Response of the Endangered red panda *Ailurus fulgens fulgens* to anthropogenic disturbances, and its distribution in Phrumsengla National Park, Bhutan

PEMA DENDUP, ELLEN CHENG, CHOKI LHAM and UGYEN TENZIN

Abstract Across much of Asia protected areas have a dual objective of conserving biodiversity and supporting rural and indigenous livelihoods. For the red panda *Ailurus fulgens* and other sensitive species of concern, even limited anthropogenic disturbance may influence their use of protected areas. We quantified the prevalence of timber collection and livestock grazing, and their impacts on red panda habitat use, in Phrumsengla National Park, Bhutan. Red pandas used sites with at least 20% bamboo cover, as evidenced by presence of their faecal pellets. They avoided sites disturbed by livestock, regardless of bamboo availability. Timber collection itself was not an important predictor of red panda presence but bamboo may be harvested opportunistically from sites where timber is collected. Conservation efforts for the red panda should not rely on protected areas alone but should explicitly consider and mitigate impacts of anthropogenic disturbances in protected areas.

Keywords *Ailurus fulgens*, bamboo, Bhutan, Himalaya, livestock, timber

Introduction

Globally 56% of the areal extent categorized under the IUCN protected area management system comprises category V or VI protected areas that support traditional and sustainable use of natural resources alongside biodiversity conservation (IUCN & UNEP–WCMC, 2016). Balancing human needs and ecological functions in protected areas is important, particularly when these sites are the home or resource base for indigenous and rural populations (DeFries et al., 2004). However, for some wildlife species of concern even limited anthropogenic disturbance can influence their use of habitat and persistence. For such species, inclusion in protected areas is not a sufficient substitute for direct conservation action.

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The red panda *Ailurus fulgens*, a cat-sized arboreal mammal of Himalayan temperate forests, may be one such species. Categorized as Endangered on the IUCN Red List, an estimated 10,000 mature individuals are distributed among five Asian countries (Glatston et al., 2015). Red pandas have been confirmed in 13 districts in Bhutan, 23 districts in Nepal, three states in India, one state in Myanmar, and three provinces in China (Dorji et al., 2012; Glatston et al., 2015).

As with many species for which few data beyond presence/absence are available, conservation of the red panda is frequently measured in terms of protected area coverage. In India and China c. 33 and 40% of potential red panda habitat is protected, respectively (Wei et al., 1999; Choudhury, 2001). Red panda habitat overlaps three protected areas in Myanmar and nine protected areas in Nepal (Glatston et al., 2015). Dorji et al. (2012) reported red panda presence in eight protected areas, one botanical park and several biological corridors in Bhutan. However, despite habitat protection and legislation against hunting in its range countries, red panda populations continue to decline. In China 40% of red panda populations may have been lost since the 1960s (Wei et al., 1999). Loss and fragmentation of bamboo habitats is a major threat to the survival of these obligate bamboo feeders (Yonzon et al., 1991). Poaching is also an increasing threat to the species' persistence (Glatston et al., 2015).

The effectiveness of current conservation efforts for the red panda is not well understood. In particular, the red panda's shy nature, slow reproductive rate and narrow ecological niche make it susceptible to anthropogenic disturbances. Human visitation and resource extraction are common in many of the > 2,800 IUCN-categorized protected areas in red panda range countries (Juffe-Bignoli et al., 2014). Therefore, even in protected areas designated for biodiversity conservation, human activities may be hampering recovery of red pandas and other sympatric species. We report here on the red panda's use of habitat in relation to subsistence-level timber extraction and livestock grazing in the 905 km^2 Phrumsengla National Park (formerly known as Thrumshingla National Park), an IUCN Category II protected area in Bhutan.

In Phrumsengla National Park and most other protected areas of Bhutan there are villages within the protected area borders. Resident communities are permitted to extract timber from protected areas within a 3–5 km multi-use zone buffering their village, or in any non-core zone. Each household can obtain a permit to cut 4,000 cubic feet (113.3 m^3) of

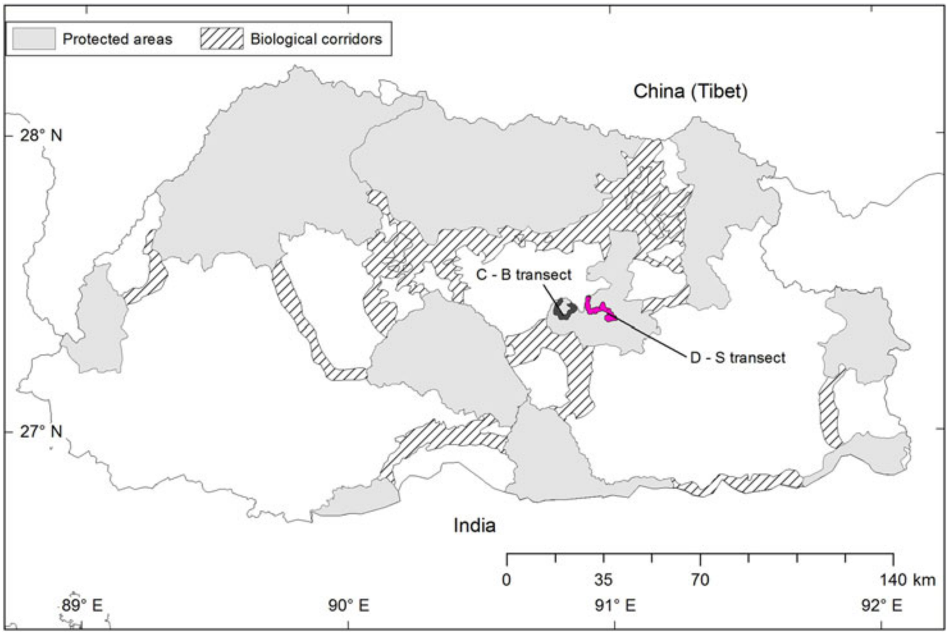

FIG. 1 Location of the Chungphel-to-Bribdungla (C–B) and Dangyungma-to-Sengor (D–S) transects in Phrumsengla National Park, Bhutan.

timber for new house construction every 25 years, and 1,000 cubic feet (28.3 m^3) for renovation and extension of their house every 3–5 years. Each household is also eligible for 200 cubic feet (5.7 m^3) of timber for other construction (e.g. cattle shed, store house, machinery shed) every 3 years (Ministry of Agriculture, 2006).

In the core zone of Phrumsengla National Park timber collection is usually concentrated within the multi-use areas surrounding villages. Livestock provide critical income for many rural households in Bhutan, including those in Phrumsengla National Park and other protected areas. Livestock are often allowed to stray in forests without restraint, unaccompanied by herders (Wangchuk, 2002), and therefore their impacts may extend far beyond the vicinity of a village.

In Bhutan collection of bamboo and most other non-wood forest products from public forests and protected areas requires payment of a royalty (Ministry of Agriculture, 2006). More than 40% of Bhutan's households collect bamboo, especially *Borinda grossa*, from forests to make mats, roofing, fencing, baskets and other household items (Royal Government of Bhutan, 2000). At the time of our study (2013–2014) most *Borinda grossa* in the study region was dead following mass flowering in 2009–2010, and therefore bamboo harvesting was relatively limited.

The extent and types of anthropogenic disturbances in Phrumsengla National Park are comparable to those reported for many protected areas of Bhutan and other red panda range countries. Our goal was to understand how timber extraction and livestock grazing, two traditional subsistence activities permitted in many protected areas of this region, affect habitat use by red pandas.

Study area

Phrumsengla National Park in central Bhutan (Fig. 1) is the site of a previous study of red panda associations with broad and fine-scale natural habitat attributes (Dorji et al., 2011). Mean annual rainfall is 700–1,500 mm, with most precipitation falling during May–August as part of the Asian monsoon. Approximately 1,000 species of plants and 70 species of mammals have been recorded in the Park (Nature Conservation Division, 2002). Dominant tree species include Bhutan fir *Abies densa*, blue pine *Pinus wallichiana*, Himalayan birch *Betula utilis* and Himalayan hemlock *Tsuga dumosa*. Common understorey plant species include rhododendrons (*Rhododendron* spp.) and bamboos (*Borinda grossa, Yushania microphylla, Yushania maling, Thamnocalamus spathiflorus* and *Chimonobambusa callosa*). Priority mammal species include the red panda, the Bengal tiger *Panthera tigris tigris*, the common leopard *Panthera pardus*, the Himalayan black bear *Ursus thibetanus* and the wild pig *Sus scrofa* (Nature Conservation Division, 2002).

Our study focused on two transects, Dangyungma-to-Sengor and Chungphel-to-Bribdungla, in the central and southern core zones of the Park. These transects were selected because they traverse areas where prime red panda habitat is juxtaposed with areas facing anthropogenic pressure from nearby human settlements. The two transects span three major forest types (cool broadleaved, mixed conifer, and fir) at 2,373–3,954 m elevation.

The 47 km Dangyungma-to-Sengor transect is located in the Park's central core zone and is part of Bhutan's Lateral Road. The Lateral Road was built in 1962 as the nation's primary east–west highway. Within a 15 m buffer of the transect there are 35 national camps housing road maintenance workers, who collect wood daily from the area for fuelwood and heating, especially during the winter. Sengor village (21 households) lies along this transect. Local people regularly traverse the transect to collect bamboo, timber and firewood. The transect is also used by the people of Ura village for moving cattle to their winter grazing grounds.

The 30 km Chungphel-to-Bribdungla transect is located in the Park's southern core zone. This transect is an unpaved walking trail frequented by people and livestock. Five villages (Zhuree, Chungphel, Bim, Tharpoling and Yirangbee), comprising 25 households in total, are located within a 1 km buffer of this transect. Local people use the transect for moving cattle and for collecting bamboo, timber and fuelwood.

Methods

Field survey

In December 2013 and January and February 2014 we conducted surveys of the Dangyungma-to-Sengor transect (one survey per month) for red panda signs and associated covariates. In the following winter we surveyed the Chungphel-to-Bribdungla transect, conducting one survey per month in October, November and December 2014. We conducted our surveys in winter because by this time of the year agricultural crops have been harvested and local people spend their time moving cattle, collecting fuelwood and extracting timber.

In an initial 2-week survey of each transect we established plot centres and collected data on plot use by red pandas, habitat and any anthropogenic disturbance. The two follow-up surveys were conducted in each plot to confirm data on red panda habitat use. Each of the six surveys (two transects × three surveys each) was conducted by the same trained personnel, following the same protocol.

At 1 km intervals along each transect we marked a plot centre in a random direction and at a random distance (0–800 m) from the transect. The maximum distance was set at 800 m because locations beyond this distance were largely inaccessible because of steep cliffs. Within a 50 m radius of each plot centre we searched for red panda faecal pellets, an indicator of the species' presence in the habitat. If red panda faecal pellets were found, the plot was categorized as present and the plot centre was shifted to the location of the faecal pellets for measurements of vegetation and any anthropogenic disturbance; otherwise, the plot was categorized as absent and the plot centre was not shifted.

To study vegetation, tree quadrats (10 × 10 m) were superimposed on the centre of each 50 m radius plot and understorey quadrats (4 × 4 m) were superimposed on the centre of the tree quadrats. Habitat measurements followed Schemnitz (1980). All vegetation covariates measured in tree quadrats (tree species, tree diameter, and downed logs > 30 cm diameter) and understorey quadrats (shrub species, % bamboo cover and % shrub cover) had been identified a priori from other research as having biologically meaningful relationships with red panda habitat use (Dorji et al., 2012; Zhou et al., 2013; Sharma et al., 2014a). In addition to vegetation covariates we recorded distance to nearest water source, defined as flowing streams or ponds, because close proximity to drinking water may be an essential requirement for red pandas (Yonzon & Hunter, 1991). Forest types were categorized based on the most common tree species recorded within a 50 m radius of the plot centre. Plots were characterized as cool broadleaved forest if they were dominated by broadleaf tree species, as mixed conifer if they were dominated by Himalayan hemlock and East Himalayan spruce, and as fir forest if the vegetation was primarily composed of fir tree species.

To assess the impacts of anthropogenic disturbances on red panda habitat use we recorded any signs of timber collection (e.g. lopping, girdling, harvest) or livestock grazing within a 50 m radius of the plot centre. Signs of livestock grazing included direct sightings, dung, and hoof prints. In addition, we recorded distance from plot centre to the nearest settlement (defined as at least one household or roadside camp) to account for other potential but unmeasured disturbances associated with human settlements (e.g. avoidance of feral dogs by red pandas). We recorded distance to road (i.e. Lateral Road for Dangyungma-to-Sengor transect and farm road for Chungphel-to-Bribdungla transect) because commuters often collect bamboo, and this activity may influence red panda habitat use.

Data analysis

We characterized each forest type (cool broadleaved, mixed conifer and fir) in the study area by the Shannon–Weiner diversity index, for tree species, and index of dominance, for understorey species (Panwar & Bharadwaj, 2005), pooled by forest type. Fisher's exact test (two-sided) was used to determine if there was non-random association between red panda habitat use and transect (Dangyungma-to-Sengor vs Chungphel-to-Bribdungla), or red panda habitat use and forest type. The Wilcoxon rank-sum test was used to explore relationships between anthropogenic disturbances and distance to nearest settlement or road. We generated a correlation matrix of predictor variables to identify highly correlated variables ($r > 0.70$) that should not be combined in a multiple regression model. Given the small sample size and data separation, we used Firth's penalized multiple logistic regression to model red panda habitat use as a function of anthropogenic disturbance and habitat variables. In addition to a global model comprising all variables, we analysed a subset of models representing various hypotheses about combinations of predictor variables likely to influence

TABLE 1 Characterization of tree and understorey diversity in the three forest types in study plots along the Dangyungma-to-Sengor and Chungphel-to-Bribdungla transects in Phrumsengla National Park, Bhutan (Fig. 1), with the Shannon–Wiener diversity index for tree species, and the index of dominance for understorey species.

Shannon–Wiener diversity index (H′) for tree species	Index of dominance for understorey species*
Fir forest (42 plots), 3,307–3,954 m	
Abies densa (5.23)	*Yushania maling*
Picea spinulosa (3.16)	*Rhododendron cinnabarinum*
Rhododendron kesangiae (2.98)	*Rosa sericea*
Acer sp. (0.74)	*Abies densa*
Betula utilis (0.73)	*Salix* sp.
Rhododendron hodgsonii (0.45)	*Rhododendron hodgsonii*
Juniperus recurva (0.09)	*Berberis asiatica*
Mixed conifer forest (16 plots), 2,677–3,295	
Picea spinulosa (3.32)	*Yushania maling*
Tsuga dumosa (3.10)	*Yushania microphylla*
Pinus wallichiana (2.52)	*Berberis asiatica*
Abies densa (1.45)	*Rosa sericea*
Larix griffithiana (0.68)	*Pinus wallichiana*
	Piptanthus nepalensis
	Rhododendron arboreum
Cool broadleaved forest (7 plots), 2,373–2,656 m	
Symplocos sp. (2.00)	*Sarcococca* sp.
Rhus sp. (1.74)	*Daphne bholua*
Acer sp. (1.73)	*Yushania microphylla*
Alnus nepalensis (1.62)	*Cotoneaster* sp.
Pinus wallichiana (0.95)	*Berberis asiatica*
Acer campbellii (0.66)	*Viburnum* sp.
Betula alnoides (0.59)	*Sorbus microphylla*

*Species are listed in order of decreasing dominance

red panda habitat use. Akaike's information criterion corrected for small sample sizes (AICc; Burnham & Anderson, 2002) was used to rank candidate models. We calculated model-averaged parameter estimates from the subset of highest ranked models that accounted for a cumulative 90% of AICc model weights. All statistical analyses were implemented in *R v. 3.2.0* (R Development Core Team, 2015), with the packages *MuMIn* (Bartoń, 2015) and *logistf* (Heinze et al., 2013).

Results

We surveyed 40 plots along the Dangyungma-to-Sengor transect and 25 along the Chungphel-to-Bribdungla transect. Seven plots on the Dangyungma-to-Sengor transect and five on the Chungphel-to-Bribdungla transect could not be accessed safely and were therefore excluded from the study. We found evidence of red panda habitat use in 15% (n = 10) of the 65 surveyed plots, at elevations of 2,860–3,597 m. During the two follow-up surveys of each plot we found no evidence of red panda presence in any plot that had been categorized as absent based on the initial survey. We did not find any significant difference in red panda habitat use along the Dangyungma-to-Sengor transect compared to the Chungphel-to-Bribdungla transect, with presence in 17.5% (7/40) and 12% (3/25) of plots, respectively (P = 0.73).

Eleven percent (n = 7) of plots were in cool broadleaved forest, 25% (n = 16) in mixed conifer forest, and 65% (n = 42) in fir forest. We recorded 29 tree species and 39 understorey species in the study plots. Altitude, dominant tree species, and understorey diversity are presented for each forest type (Table 1). Red panda habitat use did not differ significantly among forest types, with evidence of habitat use in 0% (0/7) of cool broadleaved forest plots, 19% (3/16) of mixed conifer forest plots, and 20% (7/35) of fir forest plots (P = 0.76).

Red pandas used sites with more bamboo (Fig. 2). Two species of bamboo occurred in the study plots. *Yushania maling* was found in 26% (17/65) and *Y. microphylla* in 6% (4/65) of plots. We found evidence of red panda habitat use only in sites with *Y. maling*. However, the difference in occurrence of the two bamboo species in red panda habitat use was not significant (Fisher's exact test, two-tailed, P = 0.09), probably as a result of the low availability of *Y. microphylla*.

In total, 77% (n = 50) of plots had signs of anthropogenic disturbance. Timber collection was evident in 60% (n = 39) of plots. Lopping was the most commonly observed timber disturbance, occurring in 52% (n = 34) of plots. Girdling and harvest were each recorded in 32% (n = 21) of plots. Red

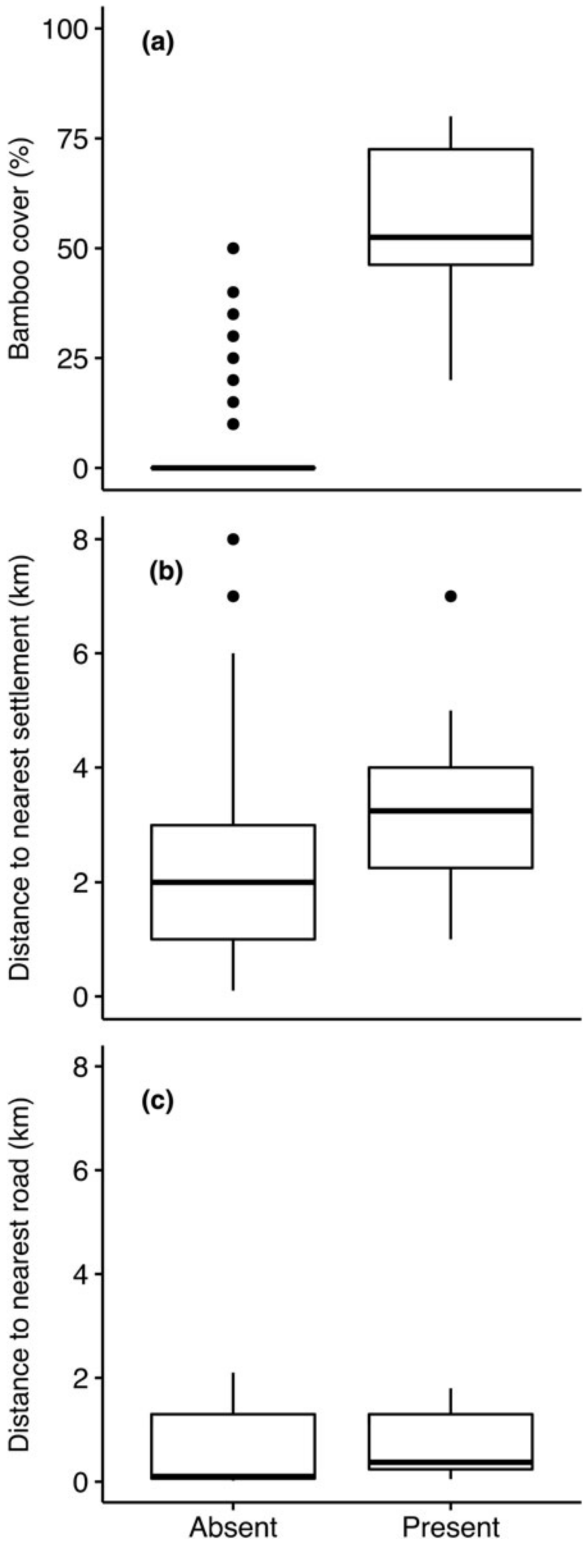

FIG. 2 Boxplots illustrating (a) % bamboo cover, (b) distance to nearest settlement, and (c) distance to nearest road, for study plots where red pandas *Ailurus fulgens* were present vs absent. The filled circles in (a) and (b) represent data outliers.

panda faecal pellets were found more commonly in plots without timber disturbance (31%; 8/26) vs plots with timber disturbance (5%; 2/39). Livestock disturbance, especially trampling and grazing on bamboo and other young shoots, was recorded in 35% (n = 23) of plots. Red panda faecal pellets were not found in any plots with livestock disturbance.

Median distance to settlement or road was greater for plots used by red pandas, compared to unused, but variability was high. Distance to nearest settlement was not significantly different for plots with (n = 39, median = 2.1 km) vs without (n = 26, median = 2.0 km) timber disturbance ($W = 540.5$, P = 0.66). Similarly, livestock disturbance was not associated with distance to settlement (with disturbance: n = 23, median = 2.5 km; without disturbance: n = 42, median = 2.0 km; $W = 411$, P = 0.32). However, plots with timber disturbance (n = 39, median = 0.09 km) were significantly closer to roads compared to those without timber disturbance (n = 26, median = 0.59 km; $W = 686.5$, P = 0.02). Plots with livestock disturbance were significantly further from roads (n = 23, median = 1.30 km) than those without livestock disturbance (n = 42, median = 0.07 km; $W = 203.5$, $P < 0.001$).

The number of downed logs was higher at sites used by red pandas (median = 6.5 logs; range 3–11 logs), compared to sites not used (median = 3 logs; range 0–10 logs). Shrub cover was lower at sites used by red pandas (median = 5%; range 0–12%), compared to sites not used (median = 30%; range 0–100%). Predictor variables were not highly correlated, and therefore all were included in a global multiple logistic regression model and various combinations were included in candidate subset models. The best-supported model, having an AICc weight of 0.63, included bamboo cover, livestock disturbance and distance to settlement as important predictors (Table 2). The three best-supported candidate models, with a cumulative AICc weight of > 0.90, were combined to calculate model-averaged parameter odds ratios (Table 3). Bamboo cover and livestock disturbance were the only predictors included in all three best-supported models, and the only predictors with model-averaged 95% confidence intervals (of the odds ratio) that did not overlap 1.

Discussion

Red pandas used habitats with higher bamboo cover and avoided areas disturbed by livestock or close to human settlements. More than one-third of all study plots had been grazed or trampled by livestock. Timber collection was even more extensive, occurring in more than half of surveyed plots, with the greatest intensity near roads. However, unlike livestock disturbance, timber disturbance was not identified in model selection as an important predictor of red panda habitat use.

Bamboo and red panda habitat use

Bamboo cover was highly associated with red panda presence, consistent with other studies across the species'

Table 2 Penalized likelihood logistic regression models that examine the influence of habitat factors and anthropogenic disturbances on habitat use by the red panda *Ailurus fulgens*, ranked according to corrected Akaike's information criterion (AICc), with number of parameters, AICc, ΔAICc, and model weight.

Model*	No. of parameters (*K*)	AICc	ΔAICc	Model weight
Bamboo + Livestock + Settlements	4	5.9	0.00	0.629
Bamboo + Livestock	3	8.3	2.42	0.188
Bamboo + Livestock + Settlements + Timber	5	9.1	3.21	0.126
Bamboo + Livestock + Settlements + Timber + Road	6	12.7	6.80	0.021
Bamboo + Livestock + Settlements + Timber + Road + Water + Shrubs + Logs	9	13.0	7.07	0.018
Bamboo + Livestock + Settlements + Timber + Water + Logs	7	13.6	7.64	0.014
Bamboo	2	16.1	10.18	0.004
Livestock + Settlements + Timber	4	37.1	31.20	0.000
Settlements + Timber + Road	4	46.7	40.76	0.000
Settlements + Timber + Road + Water	5	50.3	44.36	0.000

*Bamboo, % cover of bamboo; Livestock, evidence of livestock disturbance in plot (reference condition is no disturbance); Settlements, distance to nearest settlement (km); Timber, evidence of timber disturbance in plot (reference condition is no disturbance); Road, distance to paved or farm road (km); Water, distance to nearest water source (10 m); Shrubs, % cover of shrubs; Logs, number of logs with > 30 cm diameter

Table 3 Conditional model-averaged odds ratios and 95% confidence intervals, calculated over models within a cumulative 90% of corrected Akaike's information criterion (AICc) model weights. For example, for every 1% increase in bamboo cover, the odds of red panda presence at a site increases by a factor of 1.17 (95% CI 1.04–1.31).

Parameter[1]	Estimate (odds ratio)	2.5%	97.5%
Bamboo[2]	1.17	1.04	1.31
Livestock[2]	0.01	0.00	0.62
Settlements	2.36	0.99	5.63
Timber	0.93	0.05	16.98

[1]Bamboo, % cover of bamboo; Livestock, evidence of livestock disturbance of plot (reference condition is no disturbance); Settlements, distance to nearest settlement (km); Timber, evidence of timber disturbance of plot (reference condition is no disturbance)
[2]Bamboo and Livestock have 95% confidence intervals of the odds ratio that do not contain 1, indicating an important positive influence of bamboo and negative influence of livestock on red panda presence at a site

range (Pradhan et al., 2001; Dorji et al., 2011; Sharma et al., 2014b; Chakraborty et al., 2015). We found red panda faecal pellets only in plots with at least 20% bamboo cover. As our study was conducted in winter, diet supplements such as *Sorbus cuspidata, Sorbus microphylla, Rosa sericea* and *Berberis asiatica* were not available. Furthermore, the 2009–2010 die-off of the bamboo species *Borinda grossa* in Phrumsengla National Park decimated a potentially important food resource for the red panda. During the time of the surveys we did not see any new bamboo regeneration.

Yushania maling was the predominant bamboo species at the study site. The dwarf bamboo *Y. microphylla* was found in 6% (n = 4) of survey plots but these plots were not used by red pandas. Given the small sample size of plots with *Y. microphylla*, and confounding with livestock disturbance (3 of 4 *Y. microphylla* plots) and bamboo mortality (3 of 4 *Y. microphylla* plots had dead bamboo), we could not determine if red pandas prefer *Y. maling* over *Y. microphylla*. However, Dorji et al. (2011) reported that red pandas did not use plots where *Y. microphylla* was abundant. They suggested the low quality and low height of this bamboo species made it unfavourable as red panda habitat. This idea is consistent with findings that bamboo height can be an important predictor of red panda habitat use, with red pandas favouring taller bamboo (Pradhan et al., 2001; Zhou et al., 2013). Besides being less inaccessible to red pandas in the winter, shorter bamboo may expose red pandas to greater predation by terrestrial predators (Dorji et al., 2011). Among taller bamboos, several species may be used by red pandas, including *Bashania spanostachya* (Wei et al., 2000) and *Arundinaria* spp. (Dorji et al., 2011; Panthi et al., 2012; Chakraborty et al., 2015).

Anthropogenic disturbances

In Bhutan livestock are an integral part of rural livelihoods, and forest vegetation is the single most important source of livestock fodder (Wangchuk, 2002). Although we do not have specific numbers for Phrumsengla National Park, almost 8,000 cattle are registered in Bumthang district, where this study was conducted (National Statistical Bureau, 2013). Red pandas did not use sites that had been disturbed by livestock, even if bamboo was present.

Livestock fed extensively on bamboo where available, as most other sources of fodder were dead and dried. We also found signs of vegetation trampling, soil compaction and formation of gullies by livestock. Livestock grazing in Phrumsengla National Park may have a negative impact on red pandas in the long term by promoting growth of the dwarf bamboo *Y. microphylla* (Dorji et al., 2011). As livestock in Bhutan are often unaccompanied by herders or herding dogs, their influence on red panda habitat use is probably related to their impacts on bamboo rather than other factors. We did not distinguish ungrazed, standing bamboo from livestock-damaged (i.e. grazed and trampled) bamboo in our measurement of bamboo cover, and therefore we could not test for correlation between livestock disturbance and bamboo cover.

Several studies in Nepal have noted extensive grazing or trampling of bamboo stands by livestock (Yonzon & Hunter, 1991; Sharma et al., 2014a). The results of a study of impacts of livestock on red panda habitat use in Rara National Park (Sharma et al., 2014a) were similar to ours. Livestock use was recorded in 81% of survey plots, and red panda faecal pellets were less common in those plots.

Trees may be used by red pandas for nesting, sleeping, shelter and feeding (Pradhan et al., 2001). However, timber extraction was not an important predictor of red panda habitat use in our study. Although red panda faecal pellets were more common in plots without timber disturbance, bamboo cover was also higher in these plots. It is not clear if bamboo is removed opportunistically during timber extraction.

Red pandas seem to avoid settlements in Phrumsengla National Park, for reasons unrelated to the anthropogenic factors (timber and livestock disturbance) assessed in this study. It is unclear why, but village dogs have been known to harass and even kill red pandas in Phrumsengla National Park (Dorji et al., 2012) and in Langtang National Park, Nepal (Yonzon & Hunter, 1991), and could potentially influence red panda behaviour around settlements. Alternatively, communities may be modifying bamboo habitat around settlements but our sample sizes may be too small, or bamboo cover may be too simple a metric, to capture these habitat changes in analyses.

Other studies have identified downed logs, shrubs, and distance to water as significant covariates of red panda habitat use (Wei et al., 2000; Dorji et al., 2012; Zhou et al., 2013). In our study, plots used by red pandas had more downed logs and less shrub cover compared to unused plots. However, these two covariates were confounded with bamboo (i.e. more downed logs and less shrub cover in areas with greater bamboo cover), and thus the importance of their effects dropped out in multivariate analyses.

Management recommendations and future research

Red pandas avoid areas with livestock disturbance, probably because of livestock damage to bamboo. Free-roaming livestock grazing practices should therefore be minimized in protected area zones where red panda conservation is a priority. Livestock intensification programmes could be implemented to reduce the number of livestock in these areas, impose seasonal restrictions on livestock grazing, or promote dairy farming and other sedentary livestock programmes.

Timber disturbance was not an important predictor of red panda habitat use but opportunistic removal of bamboo from areas where timber is harvested has a negative impact on red pandas. Bamboo restoration and planting could offset damage or loss of bamboo as a result of anthropogenic activities. Until the impacts of anthropogenic activities in protected areas are accounted for and mitigated, protected area coverage should not be considered an adequate measure of the conservation of the red panda.

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Author contributions

PD conceived and designed the research, PD, CL and UT performed the surveys, PD and EC analysed the data, and PD and EC wrote the article.

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