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Original Research Article

# The Banj oak *Quercus leucotrichophora* as a potential mitigating factor for human-langur interactions in the Garhwal Himalayas, India: People's perceptions and ecological importance

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ABSTRACT

Crop-foraging by primates is a rapidly growing concern. Effective mitigation strategies are urgently required to resolve this issue. In the Garhwal Himalayas, local people's high dependency on forest resources is a major cause of habitat loss, which paves the way for human-primate interactions in this area. To investigate the socioeconomic factors that might explain langur crop-foraging, we conducted structured interviews among 215 households in the Garhwal Himalayas in India. We also examined langur resource use by monitoring their feeding and sleeping site activity. Less agricultural land, less agricultural production, and possession of large numbers of livestock significantly predicted villagers reporting crop-foraging events, although economic status of the correspondents did not have any effect. Perception of the villagers about reduction in forest resource was significantly affected by the amount of livestock possessed by the villagers. Our observations suggested that Banj oak *Quercus leucotrichophora* was the dominant species (59.2%, N = 306) in the pool of sleeping trees used by the langurs. Langurs also showed a preference in their use of sleeping sites and feeding sites, which were different from that expected by chance. Sleeping sites with high density of oak were re-used most frequently. Similarly, dense oak patches were also the preferred feeding patches. Thus, we suggest replanting of oak trees and conservation of intact oak patches, environmental education outreach, and empowerment of women in the community as potential mitigating factors to lessen the interaction between humans and langurs.


*Abbreviations:* masl, Meters above sea level.

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## 1. Introduction

Interactions between people and wildlife range from mutually beneficial or benign to harmful for one or both parties. These negative interactions are frequently referred to as “human-wildlife conflict” (Wich and Marshall, 2016). Human-wildlife conflict is a rapidly growing concern in today’s world across many regions, and manifests itself in forms such as livestock-loss by predation or crop-foraging by a number of wildlife species (Dickman, 2010). These concerns also have negative consequences for wildlife, resulting in population displacement, harassment or even eradication (Strum, 1987; Else, 1991). While many wildlife species forage on cultivated crops, primates, given their high cognitive abilities, pose an even more significant threat, often thwarting attempts to effectively deter them (i.e. Naughton-Treves, 1998; Sillero-Zubiri and Switzer, 2001; Warren et al., 2007; Nijman and Nekaris, 2010). In Africa and Asia, conflict is high between farmers and crop-foraging wildlife (Hill and Wallace, 2012). Primates alone are responsible for crop-losses of up to 70% on any single farm (Priston, 2005) and often 60% of the annual harvest (Hill, 2000). Effective mitigation strategies are urgently required to resolve this issue and to take suitable conservation actions (Breitenmoser et al., 2005). For predicting the likely success of a crop-foraging prevention model, however, it is crucial to understand the behavioral ecology of the crop-foraging species and local peoples’ perceptions of them (Decker and Chase, 1997; Hill et al., 2002; Tadesse and Teketay, 2017). Such models provide a useful framework to explore human-primate interactions and help in the development of effective management plans and conflict-mitigation strategies (Hill and Webber, 2010).

In this paper, we address the problems associated with anthropogenic pressures on the habitat of the Central Himalayan langur *Semnopithecus schistaceus*, a rarely studied, montane colobine primate, and the negative consequences arising due to habitat loss around a human-modified landscape in the Garhwal Himalaya of northern India. The Garhwal Himalayas, extending through a major part of the state of Uttarakhand, is an economically underdeveloped and ecologically fragile region of the country, with more than 74% of its population dependent on traditional agricultural practices for their livelihood (Sati, 2012). Anthropogenic pressure is reported to be one of the most significant factors causing deforestation in the Indian Himalayas (FSI, 2000; Pandit et al., 2007; Wester et al., 2019) and it is particularly high in the Garhwal Himalayas (Wakeel et al., 2005; Thakur et al., 2011; Batar et al., 2017), due to low socio-economic status of the local people and their high dependency on natural resources (Bhat et al., 2012). Local people residing in this zone primarily utilize Banj oak *Quercus leucotrichophora* (Troup, 1921; Nautiyal and Babor, 1985). This species covers extensive areas of the central Himalayas, in the altitudinal zone between 500 and 2300 masl (Champion and Seth, 1968; Singh and Singh, 1992; Gairola et al., 2010; Singh et al., 2016). Excessive dependence of the local communities on the oak forests for use as grazing lands, removal of branches for fodder and fuelwood, litter removal for use as cattle beds and as agricultural fertilizer have severely affected the regeneration of this species, having a major inluence on forest degradation (Gupta and Singh, 1962; Saxena and Srivastava, 1973; Singh and Singh 1987, 1992; Chandra et al., 1989; Thadani and Ashton, 1995; Khera et al., 2001; Rao and Pant, 2001; Arya et al., 2011; Makino, 2011; Rathore et al., 2018).

In general, the oaks are well known for their numerous ecosystem services in the Himalayas. These include conservation of soil from erosion and landslides, regulation of water flow in watersheds and maintenance of water quality in streams and rivers, (Singh and Singh, 1986; Singh et al., 2012). However, they also serve as a major component of the natural habitat and as a key food resource for the wildlife in the region (Singh, 1981; Singh et al., 2012; Nautiyal and Huffman, 2018). To what degree these changes in the oak dominated forest affect the ecology and behavior of the wildlife inhabiting this landscape, is an emerging research topic with important implications for the formulation of wildlife management and conservation strategies.

A study of the diet of a troop of Central Himalayan langurs in the Garhwal Himalayas found that their main food source was oak during the fruiting season, but also that 22% of their feeding time was spent on cultivated crops around harvest time (Nautiyal, 2015). To better frame a human-langur conflict-mitigation strategy for this particular landscape, it is important to understand the peoples’ perception of langur crop-foraging and to obtain a more detailed picture of langur habitat resource use by monitoring their feeding and sleeping site activity.

This study quantifies the loss of a key tree species, the Banj oak, and its relevance for Central Himalayan langur habitat use. We examined the services provided by oak patches as feeding and sleeping sites for the study langur population and quantified their usage of these oak patches as resource sites. Langurs are diurnal and tend to sleep perched high up on trees during the night. The role of sleeping sites has been assessed under various non-mutually exclusive hypotheses (for a comprehensive review, see Anderson, 1998; Anderson, 2000), particularly given the fact that sleep tends to take up to one third of our lifetime (Purves, 2012). As the highland species of langurs depend heavily on arboreal roosting sites, changes in forest cover and habitat, and a decline in the density of preferable tree species would mean a decrease of suitable sleeping sites as well as of feeding patches, all of which will adversely affect the ecology and ranging behavior of these langurs (Ruhiyat, 1983; Chhangani and Mohnot, 2006).

Langurs (*Semnopithecus* spp.) are one of the most widely distributed primate taxa in the Indian subcontinent, inhabiting a variety of habitats, ranging from desert to rainforest, from sea level up to 4000 masl in the Himalaya (see Kumar 1987). Although there have been extensive studies on the lowland langur *Semnopithecus entellus* (Jay 1963, 1965; Sugiyama, 1965; Yoshiba, 1967; Mohnot, 1971; Hrdy, 1974; Newton, 1992), there is little information on the ecology, behavior and conservation status of the higher-altitude Himalayan species within this group (Bishop and Bishop, 1978; Sayers and Norconk, 2008). In particular, there is scant information on the behavior and ecology of the Central Himalayan langur *S. schistaceus* living at high altitudes (Sugiyama, 1976; but see Borries et al., 2015 for lowland dwelling *S. schistaceus*). CITES and IUCN present contradictory information on the conservation status of the species, perhaps due largely to the fact that both are based on scant, unpublished information. To the best of our knowledge, no detailed account of human-langur conflict has been published in India. Leaving the conservation status of *S. schistaceus* unclear, CITES classifies this species in Appendix I as 'Threatened with Extinction' while IUCN ranks it as 'Least Concern' (IUCN, 2001). For merely listed as a subspecies of the widely distributed *Presbytis entellus*, it does appear that very little information actually exists on this newly revised species within its currently recognized high-altitude distribution, across northwest Pakistan, northern India, including the states of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, West Bengal and Sikkim, Nepal, Western Bhutan and the valleys of the Xizang Autonomous Region in southern China (Roos et al., 2014).

This is possibly the first study anywhere to investigate the factors responsible for crop-foraging by any high-altitude langur species and suggest important steps for the mitigation of conflict over resources between langurs and humans, with implications for other nonhuman species residing in and sharing resources with people across the Himalayan landscape. Such a study is likely to be critical to understand human-nonhuman primate interactions inhabiting fragile Himalayan ecosystem for the betterment of both species.

In this context, our paper aims to: (a) provide a langur crop-foraging model with the help of socioeconomic factors as explanatory variables, (b) investigate farmer perceptions of forest loss in the past few decades in relation to habitat loss and crop-foraging by langurs, and (c) evaluate the relationship between Banj oak patch density and its use as langur feeding and sleeping sites.

## 2. Materials and methods

### *2.1. Study site*

This study was conducted in the Mandal valley, Chamoli district of Uttarakhand state in the Central Himalayas of India, at an altitude range between 1500 masl−1800 masl (Sharma et al., 2009, Fig. 1). The Mandal valley has five villages, namely Gondy (G), Kunkuli (KU), Khalla (KH), Mandal (M) and Siroli (SI). The home ranges of two langur troops, S and K, lay within the study site. Troop S's home range covered Gondy, Siroli and Kunkil villages, while Troop K's home range included the Mandal and Khalla villages. The mean average temperature (±SE) of the study site ranges from a maximum of 16.41 (±3.60) °C to a minimum of 6.14 (±1.98) °C. The mean annual rainfall is typically 2044.47 ± 476.01 mm (State Forest Department climate data for 1988−2005, cited in Sharma et al., 2009). The socioeconomic conditions and agricultural practices of the valley have been described in detail by Sharma et al. (2009) and Iqbal et al. (2014).

### *2.2. Questionnaire data*

A total of 215 households, comprising >90% of all households, from the five study villages were surveyed between October and December 2015 (Table 2). A structured questionnaire was given to one adult member of each household surveyed. Whenever possible, the adult woman of the household was given the questionnaire, as they appeared to have more accurate knowledge of the forest and agricultural fields, being responsible for most work done in the fields. The questionnaire was divided into three parts: Socioeconomics, crop damage by langurs and people's perception about reduction of forest resources.

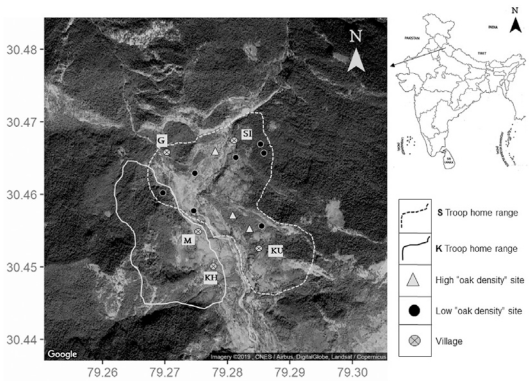


**Fig. 1.** Map of the study area, estimated home ranges of Troop S and K, the study villages and the Troop S sleeping sites.

### 2.3. Sleeping site and feeding patch use data

Sleeping site and feeding patch data collection took place between August and December 2018 on Troop S. Although we had identified two troops, K and S, in the Mandal valley, we focused on the already habituated Troop S, for this part of this study. The troop ranged over an area of 2 $km^2$. We also selected Troop S because a maximum of respondents (85% from village SI and 100% from village KU) from this troop's home range reported crop-foraging by langurs (Fig. 1). The members of this troop lived in a multi-male multi-female social group, comprising 78 individuals that included eight adult males, 32 adult females, seven subadult males, nine subadult females and 22 infant and juvenile males and females.

We recorded the location of langur sleeping sites, the tree species and feeding patch sites used to quantify habitat use patterns and to assess the relative value of different resources to the langurs. Sleeping site occupancy was recorded for 112 nights from August to December 2018. The troop was located in the early hours before sunrise at the sleeping site and was followed to the next sleeping site in the evening. The troop members typically spread out and occupied more than one tree to sleep on each evening. To keep track of this usage, every single tree that was used at least once at a sleeping site was identified to species level and marked with an alphabetical code for re-identification. Tree re-use was then scored to quantify sleeping tree species preferences. Each re-used tree had a total score greater than zero while a tree that was used only once had a re-use score of zero.

Direct and indirect methods were both used to determine sleeping sites. In the direct method, a troop was followed to the sleeping site and location was confirmed once the troop settled down at that particular site. The indirect sleeping site confirmation method, as has been employed for other primates, involved the finding of fresh fecal material under and around particular trees the next morning (Liu and Zhao, 2004; Cui et al., 2006; Stewart and Pruetz, 2013).

A feeding patch was defined as a locality that was utilized by langurs for their feeding activities for a period of at least 30 min. Feeding patches were identified during whole-day follows of the troop (N = 115 days, from August to December 2018). All individual feeding patches visited over a single day were coded according to their nearest sleeping site to quantify habitat-use patterns. On some occasions, the feeding patches were located near more than one sleeping site. For observations of feeding behavior, we conducted 20-min scan sampling sessions at 10-minute intervals (Altmann, 1974). We followed the troop for a total of 1035 h, with comparable hours of observation spent each month during the study period. A hand-held GPS (Garmin GPSMAP 62s, Garmin, Olathe, Kansas, USA) was used to mark the locations of the langur sleeping sites and feeding patches recorded during the study.

### 2.4. Vegetation data

We used the Point-Centered Quartered Method (PCQM) (see Mitchell, 2010) to estimate oak tree density at each sleeping site. PCQM was first developed by Stearns (1949), then evaluated through a comparison of different methods by Cottam and Curtis (1956). It is an efficient and economic plot-less method that has also been shown to be flexible across sample sizes (Cottam and Curtis, 1956), while causing minimal damage to the understory of the forest (Cunningham, 2001). We established 30-m line transects in the vicinity of the langur sleeping and feeding sites and recorded our data at 10-m intervals to avoid the possibility of repeating bias. At the points where measurements were taken, we drew a line perpendicular to the transect line to generate four quarters and measured the nearest tree in each of these four quarters. Although ideally no limit should be set for the "nearest" tree, we set a limit of 30 m (equal to one transect length) while identifying the nearest tree.

### 2.5. Statistical analysis

We built generalized linear mixed-effect models (GLMM) to analyze people's responses to our questionnaire regarding crop-foraging by langurs and reduction in forest resources surrounding the study villages. For the first model, we used people's perceptions of crop-foraging by langurs ('Present' or 'Absent') while the second model used people's perceptions of loss of forest vegetation in village forests ('Agree' or 'Do Not Agree') as binary response variables. In each model, socioeconomic variables such as household income, agricultural landholding, agricultural production and total number of livestock were the predictor variables. We included the total number of interview subjects (one individual from each of the 215 household was interviewed) and the villages as control variables. We specified each model with a binomial error structure and logit-link function using maximum-likelihood estimation with the package *lme4* (Bates et al., 2015) in R, version 3.5.3 (R Core Team, 2019). In R, we ran tests for homogeneity of residuals and variance inflation factors (VIF) below of around 1 (Field et al., 2012). We used an information theory approach based on Akaike's information criterion (IT-AIC) for model selection (i.e., variable selection) to extract the best model to explain human-langur interaction (Burnham and Anderson, 2002). The principle of this approach relies on ranking of the model from the candidate set of models based on smallest AIC value (Burnham and Anderson, 2002). Using the *"aictab"* function from the package AICcmodavg, we extracted the AIC value for each statistical model separately and then performed model comparisons (Mazerolle, 2016). This function also measures the model's Akaike's weight, or relative likelihood, and accumulative weight of each model that indicates the extent to which one model is more likely than another in explaining the variance in the data. The model characteristics are presented in Table 1. For both models, we first compared the full model with interactions between the socioeconomic factors with that without any interaction. We retained the model with the interactions if it outperformed the model without them and then tested it against

**Table 1**
Model characteristics.

| Models | K | AICc | ΔAICc | Weight | Cum.weight | Log-likelihood |
|---|---|---|---|---|---|---|
| **crop-foraging by langurs** | | | | | | |
| Integrated | 7 | 188.56 | 0.00 | 0.55 | 0.55 | −87.01 |
| Land-Pro-Live | 6 | 188.96 | 0.40 | 0.45 | 1.00 | −88.28 |
| Inc-Pro-Live | 6 | 202.94 | 14.38 | 0.00 | 1.00 | −95.27 |
| Pro-Live | 5 | 203.01 | 14.45 | 0.00 | 1.00 | −96.36 |
| Live | 4 | 213.27 | 24.71 | 0.00 | 1.00 | −102.54 |
| Income-Land-Pro | 6 | 216.43 | 27.87 | 0.00 | 1.00 | −102.01 |
| Land-Pro | 5 | 218.57 | 30.01 | 0.00 | 1.00 | −104.14 |
| Income-Pro | 5 | 238.68 | 50.13 | 0.00 | 1.00 | −114.20 |
| **Resource loss in village forests** | | | | | | |
| Land-Pro-Live | 6 | 265.53 | 0.00 | 0.29 | 0.29 | −126.56 |
| Pro-Live | 5 | 265.54 | 0.02 | 0.29 | 0.59 | −127.63 |
| Live | 4 | 266.85 | 1.32 | 0.15 | 0.74 | −129.33 |
| Income-Pro-Live | 6 | 267.58 | 2.05 | 0.11 | 0.84 | −127.59 |
| Integrated | 7 | 267.62 | 2.10 | 0.10 | 0.95 | −126.54 |
| Land-Pro | 5 | 270.05 | 4.52 | 0.03 | 0.98 | −129.88 |
| Pro | 4 | 272.01 | 6.49 | 0.01 | 0.99 | −131.91 |
| Income-Land-Pro | 6 | 272.15 | 6.62 | 0.01 | 1.00 | −129.87 |

Note. ΔAICc: difference in the AICc between the model with the lowest AICc and the following one; AICc: Aikaike's information criterion corrected for small sample size; Cum. weight: Cumulative weight; K: Number of variables included; Land: Landholdings (ha); Live: Total number of livestock; Pro: Crop Production (Kg); Weight: Model probabilities.

the null model, which contained only the intercept term. Alternatively, we carried out the same procedure for a model without interactions using the likelihood ratio test (LRT) and the package *lmtest* (Zeileis and Hothorn, 2002).

Sleeping- and feeding patch usage by langurs were assessed using the Poisson parameter. We first generated the frequency distributions of sleeping site re-use (Sokal and Rohlf, 1995; Day and Elwood, 1999) and then tested the differences in expected and observed distributions for the observed frequency range using the Kolmogorov-Smirnov test. Polynomial regression models were used to examine possible relationships between oak tree density and the re-use of sleeping sites and feeding patches. The models were fitted using the '*lm* ()' command in R (James et al., 2013), in order to predict the re-use of sleeping and feeding sites. We used the re-use of sleeping and feeding sites as response variables and oak density as the predictor variable in both the models. We fitted models up to 5th power of oak density to assess the relationship between usage of sleeping sites and feeding patches, and oak density, while maintaining the lower order terms in the equation in each advanced model. We compared the efficiency of these models in explaining the relationship, using Multiple R-Squared value and Residual Standard Error, for the four models. We consecutively compared the four models using the information theory approach based on Akaike's information criterion (IT-AIC) to determine the model with highest explanatory power. The model characteristics are presented in Table 4. The fitted quadratic and cubic model coefficients were further used in building the model equations. These equations, derived from the quadratic and cubic models, were used to simulate the re-use of sleeping sites and feeding patches, in Microsoft Excel. We increased the oak density in step size of 1 to graphically predict the shoot-up point in the re-use of sleeping sites and feeding patches with increasing oak density, and examined whether the re-use values reach an asymptote.

## 3. Results

### *3.1. Demographic, educational and economic characterization of the study villages*

The demographic, education and economic details of each of the study villages are shown in Table 2. At the time of the study, the total population of Mandal valley was 1,055 people. The mean (±SE) household size was 5.1 (±0.14) individuals (N = 215 households). Siroli village, with 75 households, was the most populous amongst the villages surveyed. More than 90% of the population in the Mandal valley was educated (up to higher secondary level). The mean monthly income per household across the study villages was INR 14,986 (±1402 ~ USD 237 ± 23; N = 215), with that of Mandal village being marginally higher than those of the other four villages. Villagers from Mandal and Khalla had more land and a higher annual crop yield, as compared to the other villages. The main crops produced in Mandal valley, like elsewhere in the region, were finger millet *Paspalum scrobiculatum* (*Koda* in Garhwali), barnyard millet *Echinochloa frumentacea* (*Jhangora* in Garhwali), wheat, and rice. All of these crops are used only for domestic consumption, as the Himalayan region is unsuitable for large-scale crop production because of the limitations of available space. The annual crop yields varied across the five villages. Siroli village, with its high population, also had more livestock. All households maintained bullocks for plowing the fields and cows for milk. To supplement their income, many households in the valley sold cow and buffalo milk as well. Goats and sheep were kept for consumption of their meat.

**Table 2**
Variation in the household demographic and socioeconomic variables among five villages in the study area (N = 215 households).

| Village | Total number of households | Total population | Percentage educated population | Total livestock population | Average/household | | |
|---|---|---|---|---|---|---|---|
| | | | | | Annual production (kg) | Total agriculture land holdings (ha) | Total annual income (INR) |
| Gondy | 33 | 155 | 92 | 98 | 319 | 5.0 | 179939 |
| Khalla | 53 | 261 | 91 | 152 | 539 | 10.8 | 177500 |
| Kunkuli | 23 | 117 | 87 | 105 | 244 | 6.1 | 181043 |
| Mandal | 33 | 171 | 93 | 92 | 448 | 8.3 | 210879 |
| Siroli | 73 | 351 | 90 | 375 | 249 | 3.5 | 186895 |

### 3.2. Crop-foraging by langurs in the Mandal valley

Our analysis of langur crop-foraging ('Present' or 'Absent') indicated that the GLMM model with interactions between land characteristics and agricultural production across the landscape did not outperform the corresponding model without any interaction, but did outperform its corresponding null model (LRT; ΔLogLik = 34.99, Δdf = 4, p = 2.3e-14). Our results (Table 1) thus indicate that the integrated model with the lowest AICc value of 188 was the best, given the set of eight candidate models, which comprised the variables of landholdings, agricultural production, total number of livestock and income. The economic status of the respondents had no effect on the crop-foraging issues raised by them (GLMM; z = 1.577, p = 0.1150; Table 3). Villagers with relatively less cultivated land tended to report more crop-foraging by langurs (GLMM; z = −3.676, p = 0.0003). Agricultural crop production had a significant effect on crop-foraging, with respondents having lower agricultural production reporting relatively higher levels of crop-foraging by langurs (GLMM; z = −2.105, p = 0.0034). Finally, the total number of livestock had a highly significant effect on the villagers' response towards crop-foraging by langurs; those with large livestock holdings reported more crop-foraging (GLMM; z = 4.842, p = 1.29e-06; Fig. 2) (see Photo Plate 1).

### 3.3. Reduction of forest resources in the Mandal valley

An analysis of perceived reduction of forest resources in the valley revealed that the model with interactions between land characteristics and agricultural production did not outperform the corresponding model without these interactions, but it did perform better than its respective null model (LRT; ΔLogLik = 7.35, Δdf = 4, p = 0.006). The model that combined the variables of landholdings, crop production and total number of livestock had the lowest AICc value of 265 and was the best, given the set of eight candidate models (Table 1). The income level of the villagers had no impact on their opinions about forest resource loss in the forests surrounding the villages (Fig. 3). Farmers' perception of forest resource loss was neither related to total agricultural landholdings (GLMM; z = −1.432, p = 0.1494) nor to agricultural production (GLMM; z = −1.517, p = 0.1293). The total number of livestock holdings, however, had a significant effect on farmers' perception of forest resource loss, with respondents having more livestock reporting a greater degree of resource loss in the village forests (GLMM; z = 2.529, p = 0.0114). Such loss particularly resulted in a perceived decrease of fodder availability, a possible indication of high competition for forest resources among villagers with relatively more livestock (Fig. 3).

### 3.4. Use of oak as sleeping tree

The study langur troop used a total of 306 unique trees to sleep in, on 96 nights. These trees belonged to 17 different species (Fig. 4). The troop seemed to have exhausted their utilization of unique sleeping trees, as an asymptote was reached

**Table 3**
GLMM analysis of crop-foraging by langurs and resource loss in the village forests in the study area.

| Best model (Likelihood of crop-foraging by langurs) | | | | |
|---|---|---|---|---|
| | | | AIC | *df* |
| | | | 188 | 210 |
| **Fixed factors** | **Estimate** | **SE** | **z value** | **p value** |
| Income | 0.637 | 0.405 | 1.577 | 0.1150 |
| Landholdings (ha) | -2. 248 | 0.612 | -3.676 | **0.0003** |
| Crop production (Kg) | -2.105 | 0.718 | -2.105 | **0.0034** |
| Total number of livestock | 4.125 | 0.853 | 4.842 | **1.29e-06** |
| **Best model (likelihood of resource loss in village forests)** | | | | |
| | | | **AIC** | ***df*** |
| | | | 265 | 210 |
| **Fixed factors** | **Estimate** | **SE** | **z value** | **p value** |
| Landholdings (ha) | -0.620 | 0.433 | -1.442 | 0.1494 |
| Crop production (Kg) | -0.867 | 0.572 | -1.517 | 0.1293 |
| Total number of livestock | 1.451 | 0.574 | 2.529 | **0.0114** |

**Table 4**
Model characteristics.

| Models | K | AICc | ΔAICc | Weight | Cum. weight | Log-likelihood |
|---|---|---|---|---|---|---|
| **Sleeping site re-use by langurs** | | | | | | |
| Quadratic | 4 | 74.30 | 0.00 | 0.66 | 0.66 | −29.15 |
| Cubic | 5 | 75.65 | 1.34 | 0.34 | 1.00 | −25.32 |
| Degree-4 polynomial | 6 | 85.80 | 11.50 | 0.00 | 1.00 | −22.90 |
| Degree-5 polynomial | 7 | 113.24 | 38.93 | 0.00 | 1.00 | −21.62 |
| **Feeding site re-use by langurs** | | | | | | |
| Quadratic | 4 | 75.79 | 0.00 | 0.98 | 0.98 | −29.90 |
| Cubic | 5 | 83.81 | 8.02 | 0.02 | 1.00 | −29.41 |
| Degree-4 polynomial | 6 | 98.12 | 22.33 | 0.00 | 1.00 | −29.06 |
| Degree-5 polynomial | 7 | 127.68 | 51.68 | 0.00 | 1.00 | −29.74 |

Note. ΔAICc: difference in the AICc between the model with the lowest AICc and the following one; AICc: Aikaike's information criterion corrected for small sample size; Cum. weight: Cumulative weight; K: Number of variables included; Weight: Model probabilities.

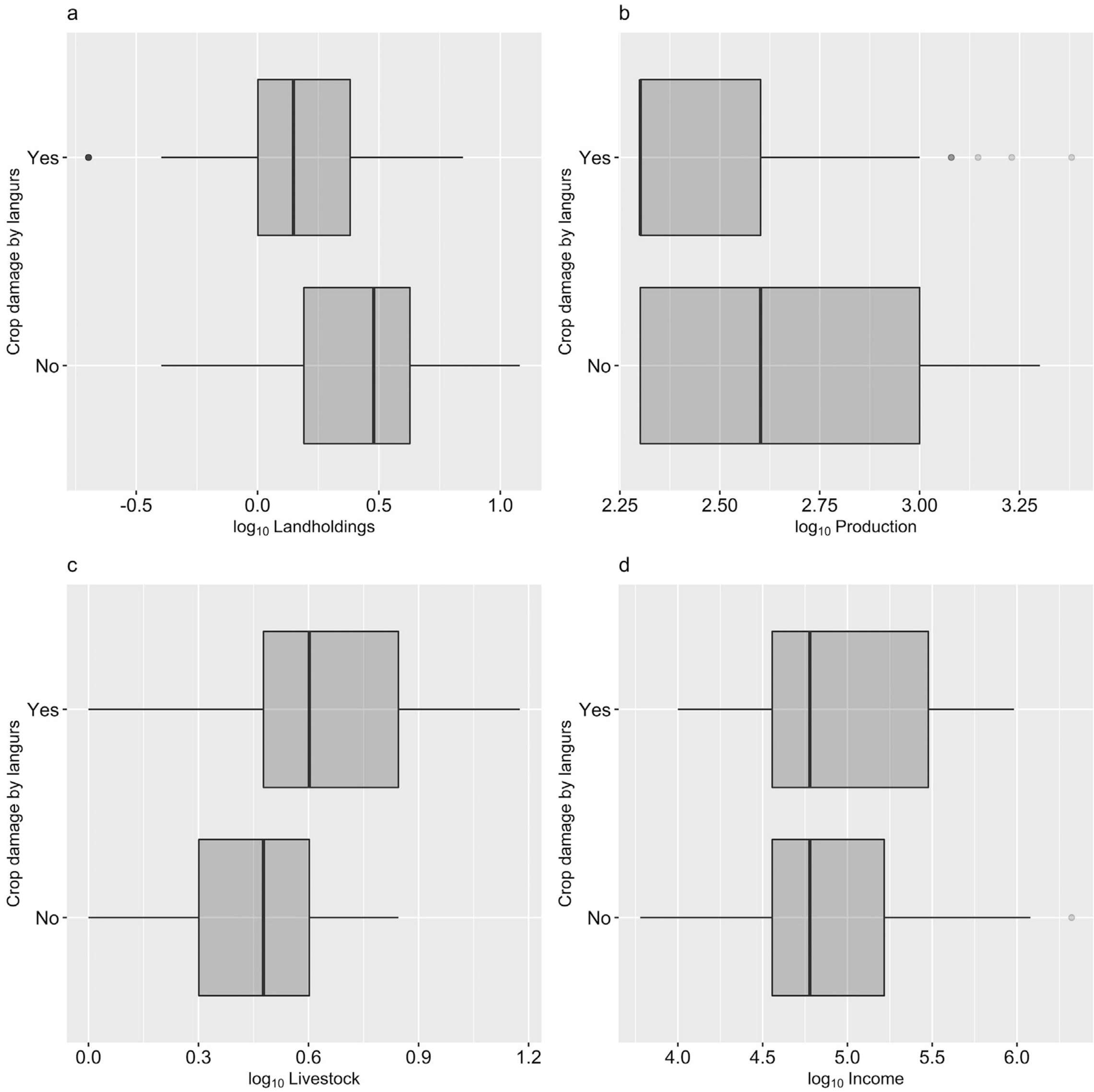


**Fig. 2.** Villagers' response to crop damage by langurs in relation to socioeconomic factors (n = 215). Residuals were extracted from generalized linear mixed-effect models (GLMM) with log-number of **(a)** landholdings (ha), **(b)** agricultural production (kg), **(c)** livestock (total number), and **(d)** income per villager (INR) as the predictor variables. The box bounds the IQR (equal distance between first and third quartiles) divided by the median while the whiskers extend to a maximum of 1.5 × IQR beyond the box.

**Photo Plate 1.** Crop-foraging by Troop S in the Mandal valley, including feeding on (a) mustard plants, and (b) on wheat. (c) Village and agricultural land in the Mandal valley landscape, and (d) oak forests on the hillsides.

for the cumulative number of unique sleeping trees over the observation period. The highest represented species in the pool of unique sleeping trees was oak *Quercus leucotrichophora*, with 181 trees (59.15%). The langur troop re-used oak trees periodically (136 times), more than they did all other species combined (88 times) (Chi-square test, $\chi^2 = 10.286$, df = 1, p = 0.0014; Fig. 4).

### 3.5. Sleeping and feeding site selection

The langurs used 14 sleeping sites, out of which we present vegetation data for 10 sites across 112 observation nights. An asymptote in the cumulative number of sleeping sites was reached after 60 days of observation. Five sleeping sites, constituting approximately 50% of all sites, were used only once or twice, one was used thrice while the remaining sites were used most of the time. The expected number of nights that a troop stayed at each sleeping site was eight (Fig. 5a). A significant difference between the expected and the observed frequency of usage of sleeping sites was found (Kolmogorov-Smirnov test, $\chi^2 = 0.72727$, p = 5.256e-08; Fig. 5a). The langurs used some feeding sites more than they did others. On some occasions, the feeding patches were located near more than one sleeping site. We observed 125 instances of usage of a patch as a feeding patch, spread across 14 sleeping sites. On average, 8.92 feeding patches were located adjoining to a sleeping site (Fig. 5b). The distribution of feeding patches across sleeping sites was significantly different from a random distribution, indicating that there was a preference for feeding in certain areas, as compared to others (Kolmogorov-Smirnov test, $\chi^2 = 0.65385$, p = 2.98e-05; Fig. 5b).

### 3.6. Relationship between oak density and habitat use

#### 3.6.1. Sleeping site re-use

The coefficients of both, the quadratic term (t = 2.479, p = 0.0423) and the cubic term (t = 2.627, p = 0.0392) in the polynomial regression models were significant predictors of the usage of sleeping sites. The cubic model differed significantly from the quadratic model (ANOVA; F = 6.612, p = 0.0422) while the higher order models beyond the cubic did not differ significantly from the previous lower order models(ANOVA; F = 3.096, p = 0.1388). The quadratic model had the lowest AICc value and Akaike weight of 0.66 while the cubic model only differed slightly from the quadratic model in terms of its AICc value ($\Delta$AICc = 1.34, Table 4). The quadratic model explained the usage of sleeping sites better than did the other three models. This relationship showed that the highly dense oak patches were regularly used as a sleeping sites by the langurs. Certain high oak-density sites such as FC (233 trees $ha^{-1}$), KOP (208 trees $ha^{-1}$), SROP (207 trees $ha^{-1}$), in particular, were re-used by the langurs 32 (36.78%), 19 (21.84%) and 14 (16.09%) times respectively during the study. Sites such as MASL, SFI and SFII, where oak was not present, in contrast, were used by the langurs only on one or two occasions (Fig. 6a). The graphical

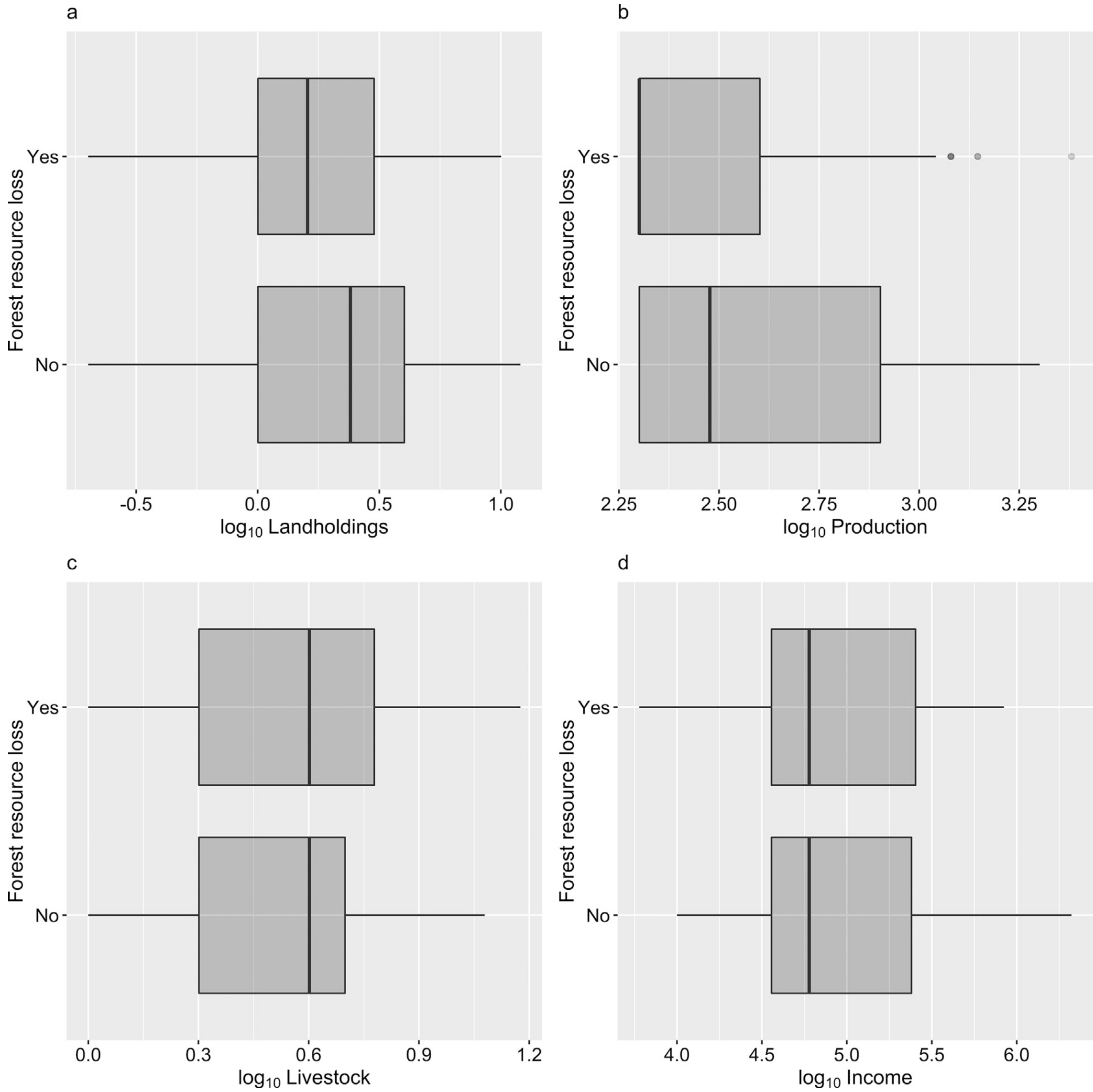


**Fig. 3.** Villagers' response to resource loss in neighboring forests in relation to socioeconomic factors (n = 215). Residuals were extracted from generalized linear mixed-effect models (GLMM) with log-number of **(a)** landholdings (ha), **(b)** agricultural production (kg), **(c)** livestock (total number), and **(d)** income per villager (INR) as the predictor variables. The box bounds the IQR (equal distance between first and third quartiles) divided by the median while the whiskers extend to a maximum of 1.5 × IQR beyond the box.

results from the quadratic regression equation show that up to a certain value of oak density, the usage of oak patches decreased, albeit going into negative values, and then gradually began to increases after a density of 95 trees $ha^{-1}$ (Fig. 6b).

### 3.6.2. Feeding site re-use

The quadratic model coefficient was alone a significant predictor of the re-use of feeding patches by the study langurs ($t = 1.924$, $p = 0\ .0957$) while no other model yielded significant values. The quadratic model had the lowest AICc value with an Akaike weight of 0.98 (Table 4). The quadratic model explained the usage of feeding sites better than did the other three models. Oak density did not, therefore, influence the choice of feeding patches as strongly as it governed the choice of sleeping sites (Fig. 7a). The most frequently visited feeding patches were the top high-density oak patches namely FC, KOP and SROP, which were used by the langurs 41 (26.11%), 47 (29.94%) and 24 (15.29%) times respectively. Vegetation patches with no oak in them, as may be expected, were the least visited sites (Fig. 6). The graphical results from the quadratic regression equation shows that the usage of oak patches as feeding patches gradually increased after a density of 192 trees $ha^{-1}$ (Fig. 7b) (see Photo Plate 2).

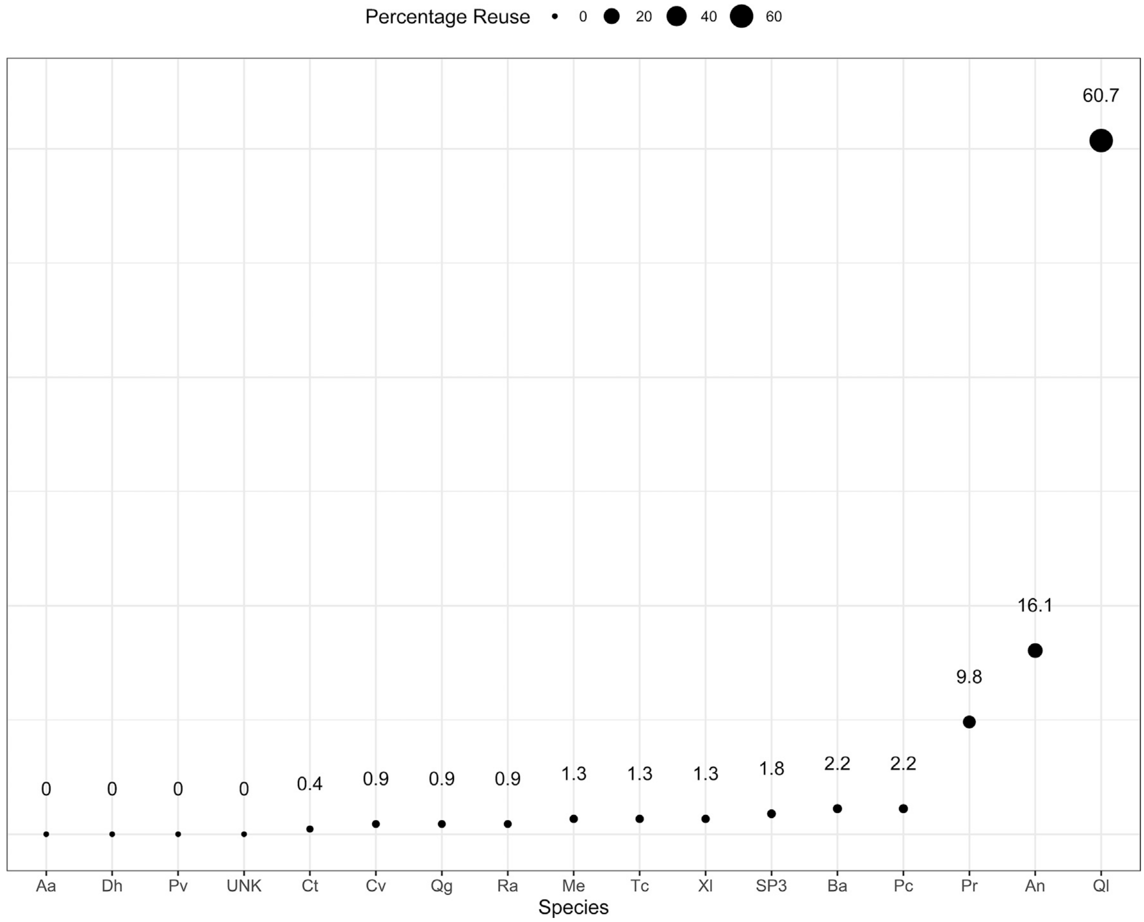


**Fig. 4.** Percentage re-use of the 17 recorded tree species, chosen as sleeping trees by the study langur troop. A total of 224 trees were re-used during the study period out of the 306 unique sleeping trees.
Note. Aa – Ailanthus altissima, Dh – Daphniphyllum himalayense, Pv – Prunus venosa, UNK – Undefined species, Ct – Cupressus torulosa, Cv – Carpinus viminea, Qg – Quercus glauca, Ra – Rhododendron arboreum, Me – Myrica esculenta, Tc – Toona ciliata, Xl – Xylosoma longifolia, SP3 – Kakaru (vernacular name. scientific name unavailable), Ba – Betula alnoides, Pc – Prunus cerasoides, Pr – Pinus roxburghii, An – Alnus nepalensis, Ql – Quercus leucotrichophora

## 4. Discussion

### *4.1. Over-exploitation of Banj oak as a potential driver of crop-foraging by langurs*

Our results show that villagers, who owned relatively more agricultural land and had good production throughout the whole year, had low interactions with langurs due to their low dependency on natural resources for their livestock. Farmers with relatively less agricultural land and low productivity depended significantly on livestock for extra income and thus relied more on the neighboring forest for grazing their cattle and collecting fodder for them. This high pressure on the surrounding forests is likely to have been a driver for langurs to forage more on agricultural crops in these areas at times of the year when natural food availability in the forest was low. Moreover, respondents who owned a relatively greater number of livestock, as compared to other households, perceived a reduction in the available resources in the nearby forests due to their intensified use of the nearby forest areas for livestock fodder. Insufficient crop yields and small cash incomes have typically led households of Mandal valley to depend heavily on forest resources (Sharma et al., 2009). Based on previous studies by Sharma at al. (2009) and by Singh and Rawat (2012), which investigated three villages in the Mandal valley - Khalla, Siroli and Mandal, the daily fodder consumption per household was observed to be significantly correlated with the number of livestock per household. Hence, we suggest that this increased livestock-driven pressure on the forest compels wild herbivores to compete with livestock for food. This may also help explain the reportedly higher crop damage to households that had more cattle and had their perceptions of significant loss of resources in the village managed forests. Agricultural land, annual crop production and livestock populations thus emerged to be the strongest predictors of crop damage by langurs in the Mandal valley.

Livestock formed an important part of subsistence activities for the human communities in the valley and there appeared to be high competition for forest resources among villagers with more livestock. In particular, the dependence of these

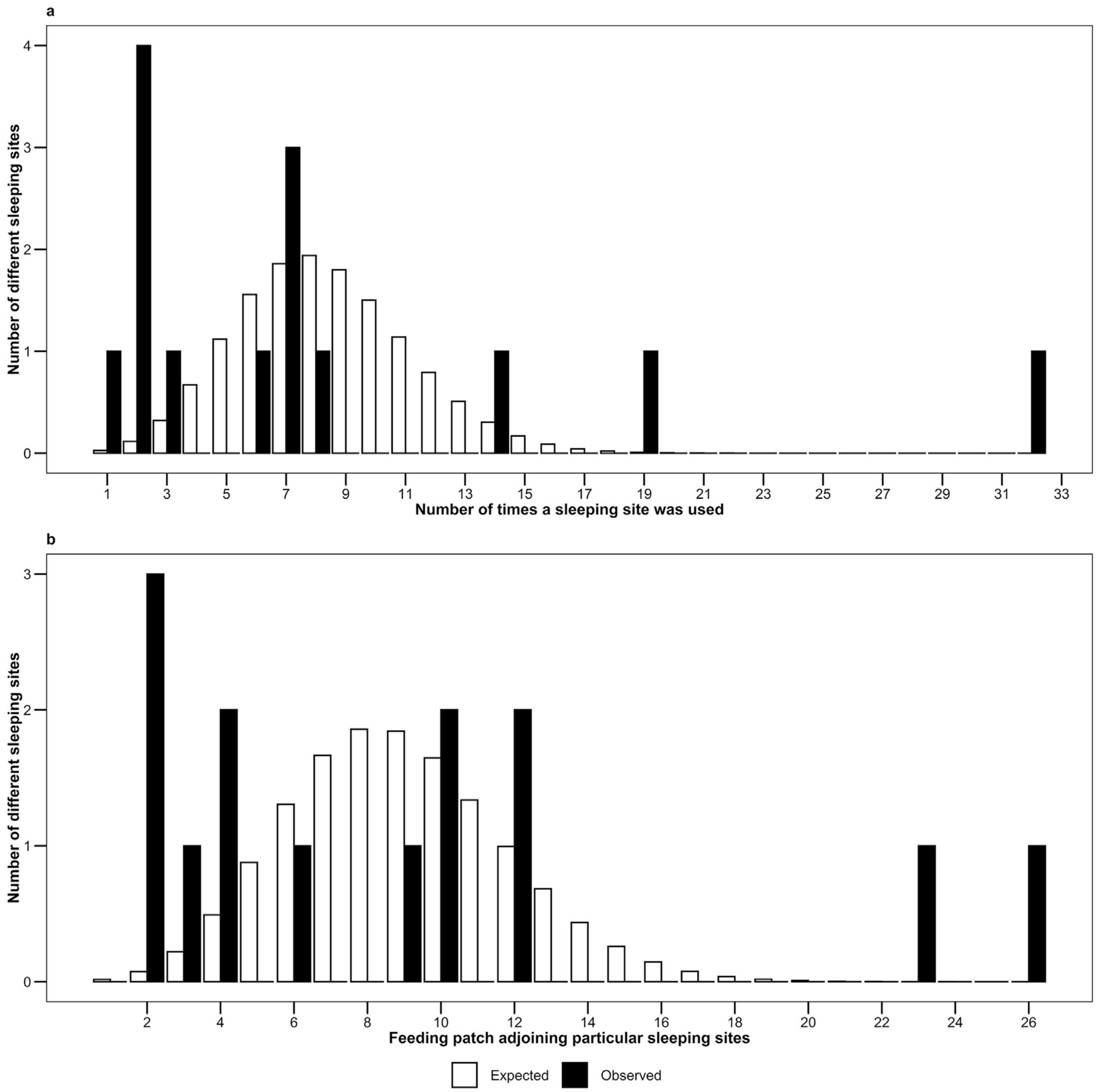


**Fig. 5.** Frequency of use of particular sleeping sites and of feeding patches by the study langur troop. The observed and expected values were derived from a Poisson distribution.

communities on the oak forests for fodder, cattle grazing and for fuel wood generated considerable stress on the forests surrounding these villages and appeared to be a major cause of degradation of Banj oak (Singh et al., 2016). A vegetation study conducted by Gairola et al. (2010) in the Mandal valley had found Banj oak *Quercus leucotrichophora* to be the dominant tree species at altitudes between 1500 and 1800 masl while this species, in general, contributed significantly to the climax plant communities of the Western Himalayas (Singh and Singh, 1992; Awasthi et al., 2003). Persistent cutting down of a forest's dominant species ultimately causes canopy gaps and reduced leaf fall, which, in turn, negatively affects the return of nitrogen to the soil. This changes ecosystem dynamics and consequently leads to poor regeneration across the forest (Yadav and Gupta, 2006).

In the Mandal valley, Banj oak branches are typically removed during winter for livestock fodder and for fuel (Singh and Rawat, 2012). An earlier study of the Central Himalayan langur in the Mandal valley also found that oak was one of the most important food in the winter diet of the species (Nautiyal, 2015). This investigation also showed Banj oak trees, especially at high-density sites, to be chosen more over other tree species as food and also as sleeping trees. The high dependency of the

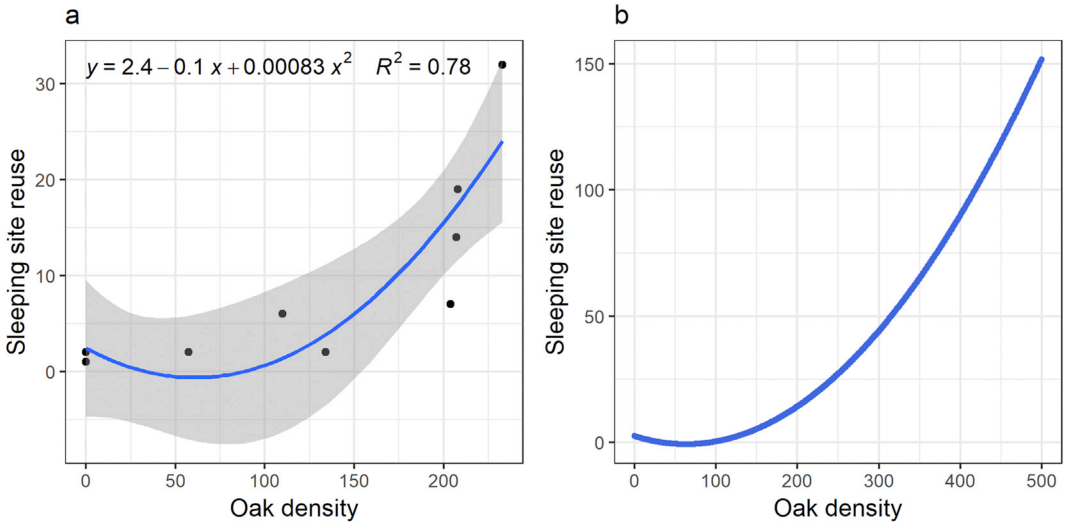


**Fig. 6.** Relationship between oak density (trees/ha) and re-use of those locations as sleeping sites, including (a) the observed relationship from 10 sleeping sites, and (b) simulated data derived from the quadratic regression equation.

villagers on this oak was, therefore, likely to be the primary factor leading to the reduction of dense oak patches within langur home ranges, thus driving them to raid agricultural fields for food, causing high levels of crop damage. Moreover, the langurs were unable to utilize all parts of their home range equally because of the loss of high-density oak patches. This, in turn, seemed to make them frequently re-use some sites more than others, leading to overcrowding at the sleeping sites and a further reduction of their food resources near these sites.

### *4.2. Can Quercus replanting promote peaceful coexistence between human and langurs?*

At the current rate of global agricultural land expansion, agro-economic models predict a significant reduction of wildlife habitats by 2050, with farmlands occupying an additional 200–300 million hectares across the world (Schmitz et al., 2014). Habitat loss due to anthropogenic activities is a key factor driving the decline in the number and habitats of many wildlife species in their native habitats. It now seems evident that the affected species can perhaps only be conserved by devising strategies for peaceful coexistence of humans and wildlife (Woodroffe et al., 2005), mainly by stemming habitat loss and minimizing negative human-animal interactions. One of the important steps in this direction would be to improve traditional techniques as well as develop new control methods to prevent crop-foraging by primates (Strum, 1994). Understanding the foraging and ranging ecology of the target nonhuman species is an obvious first step for the development of such mitigation strategies (Hill, 2005). Our study thus proposes a model incorporating the behavioral ecology of the target species and certain socioeconomic variables to address the suitable mitigation of crop-foraging by the study langur population. We recommend a long-term solution: the active conservation of *Quercus* forests and regeneration of high-density patches of the species, which serve not only as a critical food source for langurs during the harsh Himalayan winter (Nautiyal, 2015) but is also necessary to provide them with shelter and protection from potential predators. This model, we believe, may be applicable to a wide variety of wildlife species residing in forest-agricultural ecotones, not just in the Himalayan ranges but in other landscapes as well. Animal crop-foraging, especially by primates, is often directly correlated to key food resource availability in forest habitats (Strum, 1994; Treves, 1998; Siex and Thomas, 1999; Tweheyo et al., 2007; Hockings et al., 2009) and hence, a detailed understanding of the key food plant species in decline and the role of these species in the diet of the target wildlife species should be a priority in formulating conflict mitigation strategies.

*Quercus* species have been widely reported as important food sources for Himalayan langurs residing in marginal habitats across their distribution range. One of the pioneering studies conducted in the Indian Himalaya by Sugiyama (1976), for example, showed that *Quercus incana* fruits were the most important food resource for langurs in all six months of the study. Furthermore, for langurs inhabiting alpine meadows, where food resources are scarce throughout the year and negligible in winter, their main food, before the onset of harsh winter, was *Quercus semecarpifolia* (Nautiyal and Huffman, 2018). Minhas et al. (2010) suggested that *Quercus incana* was one of the essential species used both as sleeping trees and as an important food resource in both summer and winter by langurs in the Hindu Kush Himalayan range. Similarly, Bishop (1975) noted that in the Nepal Himalaya, *Quercus semicarpifolia* was often used as sleeping trees and as an important food source for the local langur populations.

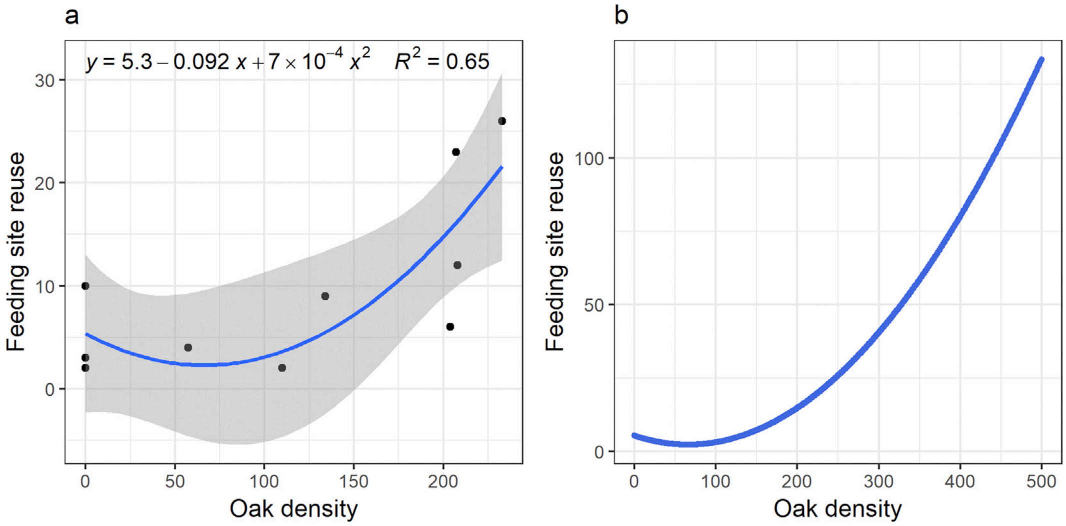


**Fig. 7.** Relationship between oak density (trees/ha) and re-use of those locations as feeding sites, including (a) observed relationship from 10 sleeping sites, and (b) simulated data derived from the quadratic regression equation.


**Photo Plate 2.** Habitat use by Troop S in the Mandal valley, including (a) feeding on Banj oak acorns at the edge of Siroli village, and (b) using Banj oak as a sleeping tree. Dependency of the Mandal valley villagers on Banj oak, showing collection of oak leaves for (c) making cattle beds, and (d) cattle fodder.

### *4.3. Future goals for coexisting with langurs*

Based on the results of this study, we have already identified and begun to implement three short- and long-term activities to help mitigate human-langur conflict in the Mandal valley; these activities are also likely to be applicable to other similarly affected areas in other *Quercus*-dominated regions. (1) Replanting efforts: As the degradation of the local forests, oak trees in particular, through human activities seems to have resulted in a decrease of available food and shelter resources for langurs, in turn leading to the observed recent increase in crop-foraging at our study sites, we have initiated the restoration of the degraded oak forest through planting of *Quercus* in the forests surrounding the study villages and intensifying the planting of alternative fodder trees other than oak. We hope that this would help reduce langur visitation rates at the villages and their raiding of the adjacent crop fields. (2) Environmental education outreach: Environmental-awareness outreach towards young children is a rather important strategy for forest protection. as they are the future decision-makers and can potentially influence the behavior of their parents now by discussing with them what they have learnt at school. We have begun outreach programs in government primary schools in each village by engaging them in different competitive activities to enhance their interest toward nature. Taking children into the forest also offers them first-hand experience with wildlife that they might not have otherwise been exposed to, free of the cultural interpretations of the value of wildlife from the perspective of adults, who often see wildlife as a threat, not as a source of knowledge. (3) Empowerment of women in the community: Nearly 95% of all agricultural work, the collection of fodder and of firewood is done by women. In spite of their central role as caregivers and providers, they receive very little return for their efforts other than producing the resources that the family needs to subsist on. Providing basic education and the means of obtaining alternative incomes empowers women, providing them with alternative choices and means to sustainably utilize forest resources, and this, in turn, indirectly promotes the conservation of wildlife and natural resources.

Our study thus establishes that crop damage by wildlife is often brought about in part by the human activities that the local communities indulge in to maintain their precarious livelihoods and to enhance their economic base. They obviously cannot be blamed for this but it is, nevertheless, important to increase conservation efforts to protect the local environment and the wildlife that it supports, while also improving the daily lives of the farmers. These two endeavors need to be strongly interconnected, as is clearly evident from our explorations on this high-altitude farming community, as indeed may be the situation for many others across the greater Himalayan region of the Indian subcontinent.

## 5. Conclusions

Our study is possibly the first ever on crop-foraging by a Himalayan langur species, with important implications for other Himalayan zones. Our questionnaire surveys clearly revealed the ecological importance of Banj oak in habitats where socioeconomic conditions and low agricultural production appeared to be the main reasons for over-exploitation of forest resources for use as animal fodder. This was clearly perceived by the respondents to have led to an increase of conflict in the form of crop-foraging by langurs. Our findings also show Banj oak tree, especially at high-density sites, to be chosen more over other trees as food and also sleeping site. The high dependency of the villagers on this oak is, therefore, likely to be the primary factor leading to the reduction of dense oak patches within langur home ranges, driving them to raid agricultural fields for food and causing high levels of crop damage. Based on our results, we propose here a resource management strategy for mitigating human-langur conflict and promoting their coexistence, which could be applied to habitats dominated by *Quercus* spp. and where langurs and humans are both highly dependent upon this resource for survival. This model, we believe, may be applicable to a wide variety of wildlife species residing in forest-agricultural ecotones, not just in the Himalayan ranges but in other landscapes as well.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2020.e00985.

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