HABITAT ASSOCIATIONS WITHIN A RAPTOR COMMUNITY IN A PROTECTED AREA IN NORTHWEST PERU

RENZO P. PIANA[1]

School of Science and the Environment, Manchester Metropolitan University,
Chester Street, Manchester, M1 5GD, U.K.
and
The Peregrine Fund, 5668 West Flying Hawk Lane, Boise, ID 83709 U.S.A.

ABSTRACT.—Knowledge of the habitat characteristics that influence the distribution of raptors in the neotropics is vital for their conservation. I used logistic regressions (General Linear Models; GLM) to model habitat distribution for eleven raptor species occurring in the Cerros de Amotape National Park, the Tumbes National Reserve, and surrounding areas in northwestern Peru. Between May and December 2008 and 2009, raptors were surveyed along transects, and associated habitat data collected in 70 randomly allocated 1-km² plots. Ten habitat variables were selected for modelling. Spatial autocorrelation in the distribution of species was measured through Moran's *I* and later habitat models were ranked using Akaike's Information Criterion corrected for small sample sizes (AICc). The most important variables that influenced the presence of species included the percentage of vegetation cover at different strata and elevation. The presence of the tree species, ceibo (*Ceiba trichistrandra*) and guasima (*Guazuma ulmifolia*), were also important. The percentage of vegetation cover from 5–15 m appeared in all models for Turkey Vulture (*Cathartes aura*), Crane Hawk (*Geranospiza caerulescens*), Great Black Hawk (*Buteogallus urubitinga*), and Harris's Hawk (*Parabuteo unicinctus*). These findings suggest that vertical structure of forested areas is of particular importance for raptors at the study site, including those of conservation concern. I recommend that forested areas north of the Cerros de Amotape National Park and close to Ecuador should be protected.

KEY WORDS: *General Linear Models*; *northwestern Peru*; *raptors*; *Tumbesian Endemic Centre*; *vegetation structure.*

ASOCIACIONES DE HÁBITAT EN UNA COMUNIDAD DE AVES RAPACES EN UN ÁREA PROTEGIDA EN EL NOROESTE DE PERÚ

RESUMEN.—El conocimiento de las características de hábitat que influyen en la distribución de aves rapaces en el Neotrópico es fundamental para su conservación. Utilicé regresiones logísticas (Modelos Lineales Generalizados—GLM) para obtener modelos de distribución de hábitat para 11 especies de rapaces que habitan en el Parque Nacional Cerros de Amotape, la Reserva Nacional de Tumbes y sus zonas de amortiguación en el extremo noroeste de Perú. Entre mayo y diciembre de 2008 y 2009, las rapaces y los datos de sus asociaciones de hábitat fueron evaluados mediante transectos ubicados en el interior de 70 parcelas de 1 km² distribuidas al azar. Se seleccionaron 10 variables de hábitat para la generación de los modelos. La autocorrelación espacial fue medida utilizando el Índice de Moran y posteriormente los modelos fueron ordenados jerárquicamente utilizando el Criterio de Información de Akaike corregido para muestras pequeñas (AICc). Las variables más importantes que influyeron en la presencia de especies de rapaces incluyeron el porcentaje de cobertura a diferentes alturas sobre el suelo y la altitud. Entre las especies de árboles, la presencia de *Ceiba trichistrandra* y *Guazuma ulmifolia* también fue importante. El porcentaje de cobertura entre 5 y 15 m sobre el suelo estuvo presente en todos los modelos generados para *Catarthes aura*, *Geranospiza caerulescens*, *Buteogallus urubitinga* y *Parabuteo unicinctus*. Estos resultados sugieren que la estructura vertical de la vegetación es de especial importancia para la distribución de las especies de rapaces que viven en el área de estudio, incluyendo aquellas de interés para la conservación. Los bosques al norte del Parque Nacional Cerros de Amotape y los cercanos al Ecuador deberían ser protegidos, así como debería detenerse la destrucción de los bosques, principalmente aquellos ubicados por encima de los 600 m de altitud.

[Traducción del equipo editorial]

---

[1] Email address: micrastursp@yahoo.ca

174

The identification of factors that determine species presence in the landscape is key for the conservation and maintenance of biological diversity (Cleary et al. 2005). Diurnal raptors cover a broad spectrum of ecological requirements and are considered good indicators of changes in ecosystems (Thiollay 2006, Piana and Marsden 2014) and although habitat destruction is considered the most important threat for tropical forest raptors, habitat fragmentation and degradation also affects their survival (Thiollay 1985, 1993).

Understanding how species are distributed in the landscape and which factors affect such distributions can be crucial for the monitoring and conservation of biodiversity (Wu et al. 2006). Habitat modeling for raptors inhabiting temperate ecosystems has contributed to the assessment of habitat features that influence the distribution of individual raptor species (Martínez et al. 2003), to the the design of conservation plans for endangered and non-endangered species (Lopez-Lopez et al. 2007), and to the identification of habitat variables that are important for maintaining the raptor community as a whole (Bustamante and Seoane 2004).

Located in extreme northwestern Peru, the North West Biosphere Reserve (NWBR) holds a particularly rich assemblage of raptor species, including the endangered and endemic Grey-backed Hawk (*Pseudastur occidentalis*), Black Hawk-Eagle (*Spizaetus tyrannus*), and the Ornate Hawk-Eagle (*Spizaetus ornatus*; Piana et al. 2010, Piana 2011). Population of these species are declining west of the Andes in Ecuador and probably in Peru due to forest destruction for agriculture and cattle grazing (Ridgely and Greenfield 2001, Piana and Marsden 2014).

Despite its status as a conservation area, forests inside the reserve are affected by human activities such as cattle grazing and logging. In the Tumbes National Reserve, which is part of the NWBR, and buffer areas, vast regions of forest have been removed for the establishment of cattle pastures.

In this report, I use General Linear Models (GLM) to develop habitat distribution models for a guild of eleven raptor species that inhabit the (1) dry, (2) deciduous, and (3) semi-deciduous forests of extreme northwestern Peru and define the most important vegetation and geographic variables that influence species presence and shape the assemblage of the community. These models may be useful for creating and refining conservation strategies for the species, particularly those of conservation concern.

STUDY AREA AND METHODS

Study Area. Located in the centre of the Tumbesian Center of Endemism, the 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]), which are considered important bird areas because of the numerous bird species present, including raptors (BirdLife International and Conservation International 2005, Piana 2011). Together they preserve 230 000 hectares of dry semi-deciduous and deciduous forests, the largest tract of these forest types still remaining in the Tumbesian endemic region (Best and Kessler 1995).

I selected a study area of 25 × 25 km (62 500 ha) in the northern part of the NWBR, centered on El Caucho Research Station (Fig. 1). The study area encompassed the northern sector of the CANP and the TNR, from the small town of El Tutumo (3°45′S) in the park's buffer area to Quebrada El Ebano (4°S), and from the small town of Belen (80°30′W) to the Tumbes River on the border with Ecuador (80°10′W; near the eastern limit of the TNR). The study area includes four main habitat types within the seasonally dry tropical forests of northwestern Peru (Linares-Palomino 2006). Classification of these habitats was based on Aguirre et al. (2006), although I further divided the deciduous forest into two habitat types. The habitats considered were: dry savanna (between 30 to 100 masl), where algarrobo (*Prosopis pallida*) and faique (*Acacia macracantha*) trees dominated the vegetation; dry deciduous forest (100–300 masl), where madero (*Tabebuia billbergii*) trees dominated, and ceibo (*Ceiba trichistrandra*) and pasallo (*Eriotheca ruizii*) trees were also present; deciduous forest (300–600 masl) where guasima (*Guazuma ulmifolia*) dominated the lower strata and ceibo the upper strata; and semi-deciduous forest (>600 masl) containing Fernán Sanchez (*Triplaris cumingiana*), guaruma (*Cecropia litoralis*), polopolo (*Cochlospermum vitifolium*) and ceibo. This study was conducted outside the rainy season and climatic conditions during fieldwork were consistent and typical for the location. 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 yearly temperature is 26°C, with overnight temperatures higher at lower elevations. During fieldwork, no nests were found and no raptors of any species were observed carrying nesting materials.
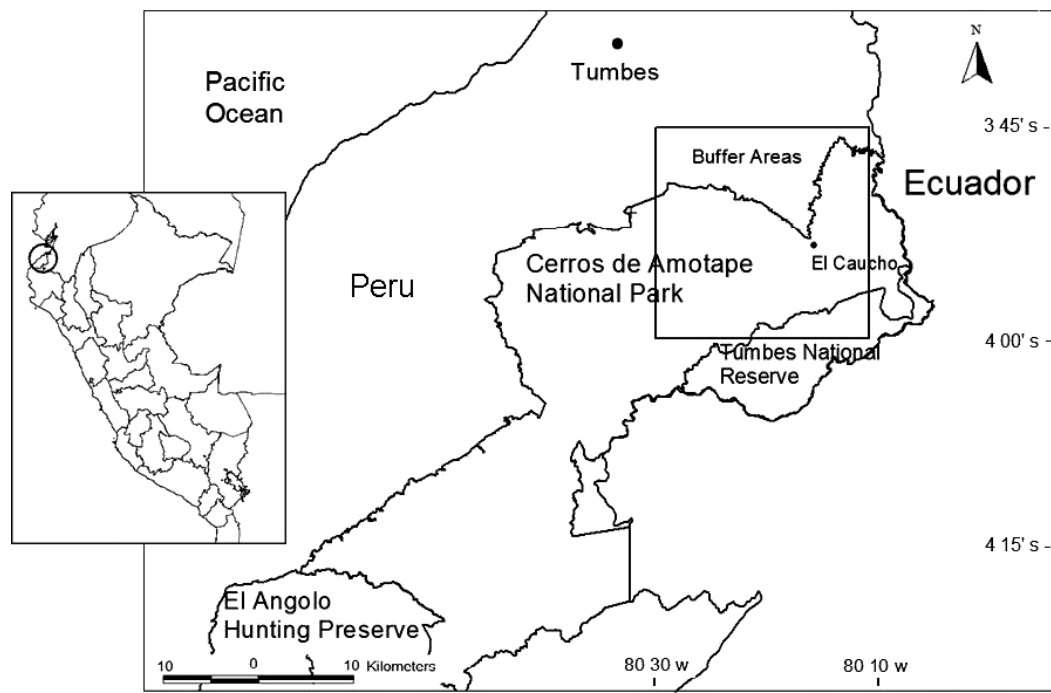
Figure 1. Map of the study area in northwestern Peru.

Raptor Surveys and Habitat Assessment. Raptors were surveyed and associated habitat measures were collected during two field seasons April–December 2008 and April–December 2009. Seventy 1-km² plots (1 × 1 km) were positioned within the 25 × 25 km study area (11.2% of the total area). Plots were allocated randomly without stratification in all areas of the study site except the Tumbes National Reserve. A small number of plots were too remote to allow safe access, so plots up to 2 km closer to existing trails were substituted for these (as in Thiollay 1993). Plots evaluated were not adjacent to each other. I used existing trails as transects or cut new ones. Transect length was 1.8 km in each square, and each transect consisted of 3 segments: ideally a length of trail 0.7 km long, followed by a section of 0.4 km perpendicular to the first, and finally another stretch of trail 0.7 km in length, parallel with the first. Walking speed was maintained at 1 km/hr. Transects were walked only once, in the morning, 90 min after sunrise or sometimes later if rainy or foggy conditions reduced raptor detectability/activity (Thiollay 1989).

Only one transect was walked per day. All diurnal raptors heard or observed perched or flying along each transect were recorded. Birds were identified to species, and age, sex, and color morph of individuals were recorded when possible. Additionally, characteristics of individuals were recorded (e.g., absence of feathers due to molting on flying birds) and birds that I suspected were previously detected were excluded from the data set. Some degree of double-counting of individuals may have occurred; however, the significance of potential double-counting is not high because analyses considered primarily bird absence/presence, rather than numbers of individuals.

Habitat measurements were made at eight points, 200 m apart, along each transect, during the bird surveys. To avoid possible biases derived from sampling along edges, evaluations were conducted 15 m perpendicular to the trail inside the forest. Elevation, latitude, and longitude were recorded with a GPS, and slope (gradient) was measured with a clinometer. Canopy height and height of upper vegetation strata (the height of the midpoint of the uppermost vegetation continuum) were visually estimated, and percentages of cover at four different vegetation strata (0–1 m, 1–5 m, 5–15 m, and 15–25 m aboveground) were also estimated. The vegetation cover was estimated by eye in increments of 5% within a 10-m-radius circle above the researcher.

These data were then averaged across the eight points on each transect, which partially ameliorated inaccuracy or unusual data at individual points. At each point, the two largest trees within 15 m of the central point were selected, and identified to species if they belonged to one of the following tree species: algarrobo, faique, madero, ceibo, guasima, or polopolo. The diameter at breast height (DBH) of these two trees was measured. Then, the number of these trees per hectare was estimated.

Habitat Association Models. In recent years, modeling of species distribution has become an important tool in conservation biology (Guisan and Thuiller 2005, Wu et al. 2006), with GLM becoming very popular for predicting species richness and distribution (Lehmann et al. 2002, Syartinilia 2008). GLM are widely used in applied ecology and conservation ecology to model species distribution with presence and absence data (Guisan and Zimmermann 2000, Guisan and Thuiller 2005, Austin 2007) and recently have been used to model breeding habitat, habitat use, and areas of conservation importance for raptor species in temperate environments (Wu et al. 2006, López-López et al. 2007).

Bird-habitat association models were created for the 11 species of raptors that were recorded in more than 10 1-km² plots. These species were: Turkey Vulture (*Cathartes aura*), Black Vulture (*Coragyps atratus*), King Vulture (*Sarcoramphus papa*), Crane Hawk (*Geranospiza caerulescens*), Great Black Hawk (*Buteogallus urubitinga*), Harris's Hawk (*Parabuteo unicinctus*), Gray-backed Hawk, Short-tailed Hawk (*Buteo brachyurus*), Black Hawk-Eagle, Laughing Falcon (*Herpetotheres cachinnans*), and Crested Caracara (*Caracara cheriway*). Models were built using a binomial GLM (binary logistic regression) between habitat variables and the presence/absence of individuals using Spatial Analysis in Macroecology—SAM 3.1 (http://www.ecoevol.ufg.br/sam/) software (Rangel et al. 2006).

Statistical Analyses. To reduce any effects of multicollinearity (Zuur et al. 2010), pairs of habitat variables were tested for correlation using Spearman's rank correlation test in PAST software (Hammer et al. 2001). Pairs of variables with absolute r_s values higher than 0.70 were considered highly correlated so one variable (the one with less biological sense in the model, according to a PCA) was removed from analysis (Lor and Malecki 2006, Dormann et al. 2013).

Spatial autocorrelation, the tendency of neighboring samples to be more similar than those expected for randomly associated observations, affects the assumption of independence of samples and of identically distributed errors, inflating type I errors (Fielding and Bell 1997, Lichstein et al. 2002, Dormann et al. 2007). I calculated spatial autocorrelation in the distribution of raptor species across the study area through Moran's *I* using SAM 3.1 software (Moran 1950, Rangel et al. 2006). Distances between pairs of squares were grouped into five classes and set to a maximum of 25 km, each class having equal number of pairs. Significance was tested using 200 permutations and a Moran's *I* correlogram was produced for each species (Legendre 1993).

Habitat variables selected for analysis were: elevation, slope, tree height, percentage of vegetation cover between 0–1 m, percentage of vegetation cover between 1–5 m, percentage of vegetation cover between 5–15 m, and number of polopolo, ceibo, algarrobo, and guasima trees. Response variable for each model was the presence of raptor species on each transect. Best habitat models were selected using Akaike's Information Criterion (AIC) values corrected for small samples (AICc) (Akaike 1973, Burnham and Anderson 2002); only those models with a difference in AICc values of <2 (compared to the model with the lowest AICc value, namely zero) were considered the best models and presented in the results (Burnham and Anderson 2002). Akaike weights (Wi), a measure of the strength of models ($0 \leq \Delta AICc \leq 2$) were used to select variables that best explained species presence (Burnham and Anderson 2002). Sensitivity (the proportion of correctly classified presences) and specificity (the proportion of correctly classified absences) were calculated with the area-under-the-curve approach (Fielding and Bell 1997) for each model.

RESULTS

Habitat Variables. Habitat in plots where raptor species were detected were described by 10 variables (Table 1, 2). For the Crested Caracara plots, mean elevation was the lowest, while the mean number of algarrobo trees was the highest; the opposite was true for the Black Hawk-Eagle. For all raptors, mean slope was less than 10%, except for the Laughing Falcon (11.1%).

Habitat Models. All habitat models selected were significant with *P* values ranging from 0.0001 (Crane Hawk, Black Hawk-Eagle, Crested Caracara) to 0.0047 (Gray-backed Hawk). Habitat variables that were related to vegetation characteristics (percentage of vegetation cover at different heights, tree

Table 1. Mean, minimum, maximum, and coefficient of variation of elevation (elev), slope (inclin), tree height (TreeH), percentage of vegetation cover from 0–1 m (%cov 0_1), from 1–5 m (%cov 1_5) and from 5–15 m (%cov 5_15) aboveground on plots where raptor species were detected.

SPECIES	VARIABLE					
	ELEV (m)	INCLIN (%)	TREEH (m)	%COV 0_1	%COV 1_5	%COV 5_15
Black Vulture	322.2 (39.1–780.1) 0.76	9.1 (2.1–39.6) 0.82	10.2 (3.8–18.0) 0.32	38.5 (1.3–80.0) 0.57	42.8 (12.5–62.5) 0.30	33.3 (3.8–72.5) 0.47
Turkey Vulture	348.1 (39.2–879.5) 0.76	8.5 (8.5–28.4) 0.68	10.5 (3.8–18.0) 0.31	33.9 (1.2–78.8) 0.58	43.2 (12.5–62.5) 0.30	33.6 (3.5–72.5) 0.43
King Vulture	515.1 (118.9–879.5) 0.53	8.8 (2.4–39.6) 1.08	10.1 (3.8–15.3) 0.28	42.2 (15.0–77.5) 0.49	47.3 (12.5–60.0) 0.28	35.4 (8.8–57.5) 0.38
Crane Hawk	306.4 (67.3–724.6) 0.85	10.4 (3.4–28.4) 0.82	13.0 (7.4–18.0) 0.25	27.6 (10.0–43.8) 0.47	42.8 (28.8–61.3) 0.24	43.1 (30.0–72.5) 0.30
Great Black Hawk	487.3 (114.6–843.5) 0.54	8.1 (2.1–34.8) 0.94	10.6 (3.8–18.3) 0.38	39.3 (8.8–78.8) 0.58	42.8 (12.5–60.0) 0.31	34.3 (3.8–61.3) 0.44
Harris's Hawk	294.8 (39.3–845.3) 0.85	9.4 (2.0–39.6) 0.82	10.5 (4.5–15.7) 0.28	30.2 (1.3–80.0) 0.66	40.6 (17.5–62.5) 0.32	31.5 (3.8–48.8) 0.38
Gray-backed Hawk	423.0 (101.4–774.8) 0.52	9.6 (2.4–34.8) 0.92	11.4 (3.8–22.6) 0.37	41.0 (6.3–77.5) 0.57	38.3 (12.5–62.5) 0.31	35.3 (3.8–57.5) 0.45
Short-tailed Hawk	430.0 (111.8–744.0) 0.59	7.4 (2.4–12.4) 0.50	10.8 (4.8–18) 0.34	43.5 (43.5–78.8) 0.46	44.8 (27.5–61.3) 0.24	42.3 (3.8–72.5) 0.44
Black Hawk-Eagle	686.8 (385.1–845.3) 0.20	7.7 (2.5–12.4) 0.33	10.1 (4.8–16.3) 0.27	36.6 (23.8–78.8) 0.39	44.4 (27.5–55.0) 0.18	40.3 (3.8–61.3) 0.33
Laughing Falcon	374.6 (74.4–875.0) 0.67	11.1 (2.4–39.6) 0.29	11.2 (4.5–19.6) 0.29	34.5 (0.0–80.0) 0.67	42.6 (20.0–63.8) 0.27	35.8 (3.8–61.3) 0.37
Crested Caracara	149.6 (39.1–297.1) 0.65	6.9 (2.4–14.8) 0.58	10.9 (7.4–15.7) 0.25	23.9 (1.3–48.8) 0.67	32.8 (17.5–53.8) 0.37	33.3 (16.3–47.5) 0.32

height, and tree species) appeared in all best models for ten species. Elevation appeared in all best models for six species and percentage of vegetation cover between 5–15 m appeared in all best models for four species. Among tree species, the number of polopolo, ceibo, and guasima appeared in all best models for two species, while the number of algarrobo was in none (Table 3).

Presence of the three vulture species was negatively associated with different values of canopy cover, with Turkey Vulture presence particularly associated with decreasing values of vegetation cover from 5–15 m. The presence of Black Vultures and King Vultures was negatively associated with tree height and positively associated with ground cover. Presence of these two species was also negatively associated with the number of polopolo and ceibo, respectively.

Among Accipitridae, Crane Hawk presence and Crested Caracara presence were negatively associated with elevation, while for the Great Black Hawk and Black Hawk-Eagle, the opposite was true. The presence of these two species was also positively related to the number of guasima, whereas Laughing Falcon presence was negatively correlated with ceibo trees. Gray-backed Hawk presence was negatively associated with algarrobo trees, but this tree species seemed to be favored by the Harris's Hawk.

Spatial Autocorrelation. Spatial autocorrelation on the distribution of the eleven raptor species that were modeled was low. Moran's I values ranged from a maximum of 0.062 (Black Vulture) to a minimum of -0.086 (Black Hawk-Eagle). Additionally, P values in correlograms were not significant for most species at any given distance, yet it was approaching significance for Black and Turkey vultures ($P = 0.056$ and $P = 0.083$, respectively) at distances close to 10 km and for the Black Hawk-Eagle ($P = 0.072$) at distances close to 13 km.

DISCUSSION

Habitat Models. Distribution of raptor species in the environment is a consequence of several variables (Janes 1985, Potapov 1997). In this study, elevation and percentage of vegetation cover from 5–15 m were the most influential in determining species presence. One important variable for some raptors (Black Vulture, Gray-backed Hawk) was ground cover, which presumably influences species' ability to detect and catch prey (Preston 1990). For species such as Turkey Vulture, Crane Hawk, Great Black Hawk, Harris's Hawk, Gray-backed Hawk and Crested Caracara, the amount of closure in the

Table 2. Mean, minimum, maximum, minimum and coefficient of variation of number of polopolo, ceibo, algarrobo and guasima trees on plots where raptor species were detected.

| | TREE SPECIES | | | |
SPECIES	POLOPOLO	CEIBO	ALGARROBO	GUASIMA
Black Vulture	1.4 (0.0–8.0) 1.41	1.9 (0.0–11.0) 1.73	1.9 (0.0–16.0) 2.45	2.6 (0.0–24.0) 2.05
Turkey Vulture	2.8 (0.0–16.0) 1.56	2.0 (0.0–8.0) 1.27	1.5 (0.0–16.0) 2.75	2.5 (0.0–24.0) 2.54
King Vulture	1.7 (0.0–14.0) 2.30	0.8 (0.0–4.0) 1.69	1.1 (0.0–14.0) 3.61	1.85 (0.0–10.0) 1.79
Crane Hawk	6.2 (0.0–16.0) 0.93	3.7 (0.0–11.0) 1.00	1.0 (0.0–8.0) 2.54	1.2 (0.0–12.0) 3.16
Great Black Hawk	3.1 (0.0–14.0) 1.42	2.1 (0.0–8.0) 1.23	0.7 (0.0–6.0) 2.44	4.5 (0.0–24.0) 1.57
Harris's Hawk	2.6 (0.0–16.0) 1.75	2.4 (0.0–10.0) 1.26	2.4 (0.0–16.0) 2.12	2.1 (0.0–12.0) 1.87
Gray-backed Hawk	2.0 (0.0–12.0) 1.97	1.5 (0.0–6.0) 1.43	0.4 (0.0–6.0) 4.12	2.1 (0.0–12.0) 1.75
Short-tailed Hawk	1.8 (0.0–12.0) 2.11	1.5 (0.0–8.0) 1.75	0.18 (0.0–2.0) 3.32	5.8 (0.0–24.0) 1.39
Black Hawk-Eagle	3.6 (0.0–14.0) 1.38	2.7 (0.0–8.0) 1.02	0.3 (0.0–4.0) 4.00	3.35 (0.0–24.0) 2.03
Laughing Falcon	2.9 (0.0–14.0) 1.53	1.2 (0.0–6.0) 1.28	2.1 (0.0–16.0) 2.32	2.0 (0.0–12.0) 1.80
Crested Caracara	1.4 (0.0–8.0) 1.79	3.2 (0.0–10.0) 1.22	3.0 (0.0–16.0) 2.00	1.2 (0.0–10.0) 2.62

canopy/sub-canopy might influence the availability of perching sites and prey, concealment to avoid predation, or availability of nesting sites (Marion and Ryder 1975, Titus and Mosher 1981), and may influence the general features of hunting areas (Williams et al. 2000). However, characteristics of habitats used by species may vary throughout the year, particularly during the rainy season, because heavy rains increase vegetative cover at different strata.

Because many raptor species exhibit habitat preferences at a landscape scale, in addition to more small-scale preferences like those in this study, plots like those I used might be too small to reflect habitat selection of raptors. However, plots 1-km² or smaller have been used in many regions of the world, including the neotropics, to model habitat use by raptors based on presence/absence data (Sanchez-Zapata and Calvo 1999, López-López et al. 2007, Pedrana et al. 2008, Piana and Marsden 2014). Additionally, in this study, habitat models consistently included the presence of ceibo, algarrobo, guasima and/or polopolo, which might indicate species' preferences for particular habitats. Although presence of a species does not necessarily reflect habitat quality, the habitat models derived herein can be used to improve the conservation value of particular areas inside the TNR, the CANP, and their buffer zones through the management of vegetation cover and tree species in places where

Table 3. Akaike weights (Wi) of habitat variables of best distribution models per species ($0 \leq \Delta AICc \leq 2$). (-) denotes a negative relationship between species and variable. Values less than 0.2 are not shown.

| | VARIABLE | | | | | | | | | |
SPECIES	ELEV	INCLIN	TREEH	%COV 0–1	%COV 1–5	%COV 5–15	POLOPOLO	CEIBO	GUASIMA	ALGAR-ROBO
Black Vulture	(-)1.00		(-)1.00	1.00		(-)0.41	(-)1.00			
Turkey Vulture		(-)0.90			0.85	(-)1.00				
King Vulture	1.00		(-)0.49	0.41	0.52	(-)0.20		(-)1.00		
Crane Hawk	(-)1.00		0.28	1.00		1.00	1.00			0.20
Great Black Hawk	1.00					(-)1.00			1.00	
Harris's Hawk	(-)0.44					(-)1.00		0.22		0.74
Gray-backed Hawk	0.20			0.87	1.00			(-)0.25		(-)0.76
Short-tailed Hawk			(-)0.20			0.29			1.00	(-)0.38
Black Hawk-Eagle	1.00		(-)0.23	0.49					0.36	(-)0.59
Laughing Falcon							(-)1.00			
Crested Caracara	(-)1.00	(-)1.00			(-)1.00		(-)0.85	(-)0.21	(-)0.43	

human activities have altered vegetation composition and forest structure. However, there might be undetected nonlinear responses of raptor species to some vegetation variables, as shown by Piana and Marsden (2014) for raptor species' responses to different intensities of cattle grazing in northwestern Peru. If this is the case, some species might exhibit a maximum (or minimum) probability of occurrence when some environmental variables are at intermediate values.

Spatial Autocorrelation. Spatial autocorrelation in species distribution is commonly caused by biological processes that can result in aggregation of individuals (Carroll and Johnson 2007, Dormann et al. 2007). Among raptor species, territory occupancy, nest-site selection, and dispersal of individuals can be significantly affected by intra- and interspecific interactions that segregate individuals (Kruger 2002, Katzner et al. 2003, Hakkarainen et al. 2004) or aggregate them (Wallace and Temple 1987), thus making their spatial distribution nonrandom. In this study, I did not find high levels of spatial autocorrelation in the presence of any of the raptor species included, suggesting that, in general, there was no clustering of individuals. Prevalence, the proportion of sites where species were recorded as present, can affect models' performance (Manel et al. 2001, Allouche et al. 2006). For all species, prevalence ranged between 14% (Crane Hawk, Crested Caracara) and 63% (Turkey Vulture) and sensitivity of best models was high (≥ 0.70), except for Great Black Hawk, Short-tailed Hawk, and Laughing Falcon. Habitat models for these three species should be interpreted with care.

Conservation Implications. Models derived here may be used to implement and strengthen conservation initiatives for single raptor species and the raptor community as a whole through the management and conservation of identified key habitat parameters in the study site. For raptors in northwestern Peru, these initiatives should prioritize management of variables related to forest structure, such as percentage of vegetative cover from 5–15 m. Additionally, protection of raptor species through the conservation of its habitats can help protect other bird species that are endemic to the region and threatened by destruction of vegetative cover at particular heights above ground (i.e., Blackish-headed Spinetail [*Synallaxis tithys*], Henna-hooded Foliage-gleaner [*Clibanornis erythrocephalus*]). The habitat models presented here may also be used to plan effective biodiversity conservation corridors and networks between CANP and Machalilla National Park, the largest protected area

in Tumbesian Ecuador, which is approximately 250 km from CANP (Best and Kessler 1995).

These models may also be useful for planning the creation of other protected areas in northwestern Peru and, particularly in the Tumbesian Zone, as they illumine key habitat features that are important for at least one endangered species of raptor endemic to this severely threatened area and whose population is decreasing throughout its entire range, the Gray-backed Hawk (BirdLife International 2010).

LITERATURE CITED

AGUIRRE, Z., R. LINARES-PALOMINO, AND L. KVIST. 2006. Woody species and vegetation formations in seasonally dry forests of Ecuador and Peru. *Arnaldoa* 13:324–350.

AKAIKE, H. 1973. Information theory as an extension of the maximum likelihood principle. Pages 267–281 *in* B.N. Petrov and F. Csaki [EDS.], Second International Symposium on Information Theory. Akademiai Kiado, Budapest, Hungary.

ALLOUCHE, O., A. TSOAR, AND R. KADMON. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology* 43:1223–1232.

AUSTIN, M. 2007. Species distribution models and ecological theory: a critical assessment and some possible new approaches. *Ecological Modeling* 200:1–19.

BEST, B. AND M. KESSLER. 1995. Biodiversity and conservation in Tumbesian Ecuador and Peru. BirdLife International, Cambridge, U.K.

BIRDLIFE INTERNATIONAL. 2010. Species factsheet: *Leucopternis occidentalis*. http://www.birdlife.org (last accessed 1 October 2010).

——— AND CONSERVATION INTERNATIONAL. 2005. Áreas importantes para la conservación de las aves en los Andes tropicales: sitios prioritarios para la conservación de la biodiversidad. BirdLife International (Serie de Conservación de BirdLife No. 14), Quito, Ecuador.

BURNHAM, K.P. AND D.R. ANDERSON. 2002. Model selection and multimodal inference: a practical information-theoretic approach. Springer-Verlag, New York, NY U.S.A.

BUSTAMANTE, J. AND J. SEOANE. 2004. Predicting the distribution of four species of raptors (Aves: Accipitridae) in southern Spain: statistical models work better than existing maps. *Journal of Biogeography* 31:295–306.

CARROLL, C. AND D.S. JOHNSON. 2007. The importance of being spatial (and reserved): assessing Northern Spotted Owl habitat relationships with Hierarchical Bayesian Models. *Conservation Biology* 22:1026–1036.

CLEARY, F.R., G.J. GENNER, T.J. BOYLE, B.T. SETYAWATI, C.D. ANGRAETI, AND S.B.J. MENKEN. 2005. Associations of bird species richness and community composition with local- and landscape–scale environmental factors in Borneo. *Landscape Ecology* 20:989–1001.

DORMANN, C.F., J. ELITH, S. BACHER, C. BUCHMANN, G. CARL, G. CARRÉ, J.R. GARCÍA MÁRQUEZ, B. GRUBER, B. LAFOURCADE, P.J. LEITAO, T. MUNKEMULLER, C. McCLEAN, P.E. OSBORNE, B. REINEKING, B. SCHROEDER, A.K. SKIDMORE, D. ZURELL, AND S. LAUTENBACH. 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* 35:1–20.

———, J.M. McPHERSON, M.B. ARAUJO, R. BIVAND, J. BOLLIGER, G. CARL, R.G. DAVIES, A. HIRZEL, W.D. JETZ, D. KISSLING, I. KUHN, R. OHLEMULLER, P.R. PERES-NETO, B. REINEKING, B. SCHROEDER, F.M. SCHURR, AND R. WILSON. 2007. Methods to account for spatial autocorrelation in the analysis of species distribution data: a review. *Ecography* 30:609–628.

FIELDING, A. AND J.F. BELL. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation* 24:38–49.

GUISAN, A. AND W. THUILLER. 2005. Predicting species distribution: offering more than simple habitat models. *Ecology Letters* 8:993–1009.

——— AND N.E. ZIMMERMANN. 2000. Predictive habitat distribution models in ecology. *Ecological Modeling* 135: 147–186.

HAKKARAINEN, H., S. MYKRA, S. KURKI, R. TORNBERG, AND S. JUNGELL. 2004. Competitive interactions among raptors in boreal forests. *Oecologia* 141:420–424.

HAMMER, O., D.A.T. HARPER, AND P.D. RYAN. 2001. PAST: Paleonthological statistics software package for education and data analysis. *Paleontologia Electronica* 4:9.

JANES, S.W. 1985. Habitat selection on raptorial birds. Pages 159–188 *in* M.L. Cody [ED.], Habitat selection in birds. Academic Press, New York, NY U.S.A.

KATZNER, T.E., E.A. BRAGIN, S.T. KNICK, AND A.T. SMITH. 2003. Coexistence in a multispecies assemblage of eagles in central Asia. *Condor* 105:338–351.

KRUGER, O. 2002. Interactions between Common Buzzard *Buteo buteo* and goshawk *Accipiter gentilis*: trade-offs revealed by a field experiment. *Oikos* 96:441–452.

LEGENDRE, P. 1993. Spatial autocorrelation: trouble or new paradigm? *Ecology* 74:1659–1673.

LEHMANN, A., J.M. OVERTON, AND M.P. AUSTIN. 2002. Regression models for spatial prediction: their role for biodiversity and conservation. *Biodiversity and Conservation* 11:2085–2092.

LICHSTEIN, J.W., T.R. SIMONS, S.A. SHRINER, AND K.E. FRANZREB. 2002. Spatial autocorrelation and autoregressive models in ecology. *Ecological Monographs* 72:445–463.

LINARES-PALOMINO, R. 2006. Phytogeography and floristics of seasonally dry tropical forests in Peru. Pages 257–279 *in* R.T. Pennington, G.P. Lewis, and J.A. Ratter [EDS.], Neotropical savannas and seasonally dry forests: plant diversity, biogeography and conservation. CRC Press, Boca Raton, FL U.S.A.

LÓPEZ-LÓPEZ, C., C. GARCÍA-RIPOLLÉS, A. SOUTULLO, L. CADAHÍA, AND V. URIOS. 2007. Identifying potentially suitable nesting habitat for Golden Eagles applied to ''important bird areas'' design. *Animal Conservation* 10:208–218.

LOR, S. AND R.A. MALECKI. 2006. Breeding ecology and nesting habitat associations of five marsh bird species in western New York. *Waterbirds* 29:427–436.

MANEL, S., H.C. WILLIAMS, AND S.J. ORMEROD. 2001. Evaluating presence-absence models in ecology: the need to account for prevalence. *Journal of Applied Ecology* 38: 921–931.

MARION, W.R. AND R.A. RYDER. 1975. Perch-site preferences of four diurnal raptors in northeast Colorado. *Condor* 77:350–352.

MARTÍNEZ, J.A., D. SERRANO, AND I. ZUBEROGOITIA. 2003. Predictive models of habitat preferences for the Eurasian Eagle Owl *Bubo bubo*: a multiscale approach. *Ecography* 26:21–28.

MORAN, P.A.P. 1950. Notes on continuous stochastic phenomena. *Biometrika* 37:17–23.

PEDRANA, J., J.P. ISACCH, AND M.S. BO. 2008. Habitat relationships of diurnal raptors at local and landscape scales in southern temperate grasslands of Argentina. *Emu* 108:301–310.

PIANA, R. 2011. Las rapaces diurnas del Parque Nacional Cerros de Amotape y la reserva Nacional de Tumbes. *Boletín Informativo de la Unión de Ornitólogos del Perú* 6(11):4–8.

———, S. CRESPO, F. ANGULO, E. ORMAECHE, AND M. ALZAMORA. 2010. Grey Hawk *Buteo nitidus* and Ornate Hawk-Eagle *Spizaetus ornatus* in northwest Peru. *Cotinga* 32:106–108.

——— AND S. MARSDEN. 2014. Impact of cattle grazing on forest structure and raptor distribution within a Neotropical protected area. *Biodiversity and Conservation* 23:559–572.

POTAPOV, E.R. 1997. What determines the population density and reproductive success of Rough-legged Buzzard *Buteo lagopus* in the Siberian tundra? *Oikos* 78:362–376.

PRESTON, C.R. 1990. Distribution of raptor foraging in relation to prey biomass and habitat structure. *Condor* 92:107–112.

RANGEL, T.F., J.A.F. DINIZ-FILHO, AND L.M. BINI. 2006. Toward an integrated computational tool for spatial analysis in macroecology and biogeography. *Global Ecology and Biogeography* 15:321–327.

RIDGELY, R. AND P. GREENFIELD. 2001. The birds of Ecuador: field guide. Vol. II. Cornell University Press, Ithaca, NY U.S.A.

SANCHEZ-ZAPATA, A.J. AND J.F. CALVO. 1999. Raptor distribution in relation to landscape composition in semi-arid Mediterranean habitats. *Journal of Applied Ecology* 36: 254–262.

SYARTINILIA, S.T. 2008. GIS-based modeling of Javan Hawk-Eagle distribution using logistic and autologistic regression models. *Biological Conservation* 141:756–769.

THIOLLAY, J.-M. 1985. Falconiforms of tropical rainforest: a review. Pages 155–165 *in* I. Newton and R.D. Chancellor [EDS.], Conservation studies on raptors. ICBP Technical Publication No. 5. World Working Group of Birds of Prey and Owls, Cambridge, U.K.

THIOLLAY, J.M. 1989. Censusing of diurnal raptors in a primary rain forest: comparative methods and species detectability. *Journal of Raptor Research* 23:72–84.

———. 1993. Response of a raptor community to shrinking area and degradation of tropical rain forest in the south western Ghats (India). *Ecography* 16:97–110.

———. 2006. The decline of raptors in West Africa: long-term assessment and the role of protected areas. *Ibis* 148:240–254.

TITUS, K. AND J.A. MOSHER. 1981. Nest-site habitat selected by woodland hawks in the central Appalachians. *Auk* 98:270–281.

WALLACE, M.P. AND S.A. TEMPLE. 1987. Competitive interactions within and between species in a guild of avian scavengers. *Auk* 104:290–295.

WILLIAMS, C.K., R.D. APPLEGATE, R.S. LUTZ, AND D.H. RUSCH. 2000. A comparison of raptor densities and habitat use in Kansas cropland and rangeland ecosystems. *Journal of Raptor Research* 34:203–209.

WU, Y., G. FUJITA, AND H. HIGUCHI. 2006. What landscape elements are correlated with the distribution of wintering Grey-faced Buzzards *Butastur indicus* in the Sakishima Islands, southwestern Japan? *Ornithological Science* 5:157–163.

ZUUR, A.F., E.N. IENO, AND C.S. ELPHICK. 2010. A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution* 1:3–14.