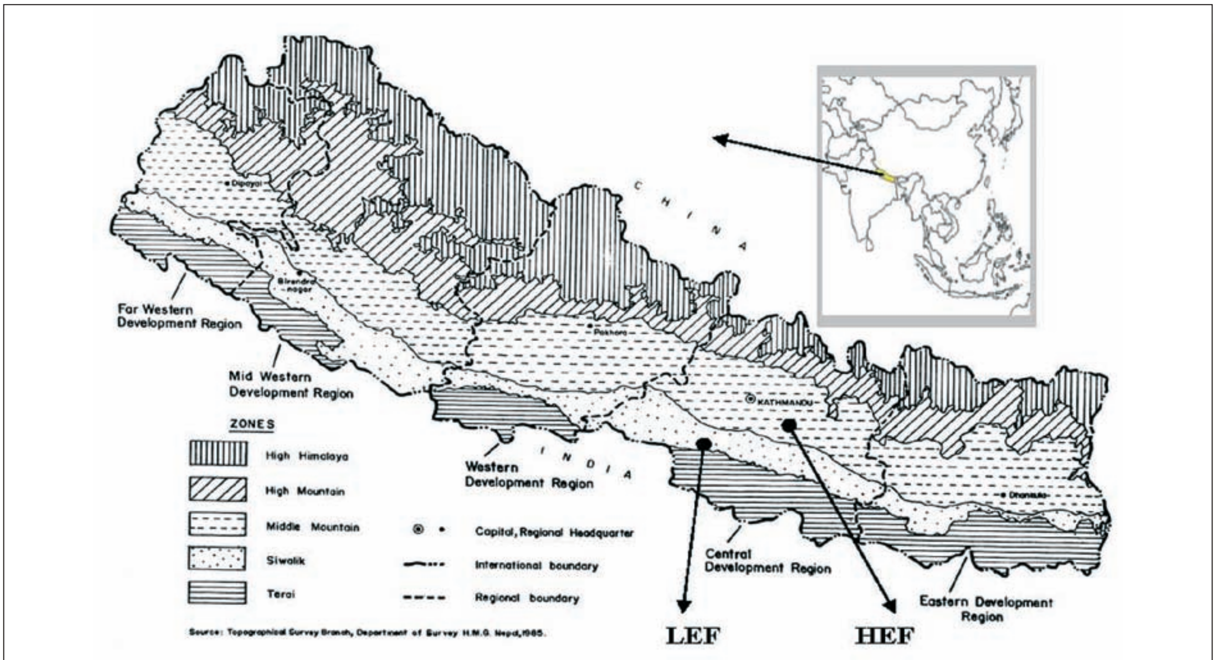


**Figure 1.**
Location of Bhabar lowland (LEF) and Hill (HEF) Sal forests (Source: Forestry Sector Master Plan, 1988).

**Table II.**
**Summary of species composition and structural attributes of Bhabar lowland (LEF) and Hill Sal forests (HEF) in Central region of Nepal.**

| Characteristics | Forest types: Low elevation | Forest types: High elevation |
|---|---|---|
| Species richness (No.) | | |
| Seedling | 17 | 18 |
| Sapling | 10 | 6 |
| Pole | 6 | 8 |
| Adult trees | 3 | 1 |
| Total | 21 | 21 |
| Abundance (stems $ha^{-1}$) | | |
| Seedling | 9 825 | 4 875 |
| Sapling | 2 950 | 2 050 |
| Pole | 363 | 844 |
| Adult tree | 94 | 19 |
| Total | 13 231 | 7 787 |
| Basal area ($m^2$ $ha^{-1}$) | | |
| Sapling | 11.2 | 7.8 |
| Pole | 5.1 | 10.8 |
| Adult trees | 18.1 | 2.2 |
| Total | 34.3 | 20.7 |

(stems $ha^{-1}$) was calculated for each tree species, and the basal area cover ($m^2$ $ha^{-1}$) was computed for individuals with dbh › 4 cm.

The importance value index (IVI) was used to describe the species composition of the two forests. The IVI of a species is defined as the sum of its relative dominance (Rdom), its relative density (Rden) and its relative frequency (Rfre), which in turn was calculated as:

- Rdom = (total basal area for a species/total basal area for all species) x 100
- Rden = (number of individuals of a species/total number of individuals) x 100
- Rfre = (frequency of a species/ sum frequencies of all species) x 100

The frequency of a species is defined as the number of plots in which the species is present. To calculate IVI, individuals with dbh › 4 cm were considered, as basal area was not computed for individuals with dbh ‹ 4 cm. Similarity in species composition between LEF and HEF was assessed using Sorensen's coefficient (Magurran, 2004), based on the presence/absence of the species, as follows:

$$S_s = \frac{2a}{(2a+b+c)}$$

where $S_s$ is Sorensen's coefficient, *a* is the number of species common to both forests, *b* is the number of species in LEF but not in HEF and *c* is the number of species in HEF but not in LEF.

To describe the diversity of each forest, the Shannon-Wiener's diversity index (H') and Simpson's index (D) were computed as follows:

$$H' = -\sum (p_i \log_2 p_i)$$

$$D = \sum \left( \frac{n_i[n_i - 1]}{N[N-1]} \right)$$

where $n_i$ = the number of individuals in the *i*th species, N = the total number of individuals and pi = the proportion of individuals found in the *i*th species ((Magurran, 2004). For straightforward interpretation of diversity, the complement of Simpson's index, expressed as 1 – D was calculated.

# Results

## Species composition

The total number of species in Bhabar lowland and Hill Sal forests was the same, albeit with slight differences in the life-cycle stages (table II; table VIII). Species richness for saplings and adult trees was relatively higher in LEF than in HEF, while species richness for seedlings and poles was slightly higher in HEF. There was a distinct association of dominant species for individuals › 4 cm dbh, as shown by the IVI (table III). An association of *Shorea robusta*, *Schima wallichi* and *Syzygium operculatum* in LEF and *Shorea robusta*, *Pinus roxburghii* and *Eugenia jambolana* in HEF was discernible. *Shorea robusta* was the single most abundant species in both forests, followed by *Schima wallichi* and *Pinus roxburghii* in LEF and HEF, respectively. Although *Pinus roxburghii* was one of the abundant species in HEF, it was found to be the rarest species in the LEF. The four rarest species in each Sal forest are shown in table IV.

The overall similarity in species composition between LEF and HEF was 30%, indicating greater heterogeneity between the two Sal forests (table V). When comparing the different life-cycle stages, similarity in species composition between the two Sal forests was relatively higher for poles than for seedlings and saplings. There was complete dissimilarity between LEF and HEF in the species composition of adult trees. Species represented by adult tree size were *Schima wallichi*, *Shorea robusta* and *Terminalia tomentosa* in LEF and only *Pinus roxburghii* in HEF.

## Stand structure

The total stem density and the density of seedlings, saplings and trees were higher in LEF than in HEF, while the density of poles was higher in the latter (table II). A typical resemblance was seen between these two forest stands, as both showed a decrease in stem number $ha^{-1}$ with a shift in life-cycle stages. In LEF, seedlings accounted for 74% of the total stem density, followed by saplings (22%), poles (2.7%) and trees (0.7%). Similarly, seedlings, saplings, poles and trees accounted for 62%, 26%, 11%, and 0.2%, of the total stem density, respectively, in HEF. In general, the total basal area was higher in LEF than in HEF (table II). When comparing the basal area of each life-cycle stage, the basal area of saplings and trees was higher in LEF than in HEF while the basal area of poles was twice as high in HEF than in LEF. The stem density and basal area for individual species making up each forest are given in the appendix. In both Sal forests, *Shorea robusta* had the highest stem density and basal area cover.

**Table III.**
**The five most abundant species with dbh > 4 cm in Bhabar lowland (LEF) and Hill Sal forests (HEF) in Central region of Nepal according to decreasing order of importance value index (IVI) together with structural characteristics.**

| Forest | Species | Rfreq (%) | Rdom (%) | Rden (%) | IVI (%) |
|---|---|---|---|---|---|
| LEF | *Shorea robusta* | 31.91 | 75.38 | 67.16 | 174.45 |
| | *Schima wallichi* | 17.02 | 10.54 | 8.99 | 36.55 |
| | *Syzygium operculatum* | 12.77 | 5.41 | 11.93 | 30.11 |
| | *Terminalia tomentosa* | 8.51 | 4.61 | 3.12 | 16.24 |
| | *Lagerstroemia parviflora* | 6.37 | 1.11 | 2.94 | 10.42 |
| HEF | *Shorea robusta* | 41.67 | 77.49 | 87.77 | 206.93 |
| | *Pinus roxburghii* | 8.34 | 13.82 | 3.0 | 25.16 |
| | *Eugenia jambolana* | 13.89 | 3.07 | 3.22 | 20.18 |
| | *Schima wallichi* | 13.90 | 2.51 | 3.00 | 19.41 |
| | *Grewia oppositifolia* | 5.55 | 0.63 | 0.43 | 6.61 |

**Table IV.**
**The four rarest species with dbh > 4 cm in Bhabar lowland (LEF) and Hill Sal forests (HEF) in Central region of Nepal according to increasing order of importance value index (IVI) together with structural characteristics.**

| Forest | Species | Rfreq (%) | Rdom (%) | Rden (%) | IVI (%) |
|---|---|---|---|---|---|
| LEF | *Pinus roxburghii* | 2.13 | 0.26 | 0.18 | 2.57 |
| | *Phyllanthus emblica* | 2.13 | 0.28 | 0.73 | 3.14 |
| | *Sapium insigne* | 2.13 | 0.28 | 0.73 | 3.14 |
| | *Engelhardia spicata* | 2.13 | 0.28 | 0.73 | 3.14 |
| HEF | *Myrsine capitellata* | 2.78 | 0.40 | 0.22 | 3.40 |
| | *Ficus religiosa* | 2.78 | 0.69 | 0.21 | 3.68 |
| | *Terminalia bellirica* | 2.76 | 0.69 | 0.86 | 4.08 |
| | *Grevillea robusta* | 2.77 | 0.46 | 0.86 | 4.09 |

## Species diversity

The species-abundance patterns of Bhabar lowland and Hill Sal forests formed a typical reverse J-distribution or log series distribution (figure 2). Shannon-Wiener's diversity index indicated that diversity was relatively high for poles compared with seedlings in LEF, while seedlings were more diverse than saplings and poles in HEF (table VI). Overall diversity was higher for HEF than LEF. When comparing the diversity of each life-cycle stage between LEF and HEF, the seedling class was more diverse in HEF than in LEF, while the diversity of saplings and poles was higher in the LEF than in HEF. The complement of Simpson's index also identified the HEF as more diverse than the LEF.

## Regeneration status

Out of the total species, the regenerating species in LEF and HEF accounted for 38% and 33% respectively, represented in considerable abundance in both seedling and advanced regeneration stages (saplings and poles). Based on the occurrence of tree species in different stages, we used three categories: (a) those represented in the seedling stage only, (b) those represented in the advanced regeneration stage only and (c) those represented in both stages (table VII). The seedling population in LEF was collectively dominated by *Shorea robusta*, *Syzygium operculatum*, *Terminalia tomentosa*, and *Cornus oblonga*, while *Shorea robusta*, *Phyllanthus emblica*, *Eugenia jambolana*, *Semecarpus anacardium*, *Grevillea robusta* and *Syzygium operculatum* dominated the seedling population in HEF (table VIII). Species that occurred solely at the advanced regeneration stage were also among the rarest species; these were *Phyllanthus emblica*, *Pinus roxburghii* and *Sapium insigne* in LEF and *Ficus religiosa* and *Myrsine capitellata* in HEF.

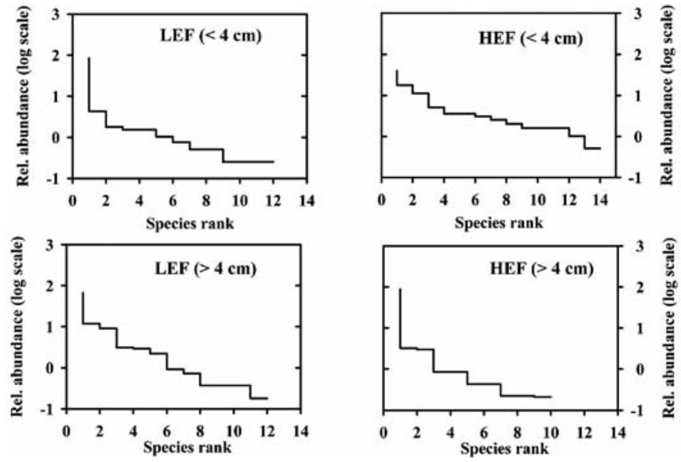


**Figure 2.**
Species abundance plots for Bhabar lowland and Hill Sal forests by size class.

Mature Bhabar Sal forests with low stand regeneration of tree species.
Photograph I. P. Sapkota.

More than 30% of the total species occurred in both seedling and advance regeneration stages (table VII). The numbers of individuals at the seedling and advance regeneration stages occurring on both sites were co-related ($r^2_{adj}$ = 0.920 for HEF and $r^2_{adj}$ = 0.982 for LEF). Species with abundant seedlings were also represented abundantly by advance regeneration (figure 3).

**Table V.**
**Comparison of species similarity between Bhabar lowland and Hill Sal forests in Central region of Nepal by size class using Sorensen's similarity coefficient.**

| Size class | Species in common | Similarity index |
|---|---|---|
| Seedling | 6 | 0.26 |
| Saplings | 2 | 0.20 |
| Pole | 5 | 0.42 |
| Tree | 0 | 0.00 |
| Overall | 9 | 0.30 |

# Discussion

The species richness reported in this study comes within the range reported earlier for tropical dry deciduous forests in the region. For example, SAGAR and SINGH (2005) reported 7 – 47 species in 1 ha sample plots in northern tropical dry deciduous forests in India. MISHRA *et al.* (2000) reported 4 – 5 species (>30 cm dbh) in 0.1 ha of Sal forests in the central Himalayas in India. However, the species richness in our plots was comparably lower than those in tropical lowland Sal forests in India, where 48 (SWAMY *et al.*, 2000) and 76 (UMA SHANKAR, 2001) species were recorded. This is perhaps due to the high rainfall as well as to legal protection measures for lowland Indian Sal forests.

The LEF and HEF varied with respect to associations of the dominant species, as shown by the IVI. A clear site-specific association along with restricted distribution and dominance of species in our study is consistent with previous studies (AIBA, KITAYAMA, 1999; PARTHASARATHY, KARTHIKEYAN, 1997). Evidence indicates that many widespread tropical species tend to be locally abundant in certain areas and relatively rare in others (PARTHASARATHY, KARTHIKEYAN, 1997). This was exemplified by *Pinus roxburghii* and *Syzygium operculatum* in our study. The former was more abundant in HEF (IVI = 25.16%) while the latter was more abundant in LEF (IVI = 30.11%). Despite sharing dominance in LEF, *Terminalia tomentosa* and *Lagerstroemia parviflora* were rare or absent in HEF. On the contrary, *Grewia oppositifolia* was absent in LEF although it shared dominance in HEF. These complexities could be attributed to species-specific characteristics and past biotic pressure (JACKSON, 1994; PARTHASARATHY, KARTHIKEYAN, 1997). One common point in both Sal forests was the remarkable dominance of *Shorea robusta* in both seedling and advanced regeneration stages. Single species dominance often indicates the extent of past dam-

**Table VI.**
**Diversity indices for different life-cycle stages in Bhabar lowland (LEF) and Hill Sal forests (HEF) in Central region of Nepal. Diversity indices were not computed for adult trees due to few numbers of species encountered, but they were considered in the computation of overall diversity indices.**

| Life-cycle Stage | Shannon-Wiener's index (H') LEF | Shannon-Wiener's index (H') HEF | Simpson's index (1-D) LEF | Simpson's index (1-D) HEF |
|---|---|---|---|---|
| Seedling | 1.12 | 2.93 | 0.28 | 0.79 |
| Sapling | 1.62 | 0.74 | 0.51 | 0.21 |
| Pole | 1.70 | 0.90 | 0.62 | 0.25 |
| Overall | 1.38 | 2.42 | 0.35 | 0.64 |

**Table VII.**
**Number of species and their abundance by stage of regeneration in Bhabar lowland and Hill Sal forests.**

| Attributes | No. of species LEF | No. of species HEF | Abundance (stems ha$^{-1}$) LEF | Abundance (stems ha$^{-1}$) HEF |
|---|---|---|---|---|
| Seedling only | 9 | 11 | 525 | 1 825 |
| Sapling and pole only | 4 | 3 | 156 | 25 |
| Both life-cycle stages | 8 | 7 | 12 456 | 5 920 |

age and the resilience of species after disturbance (Parthasarathy, Karthikeyan, 1997).

The total stem density and stand basal area reported in this study are comparable to those in other tropical dry forests. For example, Pandey and Shukla (2003) have reported 8450 seedlings ha$^{-1}$ in managed Sal forests in India, and Swamy *et al.* (2000) have recorded 310 - 1556 saplings ha$^{-1}$ in Indian Sal forests. The tree density (>10 cm dbh; pole and tree classes in our case) is also comparable to other tropical forests (Swamy *et al.*, 2000; Sundarapandian, Swamy, 2000; Pandey, Shukla, 2003). However, the basal area of individuals >10 cm dbh in both Sal forest stands in our study was apparently lower than that of other tropical forests in the region (Sundarapandian, Swamy, 2000; Swamy *et al.*, 2000), most likely due to variation in species composition and age, growth conditions and the degree of past disturbance. Stem density exhibited a decreasing pattern with increasing size class in both LEF and HEF. The seedling density was considerably higher than the sapling density, which in turn was much higher than the pole and adult tree individuals. This indicates that these forests have had no logging based on girth class in the recent past, and typical stands have good regeneration potential (Parthasarathy, Karthikeyan, 1997; Swamy *et al.*, 2000; Uma Shankar, 2001).

Shannon-Wiener's diversity index and the complement to Simpson's index identified HEF as more diverse than LEF. This implies that the majority of the species in LEF have irregular and clumped spatial distribution compared to species in HEF, and therefore HEF is characterized by high alpha diversity. It is well known that as the Simpson's index complement rises, the assemblage becomes more even (Magurran, 2004). The diversity measures reported in our study are comparable to previous studies made on Sal forests. For example, Mishra *et al.* (2000) reported values for the Shannon-Wiener diversity index and Simpson's index complements for moist Bhabar and Terai Sal forests in the range between 1.556 and 1.979, and 0.311 to 0.432, respectively. Compared to this study, our diversity index for LEF is low, which indicates a slow rate of community evolution (Mishra *et al.*, 2000) in LEF. However, the diversity index value in LEF was still greater than the value (0.78) obtained in a managed lowland Sal forest in Nepal (Webb, Sah, 2003). On the other hand, the Shannon diversity indices in LEF as well as in HEF were smaller than the value (3.59) reported by Uma Shankar (2001) in a lowland Sal forest in eastern India.

In both Sal forests, regeneration is proceeding well, as evidenced by the high population density of seedlings followed by saplings and adult trees. However, the population density of seedlings was twice as high in LEF than in HEF. Faster nutrient cycling due to the warmer climate at a lower altitude (Aiba, Kitayama, 1999) and plenty of light availability on the forest floor due to few numbers of pole-sized individuals in LEF might foster early growth and establishment of seedlings and saplings. A strong positive relationship between individuals at seedling and advance regeneration stages was found. This implies that such a high rate of early establishment could lead to higher recruitment of adults if disturbance is precluded (Sagar, Singh, 2005). However, some species such as *Lagerstroemia parviflora*, *Phyllanthus emblica*, *Pinus roxburghii* and *Sapium insigne* in LEF and *Ficus religiosa*, *Myrsine capitellata*, *Grewia oppositifolia* in HEF are not represented in the seedling layer, and might therefore face local extinction in due course if no action is taken to assist their regeneration.

**Table VIII.**
**Complete list of species in Bhabar lowland and Hill Sal forests together with density (stems ha$^{-1}$) and stand basal area (m$^2$ ha$^{-1}$) of the understory (< 4 cm dbh) and overstory (> 4 cm dbh).**

| Species | Family | Density < 4 cm | Density > 4 cm | Basal area > 4 cm |
|---|---|---|---|---|
| Bhabar lowland Sal forest | | | | |
| *Bauhinia purpurea* (Linn.) | Caesalpiniaceae | 25 | | |
| *Bauhinia variegata* (Linn.) | Caesalpiniaceae | 25 | | |
| *Carea arborea* (Roxb.) | Lecythidaceae | 25 | | |
| *Cornus oblonga* (Wall.) | Cornaceae | 175 | 75 | 0.284 |
| *Dillenia pentagyna* (Roxb.) | Dilleniaceae | 50 | | |
| *Engelhardia spicata* (Leschen. ex Blume) | Juglandaceae | 75 | 25 | 0.095 |
| *Eugenia jambolana* (Lam.)* | Myrtaceae | 50 | | |
| *Grevillea robusta* (A. Cunn. ex R. Br.)* | Proteaceae | 75 | | |
| *Lagerstroemia parviflora* (Roxb.) | Lythraceae | | 100 | 0.379 |
| *Lyonia ovalifolia* (Wall.) Drude | Ericaceae | 150 | | |
| *Myrsine capitellata* (Wall.)* | Myrsinaceae | 25 | 13 | 0.175 |
| *Phoebe lanceolata* (Nees) | Lauraceae | 100 | | |
| *Phyllanthus emblica* (Linn.)* | Euphorbiaceae | | 25 | 0.095 |
| *Pinus roxburghii* (Sarg.)* | Pinaceae | | 6 | 0.087 |
| *Sapium insigne* (Royle) Benth. ex Hook.f. | Euphorbiaceae | | 25 | 0.095 |
| *Schima wallichii* (DC.) Korth* | Theaceae | 25 | 306 | 3.613 |
| *Shorea robusta* (Gaertn.)* | Dipterocarpaceae | 8 350 | 2 288 | 25.857 |
| *Symplocos racemosa* (Roxb.) | Symplocaceae | 50 | 31 | 0.182 |
| *Syzygium operculatum* (Roxb.) Niedenzu* | Myrtaceae | 425 | 406 | 1.858 |
| *Terminalia tomentosa* (Roxb.) Wight & Arn.* | Combretaceae | 175 | 106 | 1.583 |
| Unidentified | | | 25 | |
| Hill Sal Forest | | | | |
| *Antidesma diandrum* (Roxb.) Roth | Euphorbiaceae | 50 | | |
| *Aporosa dioica* (Roxb.) Muel.-Arg. | Euphorbiaceae | 25 | | |
| *Eugenia jambolana* (Lam.)* | Myrtaceae | 550 | 94 | 0.636 |
| *Ficus benjamina* (Linn.) | Moraceae | 100 | | |
| *Ficus religiosa* (Linn.) | Moraceae | | 6 | 0.142 |
| *Grevillea robusta* (A. Cunn. ex R. Br.)* | Proteaceae | 250 | 25 | 0.095 |
| *Grewia oppositifolia* (Buch.-Ham. Ex Roxb.) | Tiliaceae | | 13 | 0.13 |
| *Maclura cochinchinensis* (Lour.)Corner | Moraceae | 100 | | |
| *Myrsine capitellata* (Wall.)* | Myrsinaceae | | 6 | 0.083 |
| *Phyllanthus emblica* (Linn.)* | Euphorbiaceae | 875 | | |
| *Pinus roxburghii* (Sarg.)* | Pinaceae | 75 | 88 | 2.859 |
| *Rhus parviflora* (Roxb.) | Anacardiaceae | 125 | | |
| *Schima wallichii* (DC.) Korth* | Theaceae | 25 | 88 | 0.52 |
| *Semecarpus anacardium* (L.f.) | Anacardiaceae | 250 | | |
| *Shorea robusta* (Gaertn.)* | Dipterocarpaceae | 1 950 | 2 556 | 16.003 |
| *Swida oblonga* (Wall.) | Cornaceae | 100 | | |
| *Symplocos paniculata* (Thunb.) Miq. | Symplocaceae | 150 | | |
| *Syzygium operculatum* (Roxb.) Niedenzu* | Myrtaceae | 175 | 13 | 0.098 |
| *Terminalia bellirica* (Gaertn.) Roxb. | Combretaceae | 25 | 25 | 0.095 |
| *Terminalia chebula* (Retz.) | Combretaceae | 25 | | |
| *Terminalia tomentosa* (Roxb.) Wight & Arn.* | Combretaceae | 25 | | |

* Species common to both Sal forests; Nomenclature follows ANONYMOUS (2002).

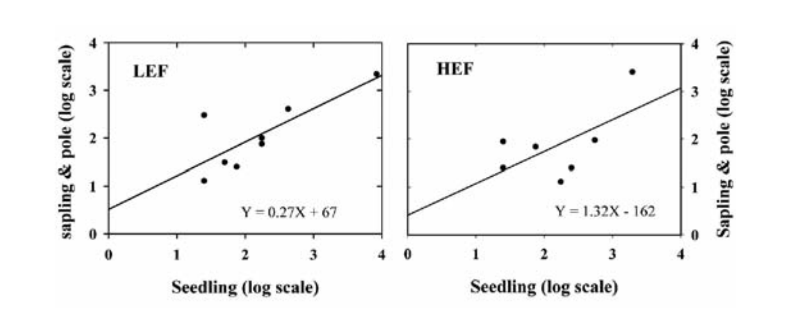


**Figure 3.**
The relationship between the abundance of individuals at seedling and advance regeneration stages for some selected species in Bhabar lowland and Hill Sal forests.

Hill Sal forests with low stand regeneration of tree species.
Photograph I. P. Sapkota.

Hill Sal forests with high stand regeneration of tree species.
Photograph I. P. Sapkota.

# Conclusions

In general, the variation in species diversity and regeneration in the two Sal forests could be related to altitude and edaphic factors (JACKSON, 1994; SWAMY *et al.*, 2000; ANONYMOUS, 2002), as well as to the extent of past disturbances. Similar observations have also been made in China (GAO, ZHANG, 2006), India (KHARKWAL, *et al.* 2005), Mexico (SANCHEZ-GONZALEZ, LOPEZ-MATA, 2005) and Ethiopia (TASFAYE *et al.*, 2002). The altitudinal variation results in variations in temperature, relative humidity, rainfall and wind movements, which are generally known as factors governing plant growth and development. Although both Sal forests were subject to disturbance, its severity is not well known, which partly explains the observed variation in stand structure, species composition and diversity.

However, the variation in vegetative attributes caused by altitudinal variation needs consideration when formulating management plans for the forests studied here and also for Sal forests elsewhere. As both forest communities are characterized by many species with few individuals, active management, such as the reintroduction of rare species, is highly desirable from the biodiversity conservation point of view. Simultaneously, immediate action should be taken to assist the natural regeneration process of species that are underrepresented in the seedling layer.

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A view over Nepal's Hill landscape.
Photograph I. P. Sapkota.