

# Impacts of cattle grazing on forest structure and raptor distribution within a neotropical protected area

Renzo P. Piana · Stuart J. Marsden

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**Abstract** Uncontrolled cattle grazing is frequent in protected areas across the tropics but its effect on habitat structure and biodiversity is poorly known. We used generalized additive models to examine the precise relationships between cattle grazing intensity, vegetation structure, and raptor occurrence and richness across 39 1-km<sup>2</sup> plots within the North West Biosphere Reserve, Peru. Cattle grazing was widespread and intensity was negatively correlated with average canopy height and percentage of vegetation cover at 5–15 m. Raptors were influenced by cattle density but they were probably more strongly influenced by canopy and sub-canopy characteristics. Raptor species responded differently to increasing cattle density: presence of species that hunted or searched for food in open habitats increased with cattle density, while presence of range restricted species that hunted from perches, and declining species decreased. Moderate cattle densities (20–60 cows km<sup>-2</sup>) may actually benefit some raptor species and help to maintain the high raptor diversity in the study area. Reserve authorities should, however, act to reduce cattle densities in some areas, which can exceed 120 cows km<sup>-2</sup>, that seriously affect some key raptor species, and cause forest to be converted to permanent cattle pasture.

**Keywords** Cattle grazing · GAM · Northwest Peru · Raptors · Tumbesian Endemic Centre

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R. P. Piana (✉) · S. J. Marsden  
School of Science & the Environment, Manchester Metropolitan University, Chester Street,  
Manchester M1 5GD, UK  
e-mail: micrastursp@yahoo.ca

R. P. Piana  
The Peregrine Fund, 5668 West Flying Hawk Lane, Boise, ID 83709, USA

## Introduction

Creation of protected areas continues to be the main strategy to protect biological diversity (Ervin 2003; Naughton-Treves et al. 2006). However, in many tropical countries, protected areas are often weakly controlled by national and local authorities, and activities that are detrimental to the maintenance of biological diversity are widespread inside reserves (Ervin 2003). Cattle grazing is widespread in tropical regions (de Haan et al. 1997), including inside protected areas (Naughton-Treves et al. 2006), where often, cattle are left to range freely to feed on the native vegetation (Stern et al. 2002). Additionally, natural areas are cleared to favour growth of native or introduced pastures that are beneficial for cattle. In the neotropics, cutting and burning of vegetation are common practices to convert natural forest stands into homogeneous cattle pastures where few plant species dominate (Nepstad et al. 2001). This practice is known to reduce animal species diversity given that grazed areas support a structurally simplified array of plants (Roth 1976; Rotenberry and Wiens 1980; Stern et al. 2002). The impacts of removal of vegetation by cattle grazing extend to those species that are preferred prey of raptors (Stern et al. 2002; Torre et al. 2007; Johnson and Horn 2008), while soil compaction caused by cattle reduces the availability of shelter for some species including rodents (Torre et al. 2007). However, grazing opens up the understory in grazed forests and this might benefit some raptors by increasing prey detectability and capture (Preston 1990).

Despite being reasonably well studied in temperate systems, little is known of the effects of cattle grazing on tropical raptors either across the wider landscape, or within tropical protected areas. Knowledge of how raptor communities and conservation-important species respond to grazing is important both to guide ‘gross’ protected area management (whether grazing should be permitted or not) and, ideally, inform us on ‘fine’ management measures as to how raptors respond to different cattle densities and grazing pressures. To this purpose, we used Generalized Additive Models (GAMs) to identify the relationships between raptor species richness measures, the presence of individual species and cattle density and habitat features affected by grazing within the North West Biosphere Reserve. We were especially interested in how important cattle density was for raptors as compared to other environmental/habitat factors. We then examined the shape of the raptor response curves to estimated cattle density to identify any threshold levels at which species reactions are disproportionately positive or negative. The goal was to provide a useful conservation tool that allows protected area managers to maintain a diverse raptor community within the ‘working’ protected area landscape.

## Study site and methods

Located in the centre of the Tumbesian Endemic Zone, the North Western Biosphere Reserve (NWBR) is a set of three adjacent protected areas (the Cerros de Amotape National Park—CANP, the Tumbes National Reserve—TNR, and El Angolo Hunting Preserve—EAHP) in Peru. Together they preserve 230,000 hectares of dry, semi-deciduous and deciduous forests; the largest tract of these forest types still remaining in the whole Tumbesian endemic region (Best and Kessler 1995). In these protected areas, at least 34 diurnal raptors have been reported (Piana et al. 2010). CANP is a strictly protected area within which no direct use of natural resources is allowed. However, due to poorly implemented control policies, the park is used for free-range cattle grazing and hunting. TNR is a national protected area where direct use of natural resources is allowed as long as

these uses are compatible with the objectives of the reserve and its management plans. In the sections we surveyed, these activities included low intensity timber extraction, hunting, cattle grazing and conversion of forest to pastures. According to the Peruvian Law No. 26834, buffer areas are not part of the protected areas yet activities conducted here should be compatible with the objectives of the protected areas adjacent to them. Human induced activities in buffer areas in the study site ranged from forest clearing for agriculture and cattle grazing, free-range cattle grazing, hunting, commercial and subsistence timber extraction, and non-timber forest product extraction.

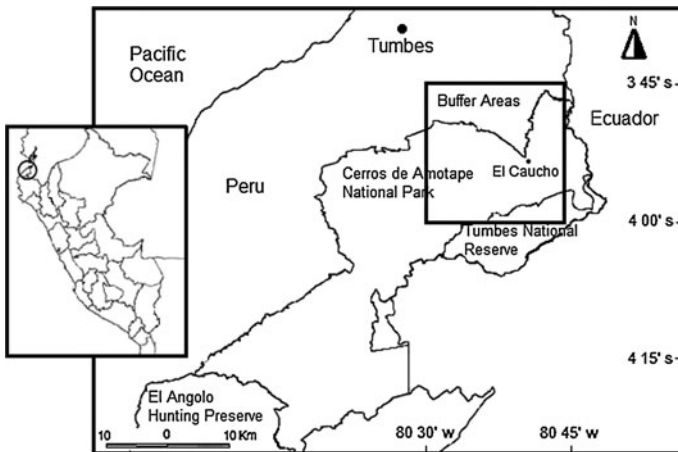
We selected a study area of  $25 \times 25$  km (62,500 ha) in the northern part of the NWBR; the centre of this square lying over the El Caucho Research Station, in the CANP (Fig. 1). The study area encompassed the northern sector of the CANP and the TNR: from the small town of El Tutumo ( $3^{\circ}45'S$ ) in the park's buffer area to Quebrada El Ebano ( $4^{\circ}S$ ); and from the small town of Belen ( $80^{\circ}30'W$ ) to the Tumbes river on the border with Ecuador ( $80^{\circ}45'W$ —eastern limit of the TNR). The study area includes four main habitat types within the seasonally dry tropical forests of north western Peru (Linares-Palomino 2006). Classification of these habitats is based on Aguirre et al. (2006) although we further divided the deciduous forest into two habitat types. The habitats considered were: dry savanna (between 30 and 100 m asl) where Algarrobo (*Prosopis pallida*) and Faique (*Acacia macracantha*) trees dominated the vegetation; dry deciduous forest (100–300 m) where Madero (*Tabebuia bilbergi*) trees dominated and with presence of Ceibo (*Ceiba trichistrandra*) and Pasallo (*Eriotheca ruizii*) trees; deciduous forest (300–600 m) where Guasimo (*Guazuma ulmifolia*) dominated the lower strata and Ceibo the upper strata, and semi deciduous forest (>600 m) with presence of Fernán Sanchez (*Triplaris cumingiana*), Guaruma (*Cecropia litoralis*), Polopolo (*Choclospermum vitifolium*) and Ceibo. Precipitation in the study area is approximately 520 mm per year and is markedly seasonal with a rainy season from January to April (85 % of annual precipitation). Average maximum temperature through the year is  $26^{\circ}C$ .

### Raptor surveys

Thirty-nine randomly placed  $km^2$  plots ( $1 km \times 1 km$ ; 6.2 % of the total area) within a  $25 \times 25$  km (62,500 ha) study area were surveyed during 2009. A small number of originally chosen plots were too remote to allow safe access so plots up to 2 km closer to existing trails were substituted for these (Thiollay 1993). No two plots were chosen if they fell in adjacent squares. Within each square, a 1.8 km long transect was set up occasionally along existing trails but more usually along a specially cut trail. Transects were ideally 0.7 km long, followed by a stretch of length 0.4 km perpendicular to the first stretch, and finally another stretch of 0.7 km parallel with the first. Walking speed during surveys was maintained at  $1 km h^{-1}$ . All transects were walked by RP, only once in the morning, 90 min after sunrise or sometimes later if rainy or foggy conditions reduced raptor detectability or activity (Thiollay 1989). All diurnal raptors seen or heard perched or flying were recorded along with their distance from the transect line, measured with a rangefinder or estimated for birds that were vocalizing but not seen.

### Habitat data collection

Habitat measurements were taken at eight points located 200 m apart along each transect. To avoid possible biases derived from sampling along edges, measurements were taken 15 m perpendicular to the trail inside the forest. Latitude, longitude and altitude were



**Fig. 1** Map of the study area

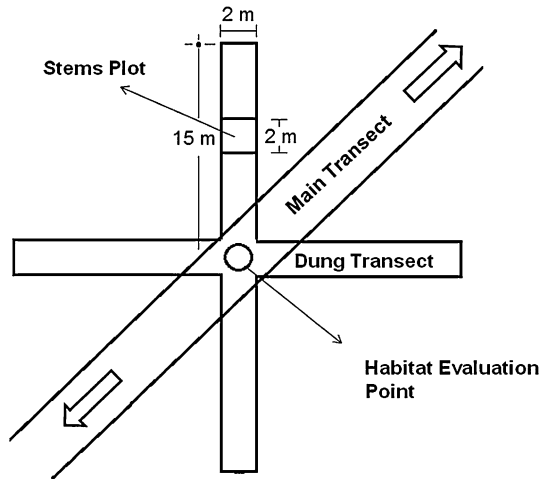
recorded with a GPS, gradient was measured with a clinometer, canopy height was visually estimated, and percentage cover at three vegetation strata (1–5 m, 5–15 m, and 15–25 m above ground) were estimated and then averaged to give a single mean value for each square.

Total number of stems from 0.1 to 2 cm diameter at 1 metre above ground were counted within four  $2 \times 2$  m square plots located inside each of the strips where cattle dung piles were counted (see later; Fig. 2). Stems were counted because it was supposed that cattle feeding in the understory would have a direct impact on the number of stems, reducing their total number. The centre of the plot was at the midpoint of the strip, 7.5 m away from the point where the above habitat variables were recorded. Number of stems was averaged across the four plots.

#### Cattle 'density' estimation

Dung pile counts have been widely used as an indirect method of estimating abundance in terrestrial vertebrates (e.g. Plumtre 2000; Palmer and Truscott 2003). The method gives accurate density estimates providing that realistic rates of defecation and dung decay are incorporated into calculations of abundance taken from robust field surveys of dung piles (Barnes 2001; Marques et al. 2001). Cattle dung piles were counted in four strip transects fifteen metres long and two metres wide in four alternate points where habitat was evaluated (Fig. 2; total area =  $120 \text{ m}^2$ ), and this figure expressed as number of dung piles per  $\text{km}^2$ . Given the abundance of rains during the wet season in the study area, the number of cow dung piles in the field was assumed to fall to zero at the end of the rains (taken to be 31 March in the year of study). While there is clearly no immediate 'switching off' of the rains at the onset of the dry season, it was assumed that cattle dung piles were accumulated in areas at a given rate per day with no destruction or degradation of cattle dung piles during the dry season. The absence of heavy rain during the dry season meant that cow dung piles simply desiccated where they were dropped. To estimate cattle 'density' within plots, cattle dung piles density was corrected by incorporating the number of days between the end of the rains and the date on which each plot was surveyed. There was a near significant

**Fig. 2** Stem and cow dung piles survey plot layout in relation to main habitat and raptor survey transect



positive correlation between density of cattle dung piles and number of days after the rainy season ended ( $r_s = +0.30$ ;  $P = 0.06$ ; Fig. 3).

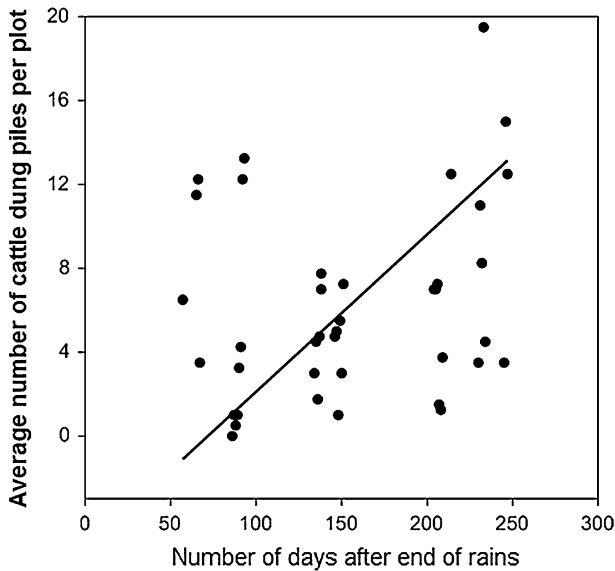
From a literature search of dung production rates (Table 1), daily production of dungs per cattle individual was estimated to be 13. Cattle density in a plot was calculated by dividing dung pile density in each plot by the number of days between the end of the rains and the date of survey, and then divided by the daily dung production rate.

#### Raptor response variables

Bicolored Hawk (*Accipiter bicolor*), Crane Hawk (*Geranospiza caerulescens*), Zone-tailed Hawk (*Buteo albonotatus*), Crested Caracara (*Caracara cheriway*) and Bat Falcon (*Falco ruficularis*) were detected in six or fewer plots. GAMs do not perform well with small sample sizes (Wisz et al. 2008) so we restricted habitat association analyses to those species recorded in 9–30 squares. These were Black Vulture (*Coragyps atratus* recorded in 26 plots), Turkey Vulture (*Cathartes aura*; 30 plots), King Vulture (*Sarcoramphus papa*; 14 km<sup>2</sup> plots), Gray-backed Hawk (*Leucopternis occidentalis*; 12 plots), Great Black Hawk (*Buteogallus urubitinga*; 12 plots), Black Hawk-Eagle (*Spizaetus tyrannus*; 17 plots), Harris's Hawk (*Parabuteo unicinctus*; 20 plots); and Short-tailed Hawk (*Buteo brachyurus*; 9 plots).

Differences in detectability in animal surveys can be problematic when comparing across habitats (e.g. Buckland et al. 2008). Our response variable was presence or absence of individual raptor species along transects so any increased detectability in one habitat over another (specifically open habitats where visibility can be greater) can introduce bias. However, in our study, mean detection distances were not significantly greater in dry savannah than in deciduous forests for Black Vulture (Mean<sub>decid</sub> = 176 m ± 129 (SD), Mean<sub>savan</sub> = 156 m ± 136), Turkey Vulture (Mean<sub>decid</sub> = 119 m ± 107 (SD), Mean<sub>savan</sub> = 124 m ± 111), or the other six species (above) combined (Mean<sub>decid</sub> = 122 m ± 122 (SD), Mean<sub>savan</sub> = 157 m ± 179). We suggest that any bias due to differences in detectability are likely to be small.

Along with the presence/absence of individual species, we considered the following three composite measures of raptor diversity and abundance. Species richness was the



**Fig. 3** Scatterplot of mean number of cattle dung piles per plot and number of days after the end of rain season

**Table 1** Mean cattle defecation rate  $\pm$  standard error (SE) or standard deviation (SD) and sample size ( $n$ ) in different habitats/regions from published sources

Country/habitat	Mean	SE	SD	$n$	Reference
New Zealand/coastal	10.5	0.31	1.32	18	Weeda (1967)
Kenya/arid savanna	13.0	0.44	–	7	Augustine (2003)
Belgium/coast	14.4	–	–	–	Cosyn et al. (2005)
New Zealand/south coast	13	–	–	–	McDowell (2006)
Japan/forest	13.6	0.48	3.32	23	Hirata et al. (2009)
Switzerland/alpine	12.5	2.5	3.53	–	Gillet et al. (2010)

number of species of any raptor recorded within the plot. We calculated the Shannon–Wiener diversity index for each plot, and an index of rarity for each plot as follows. For each species recorded within the plot, we multiplied the number of records of this species by the inverse of population density (individuals  $\text{km}^{-2}$ ) at which it was estimated to occur within the study area. The diversity index for that plot was the sum of all records divided by species density of all individuals within that plot. Density estimates were derived using line transect distance sampling and calculated from species-specific detection functions in the Conventional Distance Sampling (CDS) engine of DISTANCE 6.0 (Thomas et al. 2010). Field methods and analysis details are given in Piana and Marsden (2012).

#### Environmental data manipulation

We used principal component analysis (PCA) to identify autocorrelations among the predictor variables, and especially in an attempt to partially disentangle our cattle density

measure from the habitat measures. PCA collapses multivariate datasets onto a small number of composite axes which represent important environmental gradients which are interpretable based on the factor loadings of individual variables that contribute to them. The ten variables included in the PCA were latitude, longitude, altitude, gradient, canopy height, number of stems, and percentage vegetation covers at 0–1 m, 1–5 m, 5–15 m, and 15–25 m. A varimax rotation was used to emphasize contributions of individual variable to the derived axes. Only factors with eigenvalues  $>1.0$  were retained. Cattle density was excluded from the PCA but was then related to each of the derived factors using Spearman's rank correlation analysis. In addition to 'condensing' the predictor variables using PCA and testing for autocorrelations, we tested for collinearity among the predictors using a Tolerance test where  $\text{Tolerance} = 1 - R_j^2$ , the coefficient of determination from regression of predictor  $j$  on all the other predictors together.

### Raptor-habitat association models

Generalized additive models (GAMs) are extensions of generalized linear models (GLMs) that replace the linear regression coefficients with semi-parametric smoothing functions and additively calculate the component response (Hastie and Tibirishany 1986; Guisan et al. 2002). GAMs allows for the probability distribution of the response variable and the link between predictors and the probability distribution to be more general/flexible, and are better suited to deal with highly non-linear and complex relationships or thresholds between the response and predictive variables predictors (Granadeiro et al. 2004; Vilchis et al. 2006).

We ran binomial GAMs for the presence/absence of six raptor species, and Gaussian or Poisson GAMs for the diversity/rarity indices using the 'mgcv' package in R (R Development Core Team 2012) version 2.15.0. Predictor variables for each model were the three most important PCA axis scores and cattle density. Model selection was based on minimizing Akaike's Information Criterion (AIC; Burnham and Anderson 2002). AIC represents how well a particular model explains deviance in the data but penalizes models with a large number of parameters (Johnson and Omland 2004). All models within four or fewer AIC points compared with the model with the lowest AIC value were considered as competing models and selected for analysis (Pedrana et al. 2008). Akaike Weights ( $W_i$ ) were used as a measure of the probability that a model was the most supported among the whole set of candidate models (Burnham and Anderson 2002; Johnson and Omland 2004).

## Results

### Cattle presence and density

Cattle dung piles were recorded in all but one of the 39 plots. Mean cattle density within plots was calculated as  $29.2 \text{ individuals km}^{-2} \pm 28.9$  (SD). There were no significant differences in estimated cattle densities between habitat types (dry savanna forest; deciduous forests and semi-deciduous forest: Kruskal–Wallis Test  $H = 3.07$ ,  $df = 3$ ,  $P = 0.38$ ), nor was there a significant difference between densities in the three protected areas (Tumbes Reserve; Cerros de Amotape National Park; buffer zone: Kruskal–Wallis Test  $H = 5.03$ ,  $df = 2$ ,  $P = 0.08$ ). There was no significant correlation between cattle

density and the average distance from plots to the three main cattle ranching towns in the study area: Pampas de Hospital, Tutumo and Peña Blanca ( $r_s = -0.13$ ;  $P = 0.44$ ).

#### Autocorrelation and representation of environmental gradients

The PCA reduced the ten environmental and geographical variables to three axes accounting for 68 % of overall variability (Table 2). Squares with high scores on Factor 1 (Fac1) are situated in the eastern portions of the study site, and have increasing values of vegetation cover from 0 to 1 m and of canopy cover, while Factor 2 (Fac2) represents a gradient of increasing altitude and steepness along with a north–south gradient. High scores on Factor 3 (Fac3) are characteristic of tall woodland with relatively full canopy and mid-level vegetation cover. Cattle density was not significantly correlated with Fac1 ( $r_s = +0.05$ ;  $n = 39$ ,  $P = 0.77$ ), or Fac2 scores ( $r_s = -0.30$ ,  $n = 39$ ,  $P = 0.07$ ), but was significantly negatively correlated with Fac3 scores ( $r_s = -0.37$ ,  $n = 39$ ,  $P = 0.02$ ). Tolerances of individual variables were 0.752 for cow density, 0.785 for Fac2, and  $>0.950$  for the other variables.

#### Raptor-habitat models

Full sets of models are shown in supplementary material. Fac1 appeared in 70 % of all best supported models ( $\Delta AIC \leq 4$ ). Raptor species richness was most likely influenced by heavy ground and canopy cover and tall woodland, while presence of rarer species was influenced by cattle density and heavy ground and canopy cover. Shannon index values were mostly influenced by heavy ground and canopy cover, elevation and gradient. There was a strong relationship between the presence of Black Hawk-Eagle, Harris's Hawk and Gray-backed Hawk with elevation, and between the presence of Turkey Vulture with tall woodland.

#### Influence of cattle density

Individual species responded differently to increasing cattle densities (Fig. 4). Likelihood of Gray-backed Hawk and Black Hawk-Eagle presence decreased linearly with increasing cattle density, while that for Short-tailed Hawk and King Vulture increased linearly. Likelihood of presence of Great Black Hawk also increased with increasing cattle density but then diminished at a density of approximately 50 cows  $\text{km}^{-2}$ . Harris's Hawk presence remained similar with increasing cattle density, but increased at densities around 80 cows  $\text{km}^{-2}$  (Fig. 4). Species richness increased with increasing cattle density, while diversity (Shannon–Wiener Index) decreased. Values of our rarity index increased as cattle density increased from 20 to 60 cows  $\text{km}^{-2}$  but beyond this density, it declined.

## Discussion

Despite available evidence of its impact on vegetation (van de Koppel et al. 1997; Stern et al. 2002), cattle grazing is widely conducted in protected areas within Neotropical dry forests (Guerrero 2002; Naughton-Treves et al. 2006) and the NWBR is no exception (Leal-Pinedo and Linares-Palomino 2005). In our study area, almost every area showed evidence of cattle presence. Overall, increasing values of vegetation cover from 0 to 1 m



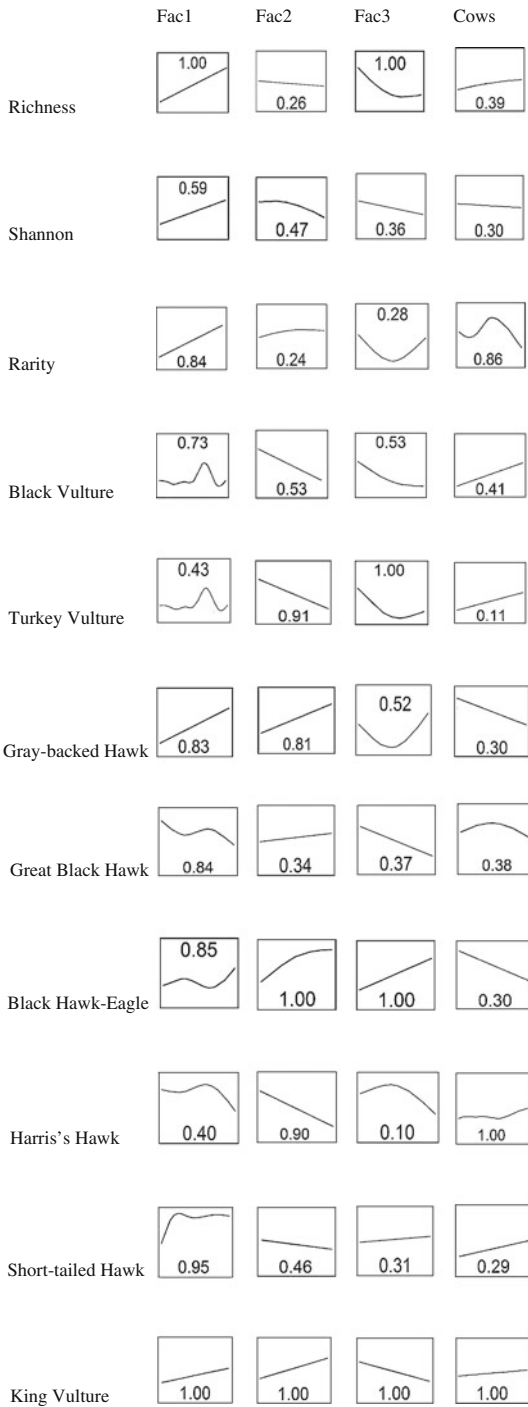
**Table 2** PCA of environmental variables

	Fac1	Fac2	Fac3
Eigenvalue	2.97	2.44	1.38
% Explained	29.7	24.4	13.8
Correlations with individual variables			
Latitude	(+)	-0.80	+0.44
Longitude	+0.80	(-)	-0.32
Altitude	-0.40	+0.86	(-)
Gradient	(+)	+0.70	(+)
Canopy height	(+)	(-)	+0.83
% Cover 0–1 m	+0.91	(-)	(-)
% Cover 1–5 m	-0.22	-0.29	+0.31
% Cover 5–15 m	-0.22	(+)	+0.82
% Cover 15–25 m	+0.63	-0.28	+0.49
No. stems	+0.49	(+)	(-)

Figures shown in addition to eigenvalues and percentage variation explained by each factor are the correlations between factor scores and individual variables. Only correlations greater than 0.2 are shown

and of canopy cover were probably the most powerful habitat variables to influence species presence. Whilst the focus of this study was cattle grazing, our findings point to an importance for raptors of upper stratum vegetation structure which is presumably not directly related to current cattle activity. For species such as Black Vulture, Turkey Vulture, Gray-backed Hawk, Great Black Hawk, Black Hawk-Eagle and Short-tailed Hawk, canopy/sub-canopy might influence the availability of perching sites and prey, concealment to avoid predation (Marion and Ryder 1975; Preston 1990), or nesting sites (Titus and Mosher 1981).

Richness and diversity measures responded differently to increasing values of cattle density. Decreasing values of Shannon–Wiener index with increased values of cattle density reflects, we believe, the increasing dominance of the raptor community by species such as Harris’s Hawk, and Black and Turkey Vulture in areas of higher grazing pressure. Similarly, dominance under high grazing pressure has been found in a number of taxa (e.g. Knopf et al. 1988; Smith et al. 1996; Cano and Leynaud 2010). Our index of raptor species abundance, weighted according to rarity, showed a non-linear response to grazing pressure. Generally across the community, grazing at cattle densities of 20–50 individuals  $\text{km}^{-2}$  actually benefited the raptor community overall, suggesting that tolerance of cattle in some areas is appropriate. However, abundance of rare raptors decreased steadily at densities beyond 60 cows  $\text{km}^{-2}$ , and such cattle densities should be used as a threshold level by protected area managers to maintain ‘healthy’ raptor communities in strictly protected areas like the Cerros de Amotape National Park. Analysis of the impact of cattle grazing has shown that animal communities tend to be dominated by generalist species after vegetation composition and structure is modified by cattle (Knopf et al. 1988; Saab and Petit 1992). In northeast Argentina, Cano and Leynaud (2010) detected changes in abundance of lizard species and in the composition of the lizard community at cattle densities close to 30 individuals  $\text{km}^{-2}$ , while in arid grasslands of southern Australia the rodent community in more heavily grazed areas tended to be dominated by the introduced common mouse *Mus musculus* (Read and Cunningham 2010). Grazing and conversion of forested areas into cattle pastures in the NWBR is not new (SERNANP 2010). It is possible



◀ **Fig. 4** Summary of Generalised Additive Models (GAM) for diversity measures and raptor species in extreme northwest Peru. Values given are the sum of Akaike weights for each predictive variable; GAM plots are also shown

that such a long history of cattle grazing in the study area has impacted the forest structure as cattle feeds in more palatable plant species. Although it was beyond the scope of this research to measure the impact of cattle grazing in particular plant species, it is possible that cattle feeding preferences have also affected forest structure (Parsons et al. 1997; Seifan and Kadmon 2006). Presence within NWBR of some generalist raptor species, such as Black Vulture, Turkey Vulture and Harris's Hawk, increased with higher cattle densities, while Great Black Hawk, a species that is more associated to forests (GRIN 2012) declined at densities of 60 individuals  $\text{km}^{-2}$ . Increased cattle grazing in the NWBR can lead to a simplification of the raptor community. Given that the density of cattle permitted in certain parts of the TNR is 127 individuals  $\text{km}^{-2}$  (SERNANP 2010), this density should be at least halved to help maintain higher raptor diversity in the reserve.

Trampling and reduction of forest understory by ungulates, including cattle, is a major cause of bird declines in grazed areas (Fuller 2001), influencing the abundance of important terrestrial prey such as amphibians, reptiles and rodents (e.g. Kutt and Woinarski 2007; Cano and Leynaud 2010). In our study, individual species responded differently to cattle density. Of particular concern was the negative effect of grazing on two species of conservation concern. Black Hawk-Eagle, a forest interior species, is restricted to semi-deciduous forests above 600 m (Piana and Marsden 2012), where its presence in the Tumbesian zone is seriously threatened by forest conversion and fragmentation (Ridgely and Greenfield 2001). The IUCN 'Endangered' Gray-backed Hawk, a border species that mostly prey on snakes in a fairly wide range of habitat (Vargas 1995; Piana and Marsden 2012), has a rapidly declining population due to continuous habitat destruction for the establishment of pasturelands and intense cattle grazing (BirdLife International 2012). Probability of its occurrence declined linearly with grazing pressure, and while strict control of grazing would benefit these species, there are possibly advantages to reducing grazing pressure at any cattle density particularly for species that were rare in the study area. The reactions of two further species were more complex. Great Black Hawk had highest probability of presence when cattle density was close to 60 individuals  $\text{km}^{-2}$  while the edge-associated Harris's Hawk (GRIN 2012) appears to prefer areas where cattle density exceeded 80 individuals  $\text{km}^{-2}$ . Short-tailed hawk, which hunts above open woodland/savanna and woodland edge (Odgen 1974; GRIN 2012) were associated with higher cattle densities, perhaps benefiting from increased densities of reptiles in pastures or recently burnt woodlands (e.g. Letnic et al. 2004; Cano and Leynaud 2010).

Dung pile counts, along with estimates of defecation and decay rates have proved useful in estimation of large forests mammal densities (Plumptre and Harris 1995; Plumptre 2000). During our research, cattle density was calculated by counting cow dung piles along narrow survey strips, within which all dung piles were detectable. In the study area rains are highly seasonal, with 90 % of the annual 950 mm average precipitation at El Caucho research station falling between January and March (Nunez and Zegarra 2006). We assumed that no cattle dung piles from previous seasons remained in the field after the end of these rains—and this assumption was born out by field observations. No rains occurred during surveys so dung pile decay rates were considered as they desiccated as the dry season progressed. Additionally no dung beetles were observed during dung pile counts. Dung pile production rates of cattle were obtained from literature search from research mostly conducted in temperate areas. Digestibility of tropical forage is generally lower

than for temperate forage (Buschbacher 1987), so it is possible that average dung pile production rate by cattle in our study site was lower than that assumed for density calculations. If this assumption holds, then cattle density in plots could be higher than this study suggests. Whatever the case, cattle grazing intensity within our study area, if not cattle density itself, can be measured using standardised dung pile counts so long as period of accumulation is accounted for (e.g. Plumptre 2000).

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