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Does Regulated Land Use Allow Regeneration of Keystone Forest Species in the Annapurna Conservation Area, Central Himalaya?

This quantitative study assesses the ecological impacts of varying degrees of forest use, describing community structure, population structure, and regenerative capacity of the understudied but much utilized Quercus semecarpifolia *Sm. in a mixed oak and* Rhododendron arboreum *Sm. forest. The Middle Hills of the Himalayas have long traditions of mixed farming, with animal husbandry and agriculture as interdependent components. Major biomass demands come from grazing and collection of fodder and fuelwood. In forested areas lopped fodder is one of the main components, and as elevation increases, so does its importance. Human impact has been used to explain low regeneration of these evergreen oaks. The anthropogenic disturbance gradient spanned from highly disturbed savanna-like sites to minimally disturbed shaded sites dominated by rhododendron. The population structure showed a bell-shaped distribution with a pronounced under-representation of saplings throughout the forest. Data indicated the best regeneration in the least disturbed sites. The degree of lopping was the best explanatory variable for the distribution of recruits. Factors preventing trees from surviving the sapling phase may inhibit long-term regeneration more than factors causing high seedling mortality. Results indicate that regeneration of* Q. semecarpifolia *may suffer to the benefit of rhododendron, which escapes biotic stress due to its poor fodder and fuelwood qualities.*

Keywords: *Conservation; recruitment; oak forests; human impact; lopping; Middle Hills; Nepal.*

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Disturbance and regeneration

Even though human settlements have existed in the Himalaya for thousands of years, it is only in the last hundred years or so that human intervention in the Middle Hills has taken place on a large scale (Moench and Bandyopadhyay 1986; Singh 1998; Khera et al 2001; Saberwal and Rangarajan 2003; Carpenter 2005; Subedi 2006). Uncontrolled common land grazing and overstocking by livestock prevent regeneration of the tree cover to some extent (FAO 1974; Kumar and Shahabuddin 2005) even though the negative impact of land use in the Himalayas may be overstated (Ives 2006). On average, 40% of Nepal's livestock is fed with leaf fodder from approximately 100 tree species (Moench and Bandyopadhyay 1986).

There is general agreement that consumption of fodder in the Middle Hills far exceeds sustainable supply and that oak species are the most heavily exploited, showing low regeneration above 2400 m (Upreti et al 1985; Saxena et al 1984; Mahat et al 1986; Thadani and Ashton 1995). Comprehensive studies on *Quercus* forests in the Himalaya have been undertaken by Stainton (1972), Dobremez (1976), Ohsawa et al (1986), Acharya et al (1991), Singh and Singh (1992), Singh et al (1997), Vetaas (2000), Sagar et al (2003), Bhuyan et al (2003), Ram et al (2004), and Kumar and Ram (2005). *Q. semecarpifolia* is a common and much utilized broad-leaf oak species, but remarkably understudied in relation to its importance. Poor regeneration of oak forests after human-induced or natural disturbances, however, has been reported in all regions in North America (Lorimer et al 1994), in Europe (Watt 1919; Andersson 1991), and in Asia (Saxena et al 1984; Singh and Singh 1987).

Population structure of forests and regeneration of canopy dominants are commonly assessed by size rather than by age distribution (Leak 1964; Hett and Louks 1976; West et al 1981), and explored by survivorship curves and density diameter relationships developed within applied forest science. This is supported by the tenet that fecundity and population growth in plants may be more dependent on size than on age (Harper and White 1974). Undisturbed old-growth forests with sustainable regeneration are found to have a reversed J-shaped size class distribution (West et al 1981). Assuming that size correlates with age, this can be expressed by a negative exponential function if the mortality rate is constant (Leak 1964). Where mortality decreases with age, a power function is used to model the size/age-class distribution (Goff and West 1976; Ross et al 1982). A bell-shaped size class distribution has been attributed to disturbed forests where regeneration is hampered (Saxena et al 1984).

We aimed to elucidate whether regulated land use in the Annapurna Conservation Area (ACAP) restricts regeneration of *Q. semecarpifolia*. ACAP is the largest protected area in Nepal, covering 7629 km^2, where local communities are involved in conservation planning and management, and allowed to continue their traditional land use practices. Cutting of live trees is prohibited, however, and lopping is to be avoided between May and November when new leaves develop. ACAP aims to create awareness among local people and visitors about the consequences of increased forest exploitation. This study assesses the impacts of different levels of human disturbance on vegetation structure and regeneration of *Q. semecarpifolia*. Anthropogenic disturbances are: lopping for fuelwood and fodder,

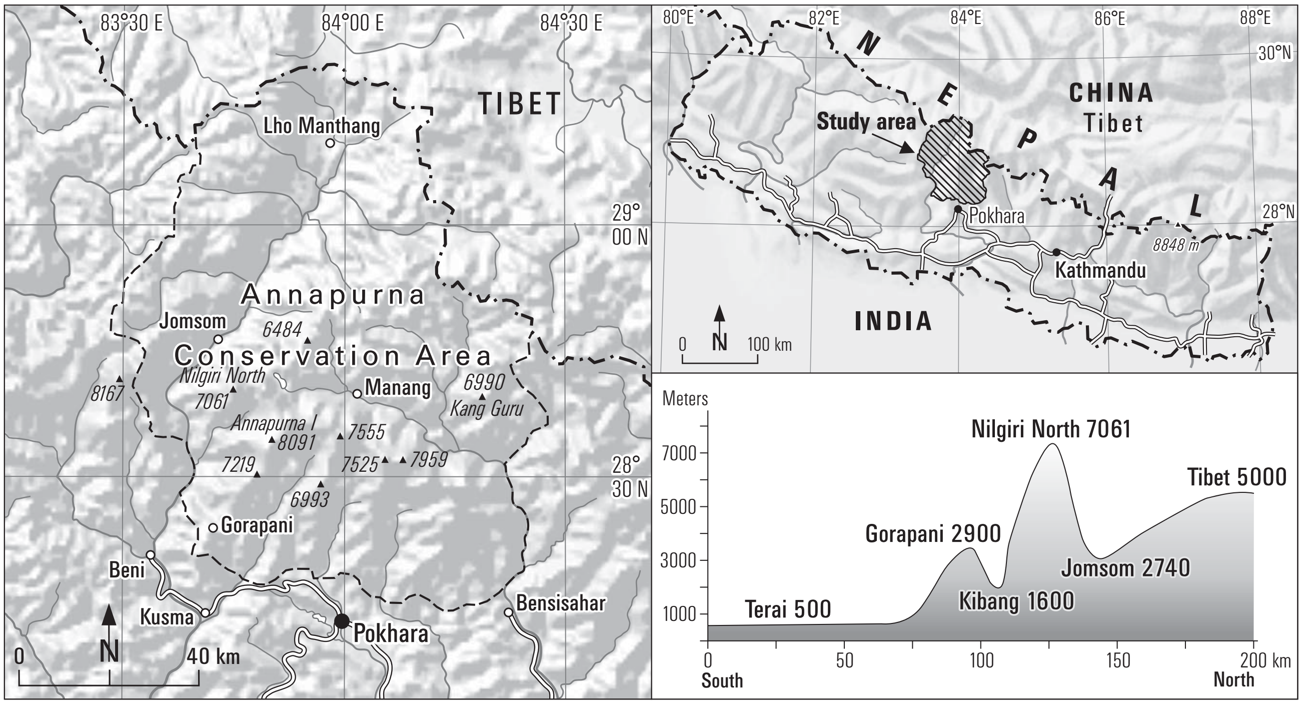


FIGURE 1 Location map showing the Gorapani study site with mixed *Quercus semecarpifolia* and *Rhododendron arboreum* forest situated within the Annapurna Conservation Area, Nepal. (Map by B. Helle and I.E. Måren)

burning, livestock grazing, collection of various products such as forest floor biomass, fruits, fiber, and medicinal plants, and conversion of forest to cropland. Our aims were to 1) quantitatively describe the complex disturbance gradient by means of ordination; 2) analyze the population structure of *Q. semecarpifolia*, by means of size distribution and the theoretical population models described above; 3) test whether the disturbance gradient influences recruitment, and discuss which disturbance factors may have a major negative influence on the recruitment of *Q. semecarpifolia*.

Materials and methods

Study area and anthropogenic pressure

The study area was situated close to Gorapani village in Annapurna Conservation Area Project, central Nepal, at 83° 45′ E and 28° 25′ N (Figure 1); the study was carried out in spring of 1995. The altitude ranged from 2650 to 2850 m, relatively flat compared to similar oak forests in the Middle Hills. Mean temperature is estimated to vary between 1.5°C in winter and 13.5°C in summer (laps rate 0.51°C/100 m, Vetaas 2000). Exact rainfall data were not available, but Lumle Forestry Research Center 15 km away receives 5550 mm of precipitation annually (Shakya 1985). Throughout the Hill regions the bedrock is dominated by competent phyllites and various degrees of metamorphosed schist with interbedding of quartzite, and loams and sandy loams are the most common soil types (Carson 1992).

The forest studied is classified as "low to mid-montane hemi-sclerophyllous broadleaf forest with concentrated summer leaf drop" (Singh and Singh 1992). *R. arboreum* constitutes large parts of the forest and can be identified as "the Annapurna formation" described by Dobremez (1976). Blooming rhododendron is an important tourist attraction for ACAP. Land use affecting the forest includes logging, lopping, cropping, burning, browsing, and trampling. *Q. semecarpifolia* was the most important fodder tree, but *Ilex dipyrena* and *Acer* spp. were lopped for fodder in the dry season from November to March, when grazing resources are insufficient. Firewood was collected from trees and branches broken by the wind. Thunderstorms and lightning are very common in the area, causing wildfires. A major fire damaged half of the forest area 15 years prior to data collection.

Sampling methods

A total of 68 quadrats, each measuring 10 m by 10 m, were sampled within a forested area of 2 by 5 km. Plots were located in a stratified random approach; stratification allowed equal repetition of the different levels of anthropogenic disturbance, based on lopping intensity and fire damage, forming 6 disturbance classes (Table 1). Grazing was considered to be continuous throughout the forest studied. It was not measured as a separate criterion, but presumed to increase in impact from classes 0 to 5. However, droppings were recorded as an indirect measure of grazing pressure.

Each plot was divided into 4 subplots of 5 m × 5 m and the presence of all non-epiphytic vascular plant species was identified and recorded. An estimate of abundance (0–4 scale) weighted on the number of individuals of each species represented was used in the ordination analysis. Light intensity was measured with a lux-meter, Megatron DA4 Lightmeters, on clear days between 11 and 12 am. Canopy and litter covers were visually estimated.

The physical variables measured were altitude, slope inclination, and aspect; the latter 2 were combined in a Radiation Index, RI = f (aspect, inclination, latitude) (Oke 1987). Soil samples were analyzed for Loss On Ignition (LOI) by burning at 550ºC for 6 hours, and for pH in water:suspension (1:2). All methods are described by Black (1965). All *Q. semecarpifolia* trees above 1.37 m in height (West et al 1981) were measured and divided into diameter at breast height (DBH) classes of 20 cm intervals, giving a total of 11 size classes. All *recruits*, ie individuals less than 10 cm DBH, were counted; *saplings*: > 1.37 m, DBH < 10 cm; and *seedlings*: < 1.37 m, DBH = 0. Nomenclature follows Hara et al (1978), Hara and Williams (1979), and Hara et al (1982).

Data analysis

Detrended Correspondence Analysis (DCA; Hill and Gauch 1980) was used to determine whether the different disturbance classes could represent the main species compositional gradient. We used Principal Component Analysis (PCA) to detect a complex disturbance gradient based on all measured factors related to disturbance—disturbance classes, light intensity, canopy cover, and lopping—providing a continuous variable as a measure of the disturbance.

The relationship between *Q. semecarpifolia* recruits and environmental variables including the disturbance factors was analyzed by Generalized Linear Models (GLMs; McCullagh and Nelder 1989), linking the expected response variable to the independent variable by a log-link function. The negative exponential function and power function models were fitted to the size structure of the total sampled population by linear regressions to check whether they could account for the observed diameter distributions (West et al 1981).

Analysis of Variance (ANOVA) (Statistical Science 1993) was used to detect significant differences ($p < 0.05$) between the mean tree density, canopy cover, and recruits in slightly lopped, moderately lopped, and heavily lopped areas, and in burnt and not burnt areas. Regression analyses were performed using the S-plus program (Statistical Science 1993). Ordination analyses were performed using the software package CANOCO 4.5 (ter Braak and Šmilauer 2002), and ordination diagrams were drawn in CanoDraw 4 (ter Braak and Šmilauer 2002).

TABLE 1 Disturbance classes for the plots surveyed. Trees standing in closed forest with mature branches and canopies: least disturbed, only found in the area not affected by fire. Trees in closed to fairly open forest with one or no mature branches: moderately disturbed, found in both burnt and not burnt areas. Trees with a pole-like morphology in flat savannah like areas: most disturbed, found in both burnt and not burnt areas. Plots in areas of pure *R. arboreum* stands: undisturbed, no signs of fire or lopping. Due to close proximity to the main trekking route, heavily used by people and animals, 3 plots were excluded from the data.

Class	Disturbance criteria	Dominant tree species
0	Undisturbed	*Rhododendron arboreum*
1	Slightly disturbed, closed forest, mature branches, not burnt	*Quercus semecarpifolia*
2	Moderately disturbed, closed/fairly open forest, not burnt	*Quercus semecarpifolia*
3	Moderately disturbed, closed/fairly open forest, burnt	*Quercus semecarpifolia*
4	Heavily disturbed, pole-like trees, open grassland, not burnt	*Quercus semecarpifolia*
5	Heavily disturbed, pole-like trees, open grassland, burnt	*Quercus semecarpifolia*

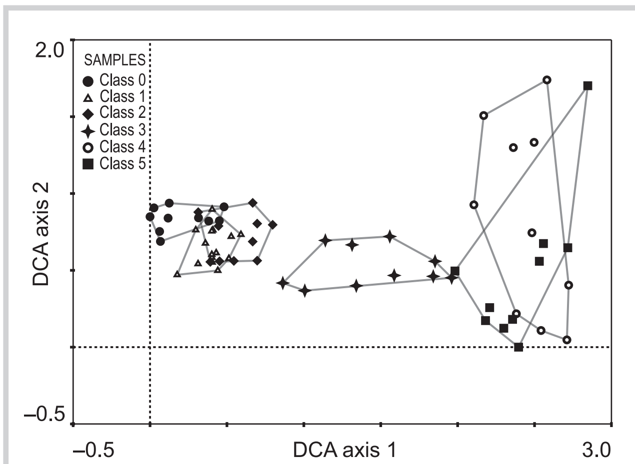


FIGURE 2 DCA ordination diagram of samples from the mixed *Quercus semecarpifolia* and *Rhododendron arboreum* forest at Gorapani, Annapurna Conservation Area, Nepal. The different disturbance classes (see Table 1 for legend) are distributed along a complex disturbance gradient.

Results

The anthropogenic disturbance gradient

DCA analysis (Figure 2) yielded a first ordination axis with a length of 2.85 SD-units, which correlated with a complex disturbance gradient; from slightly disturbed closed canopy forest with more or less uniform shade, dominated mainly by *R. arboreum* and several subcanopy species, via moderately disturbed forest exposed to a mosaic of different light intensities, to heavily disturbed savanna-like grazing grounds subjected to uniform light exposure with sparse and severely lopped trees. *Arundinaria* spp., characteristic of undisturbed to

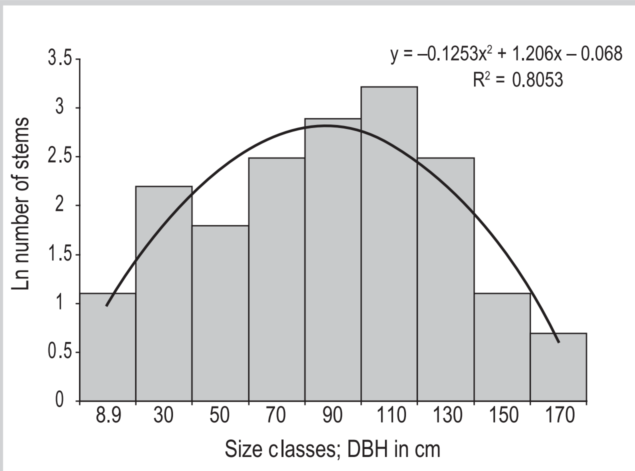


FIGURE 3 Population structure of *Quercus semecarpifolia,* with an adapted polynomial trendline based on a combination of all study sites (0.55/ha).

slightly disturbed *Quercus* forests, were found in the least disturbed forest sites. *Berberis* spp., commonly recognized in disturbed *Quercus* forests, were found in nearly all the moderately to heavily disturbed sites. Species of the genera *Berberis, Rosa, Rubus* and *Pyrus* that are not browsed or scarcely browsed, due to their unpalatable, spiny, poisonous or hard growth forms, were found in the most disturbed sites, with disturbance factors being severe lopping combined with trampling, fertilizing, and grazing. Grazing animals tended to gather on the flat savanna-like sites where the flora was cosmopolitan with disturbance and nitrogen indicator species such as *Rumex, Primula, Heracleum, Ranunculus, Aconitum, Taraxacum, Gerardinia diversifolia, Cirsium wallichii,* and several graminoids dominating. Here, grazing causes mechanical damage to the plants, and manure from the grazers fertilizes the soil. It also affects the spatial organization and age structure of populations.

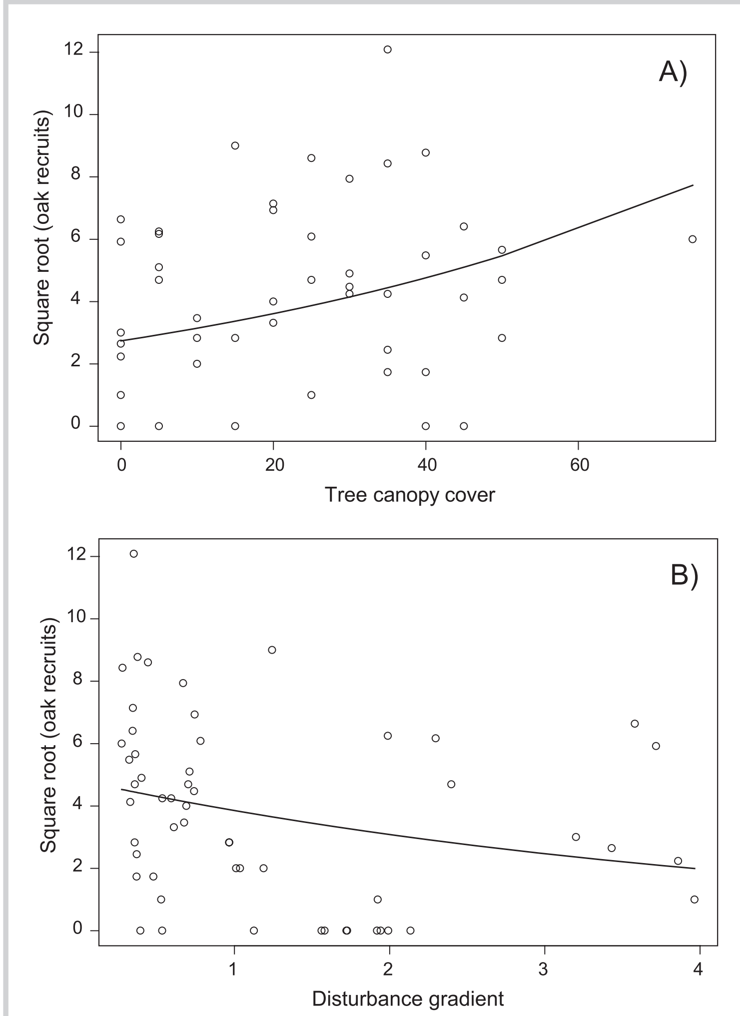
Size structure and regeneration of *Quercus semecarpifolia*

The population structure of *Q. semecarpifolia* showed a bell-shaped distribution of mature trees (Figure 3). The negative exponential function model (p = 0.67) and the power function model (p = 0.98) showed no fit to the present population structure of this forest. Saplings were almost absent, only found in the least disturbed oak sites; hence, recruits are mainly represented by seedlings. We found an uneven distribution of seedlings both within and between disturbance classes, seedlings being predominantly very small, indicating a drastic thinning process as seedlings age. Most seedlings were found in sites where *Q. semecarpifolia* was slightly lopped, while very few or no seedlings were found in plots dominated by dense *Rhododendron* canopy and in the most disturbed classes. The number of seedlings in the oak stands correlated with factors indicating increasing disturbance, ie increasing light intensity and decreasing canopy cover. ANOVA showed a significant difference (F = 7.78, df = 5, p = 0.001) in mean numbers of seedlings with varying degrees of lopping. There was, however, no significant difference (F = 0.51, df = 53, p = 0.480) in burnt and not burnt areas. The results of the GLM analyses on *Q. semecarpifolia* recruits are shown in Table 2 and Figure 4. The variation in the number of recruits is very high under a low disturbance situation, but increased disturbance has a significant negative effect on the average number of recruits. Regression analyses show significant relationships between recruits and inclination, indicating low numbers of seedlings in flat areas, ie areas with high levels of canopy and ground cover disturbances. The 3 regression analyses representing light intensity measurements showed significant relationships with seedling numbers. The greater the light availability at ground level, the fewer seedlings occurred. These results agree with the results of ANOVA, showing significant difference in

TABLE 2 GLM analyses of environmental predictors and *Quercus semecarpifolia* recruits (total deviance = 150.72; df = 54); RRI = Relative Radiation Index, LOI = Loss On Ignition.

Predictor	df used	Residual deviance	Percent deviance explained	χ (p)
Canopy cover	1.0	136.8	7.5	*p* < 0.0002
Lux (ln)	1.0	139.7	5.4	*p* < 0.0009
Disturbance classes	1.0	136.2	7.9	*p* < 0.0001
pH	1.0	147.6		*ns*
LOI	1.0	137.8	5.1	*p* < 0.0016
RRI	1.0	139.4	5.8	*p* < 0.0007

FIGURE 4 Relationships between the square root of oak recruits and canopy cover (above) and the complex disturbance gradient (determined by Principal Component Analysis).



seedling numbers within different lopping regimes, ie different light regimes. There were no significant relationships between recruits and measured soil variables.

Discussion

The current study, with its emphasis on anthropogenic impacts, represents an addition to the quantitative knowledge of forest regeneration of the important but understudied *Quercus semecarpifolia* of the Himalayan Middle Hills. Mixed oak forest seems to be essentially intolerant to recent and present degrees of disturbance, as evidenced by its current failure to regenerate adequately. Our study shows significant impacts of past and present forest utilization. Although regeneration occurred along the entire disturbance gradient, it was on average higher under high canopy cover and where signs of past and present forest utilization were minor. Selective removal of oaks has resulted in a greater representation of sub-canopy species with smaller diameters. These escape biotic stress due to their poor firewood and fodder qualities. *Rhododendron* spp. regenerate well under oaks and the present management situation may promote its regeneration at the expense of *Q. semecarpifolia*. Rhododendron is not cut, browsed, or lopped due to ACAP regulations; it is also more fire-resistant. *R. arboreum* is thus expected to remain as an associate of oak dominants or slowly expand if selective biotic pressure is maintained or increased. Further depletion of smaller-sized trees, seedlings, and seed production by heavy logging, lopping, and browsing will most likely result in reduced regeneration of *Q. semecarpifolia*. These findings are, however, not as severe as for other Middle Hills oak stands. This is most likely due to ACAP's community-based approach in conservation and management, which has a positive effect on forest structure and diversity, as pointed out by other research (Bajracharya et al 2005).

The population of relatively large similar-sized individuals, presumably older trees, may be explained by several factors. Low light intensities seem to limit seed germination and seedling survival in *Q. semecarpifolia*. However, regression analyses indicate that there may be other factors influencing seedling survival and growth. Browsing may be an important factor in dramatically reducing the numbers of established seedlings due to their high palatability; we observed seedlings to be most abundant in the least-disturbed oak sites. Close follow-up of protective measures such as proper lopping, rotating lopping cycles, and protection from over-grazing and cutting may result in important improvements in seedling and sampling survival and in seed dispersion.

The assumptions of stable population size and constant recruitment and mortality rates (Hett and Louks 1976) may seldom be met within natural populations. Vegetation is often determined by specific past episodes. In many tree populations high levels of recruitment may be possible only during periods following major disturbances or at certain intervals caused by competitive interactions between different ages and sizes (Ross et al 1982). The size structure of the studied *Q. semecarpifolia* varies considerably with different levels of disturbance. The obvious lack of saplings and smaller sizes is very apparent when the different disturbance classes are considered separately. However, under-representation of saplings may be a relatively widespread phenomenon (Goff and West 1976; Hett and Louks 1976; Lorimer et al 1994). The negative exponential function and power function models fit the population of *Q. semecarpifolia* at Gorapani poorly, while in Langtang and Phulchok Hill the negative exponential model fit well (Vetaas 2000). The pattern of size distribution contrasts with those recorded for uneven-aged mixed stands (Schmelz and Lindsey 1965), giving an overall straight-line relationship, and those obtained from large hardwood forests giving a rotated sigmoid curve (West et al 1981).

Bell-shaped distributions may commonly be indicative of successional stands where regeneration has been inhibited by vigorous growth of young cohort populations of the dominant canopy tree, or of populations that are recovering from a time-specific disturbance (Parker and Peet 1984). Saxena et al (1984) found the bell-shaped age structure assumed by relatively aged stands to be typical of even-aged stands, regardless of species composition. Schmelz and Lindsey (1965) identified the same pattern in old-growth forest. It is important, however, to realize that the survivorship models do not take account of sudden catastrophes. We found a clear bell-shaped size structure; the large number of *Q. semecarpifolia* trees in intermediate size classes most likely indicates a quite recent exploitation, ie a time-specific event. It coincides in time with the explosion of tourism about 20–30 years ago and the expansion of Gorapani village from one lodge in 1986 to about 20 in 1997. A massive increase in demand for firewood and building materials must have followed this expansion and must have resulted in extensive logging of the nearby forests.

In conclusion, these Himalayan mid-elevation anthropogenic landscapes function as complex agro-ecosystems where management and conservation need to balance the knowledge, practices, and needs of a diversity of users, with global aims such as conservation of biodiversity and sustainability for future users. If human impacts take on the form of chronic disturbance (Singh 1998) by overgrazing, lopping, or cutting, forest-forming species such as *Quercus semecarpifolia* are not allowed to progress to mature tree size.

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