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Full Length Research Paper

A case study of termite mound occurrence in relation to forest edges and canopy cover within the Barandabhar forest corridor in Nepal

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The Barandabhar forest corridor (BFC) in the Royal Chitwan National Park is an example of a buffer zone implemented to mitigate the effect of local communities on conservation and the effect of conservation on local communities. However, the effectiveness of these actions for conservation may depend on the intensity of human activity and the species considered. We conducted a field survey within the BFC to study how termite mound occurrences relate to forest edges, human activity and canopy cover, and to examine the spatial patterns of the edge effect in terms of dead wood availability, logging and canopy cover. The results show that termite mound abundance was significantly affected by edge effects such that the abundance increased from ~5 mounds/ha along the edge to ~14mounds/ha in the core areas 2 km inside the forest. The forest edge was partly defined by decreased canopy cover and increased signs of logging. Our results suggest that buffer zone practices may be a valid method to mitigate edge effects on termites in core areas. However, we also found indications of human activities effecting canopy cover that could influence the effectiveness of buffer zone management in this area.

Key words: Chitwan, isoptera, spatial distribution, dead wood, gap dynamic, disturbance, microclimate, buffer zone, edge effect**.**

INTRODUCTION

Buffer zone practices are widely used strategy for mitigating the impacts of conservation on local communities and local communities on conservation (Wild and Mutebi, 1997). For example, in Nepal, buffer zones around the Royal Chitwan National Park (RCNP) may be used by local communities for the collection of natural resources such as dead branches and fallen logs (Nepal and Weber, 1995; Straede and Treue, 2006). Such harvesting may support community development in the region by providing local communities with important resources. At the same time, positive effects of buffer zone practices on conservation may be derived from mitigation of edge effects and lowering human activities inside protected core areas. For some species, the buffer zone itself may also function as complimentary core areas. Nevertheless, conflicts between the different objectives may influence buffer zone usefulness.

The effectiveness of buffer zone practices for conservation may depend on the species considered and their ecology, human demography and economical uses of the area (Groom et al., 1999). Meanwhile, the urgent need of nature-based development may cause overexploitation (Straede and Helles, 2000), which could

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compromise the effectiveness of conservation efforts. Thus, the level of sustainable exploitation is in practice hard to evaluate (Wells and Brandon, 1993). Since most efforts to monitor response from human activities on wildlife lies in surveying large and charismatic mammals (Joshi et al., 1995; Kanagaraj et al., 2011; Martin, 1998; Pradhan et al., 2008), the effects on lower taxa might have an overlooked, although prominent role in conservation (Chakravarthy et al., 2008). Some taxa may despite their uncharismatic appearance have significant and far-reaching effects on many important properties of ecosystems.

Termites (Isoptera) are a group of organisms whose activities may have a disproportionately large impact on the environmental conditions faced by other species (Jones et al., 1994; Jouquet et al., 2006; Moe et al., 2009). The activities of such 'ecosystem engineers' (Jones et al., 1994; Mills et al., 1993) may increase environmental heterogeneity (Jouquet et al., 2004, 2005) and thus promote coexistence and biodiversity (Bartel et al., 2010; Choosai et al., 2009). For example, termite activity in association with mound construction may create patches rich in nutrient and thus increase landscape heterogeneity in otherwise nutrient deficient landscapes (Jouquet et al., 2005; Moe et al., 2009). Moe et al. (2009) showed that the density of termite nests explained 89% of the variation in floral community composition and diversity. Given this potentially large influence, the environmental factors effecting the spatial distribution of termite mounds may have a prominent importance for the understanding of the ecology of diverse ecosystems. Therefore, termites as an important ecosystem engineer in many habitats should arguably be a priority in conservation and management efforts (Crain and Bertness, 2006).

For Nepal, the published literature on termite ecology and conservation is limited. Joshi and associates (Joshi et al., 1997, 1995, 1999) found that the sloth bear (*Melursus ursinus* (Shaw)) was dependent on termites as a complimentary food source during parts of the season, suggesting that the biotic association between this mammal and termites is strong. Although the data presented in Joshi et al. (1997) indicates that mound building termites may prefer sal (*Shorea robusta* Gaertn. f.) forests over grasslands and upland forests over riverine forests, direct studies on the environmental requirements of termites in Nepal are scarce. Such scarce knowledge is compromising for the understanding of termite ecology in the region and may restrict conservation efforts.

The objective of this study was to broaden the knowledge of termite ecology in Nepal by investigating how termite mound occurrence relates to forest edges and canopy cover within the BFC of the RCNP buffer zone. Since the BFC borders human settlements, we further wanted to describe the characters of human induced edge effects within the same corridor in terms of dead wood availability (available logs and snags), logging (occurrence of stumps) and canopy cover. Edge effects, whether they are anthropogenic or natural, may have a pronounced influence on various organisms ranging from birds (Flaspohler et al., 2001), mammals (Goosem, 2000), and insects (Rand et al., 2006) to plants (Alverson et al., 1988; Gehlhausen et al., 2000). Such effects can be both positive and negative (Caruso et al., 2011; Goosem, 2000) and may occur as a consequence of changes in microclimate (Caruso et al., 2011; Gehlhausen et al., 2000), resource availability and predation pressure (Alverson et al., 1988; Rand et al., 2006).

Forest activities may affect conservation in Nepal (Thapa and Chapman, 2010; Webb and Sah, 2003) and are known to effect termites in other regions by influencing canopy cover (Dibog et al., 1999; Vasconcellos et al., 2010). Based on previous studies, we hypothesized that the placement of termite mounds should be affected by: (i) edge effects through a mechanism of (ii) canopy cover. We further hypothesized that iii) part of the edge effect within the corridor would be affected by human harvest activities in a declining gradient away from forest edges.

MATERIALS AND METHODS

Study area

The survey was conducted inside the BFC located in the northern part of the RCNP buffer zone (27°35´N, 84°27´E; Figure 1). The RCNP is a semi-pristine remnant of the Terai region which once covered the foot of Himalayan range through India and Nepal. RCNP is well renowned for its diverse habitats and the many endangered species roaming the area (Heinen and Kattel, 1992). The maximum daily temperature in the region is reached in May to July with 30°C, while the minimum temperature is 15°C in January. Most of the precipitation falls during the summer monsoon in June through September, when 80% of the annual 1900 mm falls as heavy rainfall. The soils are mainly alluvial with a 5 to 15% slope and generally with a shallow ground water table (Dhakal et al., 2011).

The BFC was established for the Indian rhinoceros and the Bengal tiger within RCNP to access the upland forests and mountain habitats during the monsoon when the lowlands are flooded. Within the buffer zone on both sides of the corridor, human settlements are present and the area is used for grazing and agricultural purposes (Figure 1). The forest corridor is also subjected to community-based harvesting of natural products like fuel wood and timber. Consequently, the forest corridor is likely to be under the influence of edge effects from the surrounding matrix (Figure 1). The area is dominated by sal but also associated with Asna (*Terminalia tomentosa* Wight & Arn), Barro (*Terminalia belerica* (Gaertn.)) and Kyamun (*Syzygium cerasoides* (Roxb.)). At our survey location, patches of the forest were occasionally disrupted by smaller areas of grassland and swamps which prevail as a consequence of seasonal flooding events during the monsoon (Figure 2).

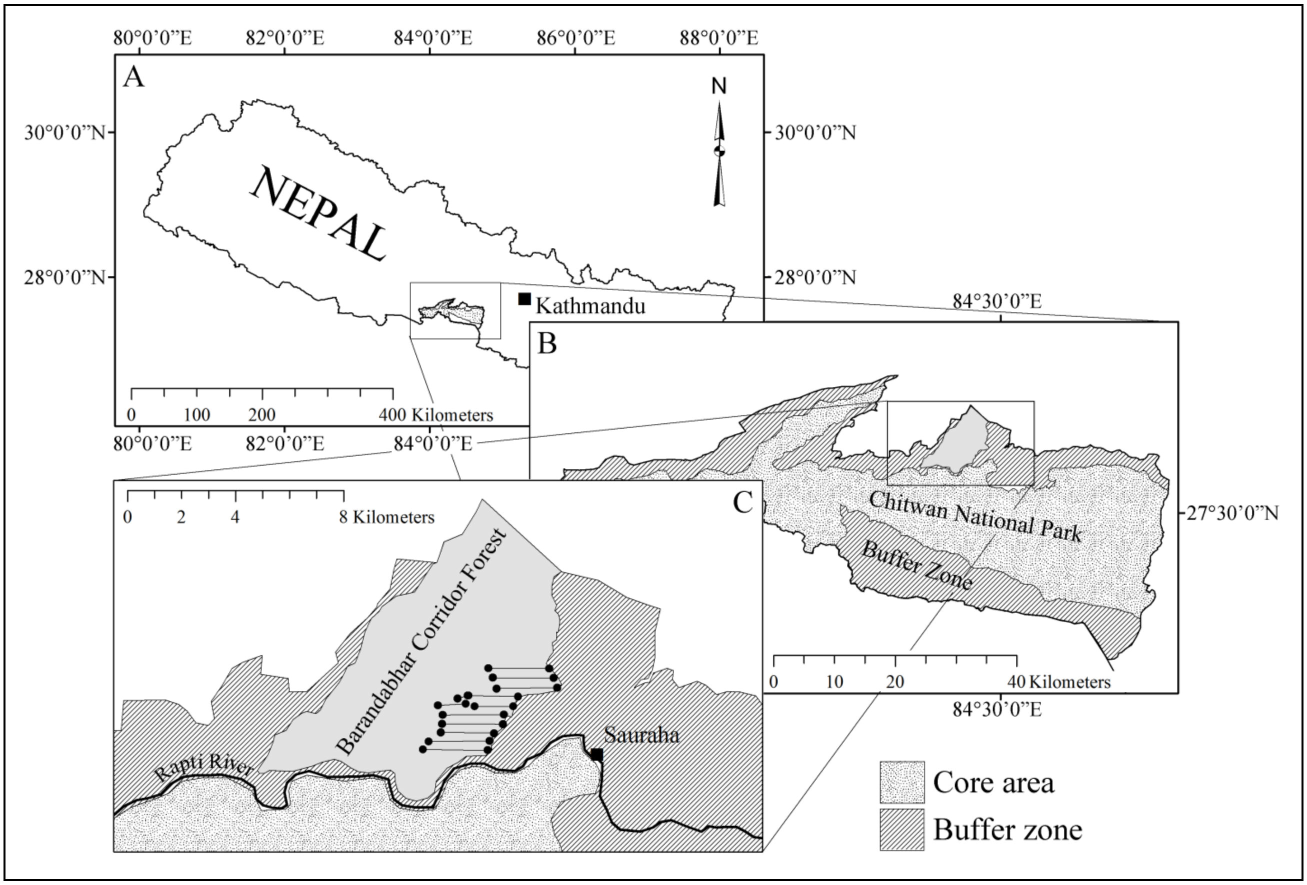

Figure 1. Nepal (A) with Chitwan National Park (B) and the Barandabhar Corridor Forest (C). The ten transects within the Barandabhar corridor forest can be seen in map C. The areas on both sides of the forest corridor consist of scattered human settlementsin a matrix of fields used for agriculture and grazing. Thus, the transect direction is likely to express human induced edge effects decreasing away from the settlements in the east.

Termite taxonomy

As previously mentioned, the knowledge concerning termites in the area is limited. However, Joshi et al. (1997) mentioned five termite genera (*Macrotermes*, *Odontotermes*, *Microcerotermes*, *Hypotermes* and *Reticulitermes*) found in the diet of sloth bears in the RCNP. In our study, we were strictly forbidden to further investigate the mound building termite species found during the survey. The visual impressions in shape and colour of the mounds was however similar throughout, although observed size differences ranged from ~20 cm to mounds that was more than 3 m high (Figure 3). Termite mounds were typically located in the forested areas and never occurred in the seasonally flooded grasslands (Figure 2), and mounds were constructed both alone and in association with tree trunks. Local communities traditionally harvest these mounds for mushrooms, suggesting that they belong to some of the fungus-growing taxa. The size of the mounds points to the fact that the surveyed termites belong to the Macrotermes genera (anonymous reviewer).

Field survey

Between the 27 February and 3 March in 2010, we established 10 transects in the BCF. The transect were placed in an east to west direction, separated from each other by 400 m and had a length of 2000 m each. The direction and length of transect permitted surveys throughout a forest gradient likely subjected to edge effects in the east (e.g. close proximity to areas used for grazing, agriculture and human settlements) and at the west of core forests. Along each transect, all termite mounds and dead wood objects (e.g. logs, high stumps and low stumps) within a distance of 5 m on each side of transects were surveyed, covering a total of 20 hectares. The transect width also enabled the detection of fairly small objects despite the presence of an occasionally dense understory.

The survey was restricted to visibly active or intact mounds. Mounds that were degraded or destroyed with no signs of activity were excluded. We also estimated the size of each mound in a three level scale (e.g. <90 cm = level 1, 90 – 185 cm = 2 and >185 cm = 3). Coordinates of each mound and dead wood object were recorded with a GPS (Garmin^{TM} GPSmap 60CS) and we later used these coordinates to calculate distances from the transect start-points (forest edge) in appropriate software (ESRI 2009). A small lake intercepted transect six and seven and these sections were consequently marked with the GPS and excluded from the total transect length (Figure 1; Total excluded length ~200m). The occurrence of mounds and dead wood objects were later pooled

Figure 2. Photos taken from the same position but in opposite directions illustrating habitat differences in the dominating forested area, which was utilized by termites for mound construction (A) and the seasonally flooded grassland in which termite mounds was absent (B). In the picture of the forested area, two termite mounds can be seen (centre and far right).

into blocks of distances of 100 m each- that is, objects found within the first 100 m of each transect were pooled into the first group and the objects found within the next 100 m were pooled into group two and so on.

To study the light exposure along the transect, we took a photo of the canopy at 100 m distances from the starting point of each transect with a four-megapixel (Fujifilm Finepix A340) digital camera. Thus, each photo corresponds to one unique 100 m block. To further assist interpretation of the effect of light exposure on mound placement, a photograph of the canopy were also taken above each mound. The percentages of visible sky on all the photos were calculated using the magic-wand and the pixel-count functions in Photoshop Elements (Ver. 8.0, 2009). Photos shot over termite mounds associated with tree trunks that were blocking large part of the canopy, were excluded from the analyses. Similarly, reference photos associated with areas categorized as open grassland were also omitted. Thus, the canopy-cover survey addresses the placement of termite mounds within forested areas only, not including the seasonally flooded and by termites avoided grasslands (Figure 2A and B, respectively). In agreement with the strict management regulations of the area, all surveys were observational and conducted with non-invasive methods.

Statistical analysis

To explore the predictors of termite mound abundance, we used a multiple linear regression including the distance to edge, average canopy cover and the average number of dead wood objects (logs, snags and stumps) as explanatory variables. Since distance was

Figure 3. Termite mounds were occasionally quite large and with increased height the complexity of the mound typically increased.

Table 1. A matrix showing the correlations among the independent variables.

Data	Distance	Light	Logs	Snags	Stumps
Distance		**-0.474**	-0.100	-0.092	**-0.455**
Light	**0.035**		0.170	-0.153	0.438
Logs	0.674	0.474		0.051	0.336
Snags	0.700	0.519	0.830		-0.032
Stumps	**0.044**	0.054	0.148	0.894	

The values on the upper right side of the vertical line are correlation values and the ones on the lower left side are *p*-values for each combination. Significant correlations are highlighted in bold.

correlated with both canopy cover and number of stumps (Table 1) and to assist interpretation, we reported the results both from the full model and a model excluding distance as an explanatory variable. The best multiple regression models were selected based on AIC criteria with the function "stepAIC" (Venables and Ripley, 2002). In the univariate linear regression with distance from forest edge as explanatory variable, we used the average number and size of mounds, the average number of dead wood objects and the average percentage of visible sky. To compare canopy cover over termite mounds with reference photos, we used variance tests and the nonparametric two-sample Wilcoxon tests. All statistical analyses were conducted in the statistical software R (Ver. 2.13.0).

RESULTS

In total, we recorded 168 termite mounds along the 10 transects, which gave a mean abundance of 8.4 mounds/ha. After AIC optimization, the main factor significantly influencing termite mound occurrence was the distance from forest edges (Table 2; $P < 0.01$). These analyses further predict that the termite mound abundance increased from approximately 5 mounds/ha along the edges to approximately 14 mounds/ha in the core areas 2 km into the forest (Figure 4a). The same model without distance showed, however, that stumps had a marginally significant effect (Table 2; $P < 0.10$). Analyses comparing canopy cover over termite mounds with canopy cover of reference points showed that the variances of the samples differed ($F = 0.3596$, $P < 0.001$), and the subsequent nonparametric test was significant; e.g. photos taken over termite mounds had

Table 2. Results from the regression analysis with number of mounds and mound height as response variables and stumps, snags, logs, light and distance from the edge as independent variables.

Response variables	Adj. R2	F	p	Best fit model
All variables except distance				
Number of mounds	0.34	5.98	0.011	- 0.02 Light - 0.54 Stumps†
Mound height	0.17	4.78	0.042	0.01 Light*
Distance				
Number of mounds	0.40	13.49	0.002	0.00 Distance**
Mound height	-0.06	0.00	0.941	- 0.00 Distance

†: < 0.1; *< 0.05; **< 0.01.

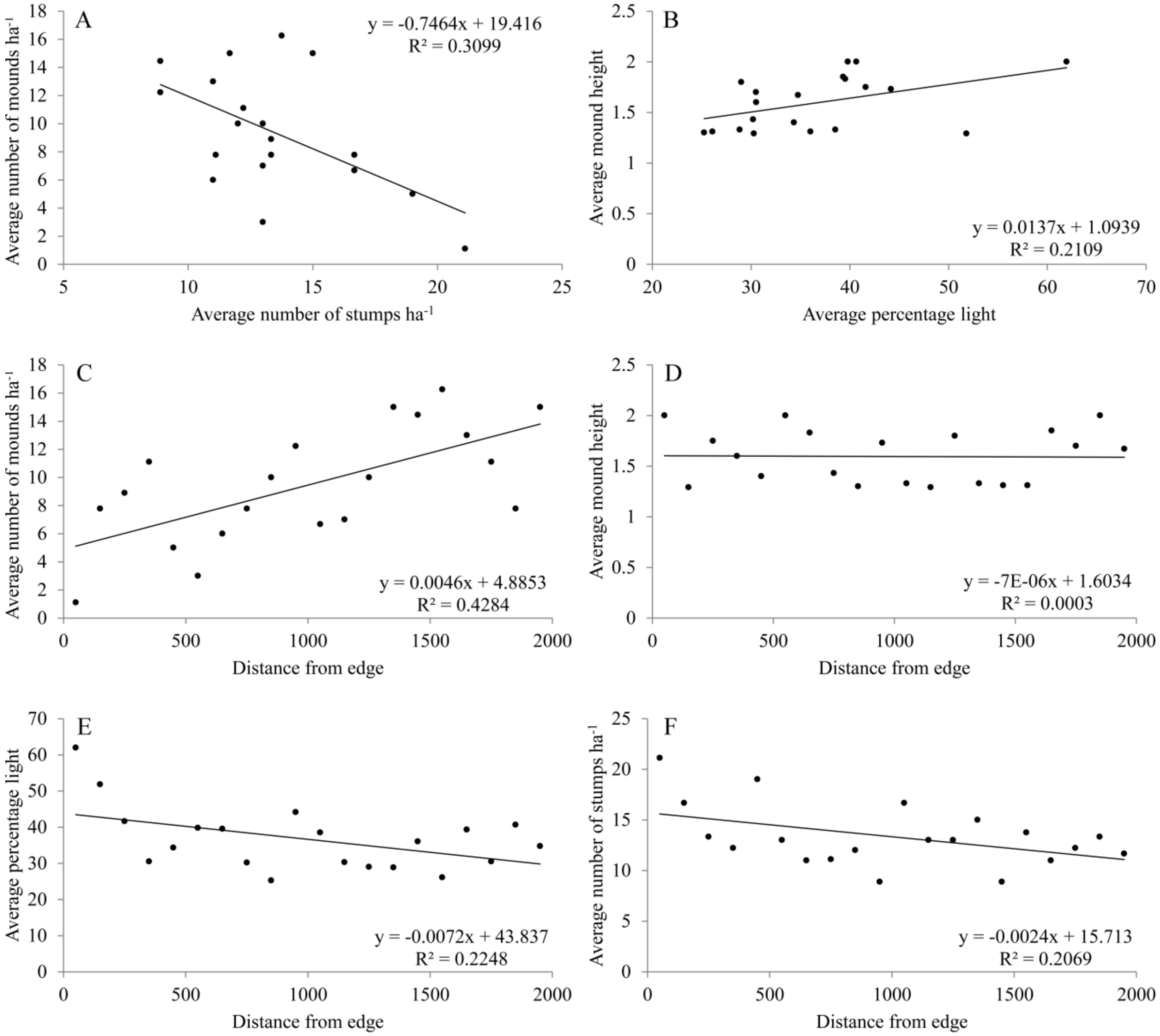

Figure 4. Graphs (A – D) showing the models from the regression analysis and graphs E and F are showing the significant relations from the correlation analysis.

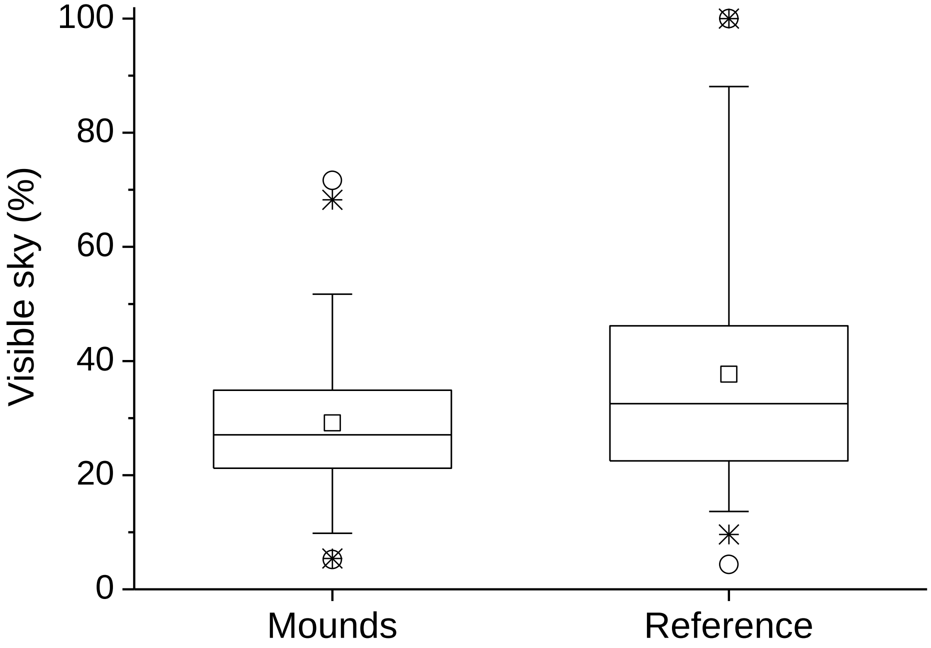

Figure 5. Box plot showing the distribution o f termite mounds and reference points in relation to visible sky measurements. Squares, stars and circles designate the mean, 1 and 99% percentile, and max and min values, respectively.

significantly lower values of visible sky compared to reference photos (Figure 5; *P* < 0.001). The analyses of edge effects showed that the number of stumps and the percentage of visible sky decreased with increasing distance from the forest edge (Figure 4c and f). The occurrence of high stumps and logs was in this study not dependent on distance from the forest edge (Figure 4d and e).

DISCUSSION

The objective of this study was to add to the limited knowledge of the ecology of termites in Nepal by investigating how the spatial distribution of termite mounds within the Barandabhar Forest Corridor relate to forest edges near the settlements located outside the corridor, and to explore possible edge effects of importance. Along with our first hypothesis, the occurrence of termite mounds was influenced by edge effects such that the abundance increased 2.8-fold in core areas compared to edges. Although our second hypothesis was not accepted (e.g. canopy cover had no significant effect on termite mound abundance), the confirmation of our third hypothesis (e.g. the forest gradient is partly determined by human activity) suggests that canopy cover and the number of stumps partly defined the change along the forest gradient. Further, the complimentary analyses on canopy cover above mounds suggest that mounds predominately occurred in sites with denser canopies. Thus, our results give partial support on the opinion that canopy cover may influence termite mound occurrence.

The reason why mounds were predominately located in the core of the corridor is likely due to some environmental aspect influencing site suitability along the edge. One apparent aspect of the forest gradient studied here was that core areas generally had a denser canopy cover compared to edges. Dibog et al. (1999) showed that denser forest plantations harbored higher abundances of termites than stands with thinner canopies and argued that canopy cover is important due to its influence on sun exposure, micro climate conditions and ground moisture. These parameters are all influential attributes potentially affecting the environmental conditions along the forest edge. Microclimate may influence termites (Korb and Linsenmair, 1998a), and termites construct their mounds in part to regulate these conditions (Korb and Linsenmair, 1999; 2000). Thus, an appropriate mound site in terms of microclimate may put less demand on the regulation efficiency of the mound (Korb and Linsenmair, 1998b).

However, Gardner and Gerrard (2002) showed that canopy cover in the forests of Nepal had a significant influence on rainfall runoff and soil erosion. Heavy rain followed by soil erosion events might have a direct eroding effect on termite mounds. We did observe termite mounds that were degraded (presumably by rainfall) during our field survey. Unfortunately degraded mounds were not included in our sampling and we can consequently not relate this to canopy cover or forest edges. It is noteworthy that our analyses further showed that canopy cover also influenced the height of mound with larger mounds predominantly occurring in sites with a more open canopy. Mound size could potentially be an important factor both for mound climatic regulation, and mound prevalence in rain exposed sites. Meanwhile, the actual mechanism behind why termite mounds predominately occurred under denser canopies away from edges remains to be explained.

The conservation benefits from buffer zones are typically mitigation of adverse effects of the surrounding matrix on core areas. Such influences may be made up by various effects which typically decline with the distance to the edge. In our study, edge effect was predominantly expressed through signs of selective logging (e.g. stumps was more abundant in the edge) and that the edges had a more open canopy. Although other attributes of forest edges may be ecologically important for various organisms (Alverson et al., 1988; Caruso et al., 2011; Gehlhausen et al., 2000), these results indicate that the edge effect studied herein is in part due to human activities. Environmental sensitivity such as suggested herein may be critical in systems subjected to anthropogenic disturbance. Results from studies addressing similar topics suggest that human activities in Nepal may affect other attributes such as forest structure and floral diversity (Christensen and Heilmann-Clausen, 2009; Dhakal et al., 2011; Thapa and Chapman, 2010). Thus, it is possible that thinning of multi-use forests may influence site suitability. Furthermore, given that edge effects did influence termites, it is possible that human activities causing forest fragmentation may lower the effective forest area that actually can be utilized by these mound building termites. In this respect, it may also be important to consider the possible effect of termites on associated flora and fauna as observed in other regions (Bartel et al., 2010; Choosai et al., 2009). If anthropogenic disturbance affects termites, this could influence the prevalence of other taxa as well.

Nevertheless, the results from this study also highlights the value of implementing buffer zone practices in conservation planning as previously suggested (Shafer, 1999). The numbers of termite mounds increased with the distance to the edge which indicate that the implementation of buffer zones may to some extent facilitate termite prevalence in core areas. Buffer zone practices have shown effectiveness for various organisms (Freidenfelds et al., 2011; Thorell and Götmark, 2005) and the results presented herein indicate that this may to some extent also hold for forest dwelling mound building termites in the BFC. However, as mentioned herein, the effectiveness of buffer zones will likely depend on the level of exploitation.

Conclusions

So far, the occurrence of termite mound was significantly affected by edge effects. This edge effect was characterized by denser canopies in core areas, which in part may results from human activities such as selective logging along the edge. The results obtained herein not only suggest that buffer zones may help mitigate edge effects on termites but also that the effectiveness of such practices may depend on exploitation levels. We believe that multi-function buffer zones used for extraction activities would be most effective for conservation if placed outside focal areas rather than incorporating community development activities into such high priority set asides. Balancing socio-economical needs and conservation goals will be a future challenge.

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