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PREDICTING OCCURRENCE OF MEXICAN SPOTTED OWLS IN ARID CANYONLANDS OF SOUTHERN UTAH

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ABSTRACT.—The Mexican Spotted Owl (*Strix occidentalis lucida*) was listed as ‘‘threatened’’ by the U.S. Fish and Wildlife Service in 1993. Predicting the distribution of suitable habitat is an important step in the owl's recovery, and Geographic Information Systems (GIS) provide appropriate spatial and analytic tools. We developed and validated a GIS-based occurrence model for Mexican Spotted Owls in arid canyon environments in Utah. We generated a set of competing models with topographic and vegetation covariates, and ranked models using information theory. Our top-ranked models indicated slope and variation in elevation were important predictors for the occurrence of Mexican Spotted Owls in rocky habitats, and we averaged coefficients from the top models to estimate probability of owl occurrence. During a model validation survey, we detected Spotted Owls in 22 test plots, where mean estimated probability of occurrence, an index to habitat suitability, was 0.68 (SE = 0.03). In addition, we evaluated model performance at 30 known Mexican Spotted Owl use sites from outside our model development areas, and observed an overall mean probability of occurrence equal to 0.78 (95% CI = 0.71–0.81). For the 30 known owl use sites, estimated probability of occurrence using our top model ranged from 0.54–0.90. Our results suggest that GIS modeling can be an important tool for predicting the potential distribution of Mexican Spotted Owls and their habitat in arid canyonlands in Utah.

KEY WORDS: *Mexican Spotted Owl*; Strix occidentalis lucida; *habitat*; *Geographic Information Systems*; *Utah.*

PREDICIENDO LA OCURRENCIA DE *STRIX OCCIDENTALIS LUCIDA* EN CAÑONES ÁRIDOS DEL SUR DE UTAH

RESUMEN.—*Strix occidentalis lucida* fue categorizada como ‘‘amenazada’’ por el Servicio de Pesca y Vida Silvestre de EEUU en 1993. La predicción de la distribución de hábitat apropiado es un paso importante en la recuperación de *S. o. lucida,* y los Sistemas de Información Geográfica (SIG) proporcionan herramientas espaciales y analíticas apropiadas. Desarrollamos y validamos un modelo de ocurrencia basado en SIG para *S. o.* lucida en ambientes de cañones áridos en Utah. Generamos un conjunto de modelos rivales con covariables topográficas y de vegetación, y clasificamos jerárquicamente los modelos utilizando la teoría de la información. Nuestros modelos mejor clasificados indicaron que la pendiente y la variación altitudinal fueron predictores importantes de la ocurrencia de *S. o. lucida* en hábitats rocosos y promediamos los coeficientes de los modelos mejor clasificados para estimar la probabilidad de ocurrencia de las lechuzas. Durante un muestreo para validar el modelo, detectamos individuos de *S. o. lucida* en 22 parcelas de prueba, en las cuales la probabilidad media estimada de ocurrencia, un índice de aptitud del hábitat, fue 0.68 (EE = 0.03). Además, evaluamos el desempeño del modelo en 30 sitios conocidos por ser utilizados por individuos de *S. o. lucida* y localizados afuera de las áreas de desarrollo del modelo y observamos una media general de probabilidad de ocurrencia igual a 0.78 (95% CI = 0.71–0.81). Para los 30 sitios conocidos por ser utilizados por las lechuzas, la probabilidad estimada de ocurrencia utilizando nuestro modelo mejor clasificado osciló entre 0.54–0.90. Nuestros resultados sugieren que los modelos basados en SIG pueden ser una herramienta importante para predecir la distribución potencial de *S. o. lucida* y su hábitat en los cañones áridos en Utah.

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The Mexican Spotted Owl (*Strix occidentalis lucida*) is primarily associated with late-seral forests (Ganey and Balda 1989, Ganey and Dick 1995), but is also distributed among rocky canyons of the Colorado Plateau (Kertell 1977, Rinkevich 1991, Willey and van Riper 2007). The Mexican Spotted Owl was listed as threatened by the U.S. Fish and Wildlife Service in 1993 (Cully and Austin 1993). In rocky canyonlands, protecting Mexican Spotted Owl habitat is germane to its conservation (USDI 1995), yet most studies of its habitat have focused on forest environments (Ganey et al. 2000, Ganey 2004, May et al. 2004) and little is known about the distribution of suitable habitat in Utah (Willey 1998, Mullet and Ward 2010).

Accurately predicting the distribution of Mexican Spotted Owl habitat is an important step toward monitoring habitat quality and supporting population management, yet this information is lacking for the Colorado Plateau (USDI 2012). Several previous efforts developed predictive models for the owl's occurrence within diverse canyon environments; for example, Johnson (1990) developed a series of GIS-based models for Mexican Spotted Owl roost and nest habitat in the Jemez Mountains, New Mexico, where he predicted habitat availability based on timber inventory data (Johnson and Johnson 1988). Johnson (2001) developed and tested a model across the range of this owl in the southwestern U.S. using a database of known owl locations (White et al. 1995) and, although the model performed well in New Mexico, its accuracy declined toward the western portions of the owl's range, for example, in canyonlands of Utah.

Several studies described Mexican Spotted Owl habitat associations in rocky canyons within Utah; for example, working in Zion National Park, Rinkevich (1991) reported that availability of relatively cool and mesic habitat for nesting and roosting was a limiting factor in the distribution of Mexican Spotted Owls. Willey (1998), working in south-central Utah, observed that Mexican Spotted Owls used narrow steep-walled sandstone canyons with high cliffs and relatively low tree cover, and roosts sites were primarily caves and rock ledges. Ganey and Balda (1989) located Mexican Spotted Owls in steep, rocky limestone canyons in north-central Arizona, and found roosts included caves, conifers, and various hardwood tree species.

To identify areas with potential Mexican Spotted Owl habitat in rocky canyon terrain in Utah, we had the following objectives: (1) identify a best-approximating model to predict the probability of occurrence of Mexican Spotted Owls within rocky canyon habitat, (2) conduct field surveys to assess the GIS-based model predictions, and (3) assess model performance using independent Mexican Spotted Owl locations from outside our modeling study areas. We developed a set of *a priori* candidate models to predict the distribution of rocky canyon habitat for Mexican Spotted Owls in southern Utah. We identified potential associations between Mexican Spotted Owls and their canyon environments by evaluating previous information concerning suitable rocky canyon habitat (Ganey and Balda 1989, Rinkevich 1991, Willey 1995, 1998). Based on these associations, we developed *a priori* models to represent potential relationships between owl occurrence and habitat characteristics, and used a GIS-based approach to predict the distribution of potential habitat (Johnson 1998, Hatten and Paradzick 2003, Mullet 2008).

METHODS

Study Areas. At the broadest scale, our goal was to model potential rocky canyon habitat within the Mexican Spotted Owl Colorado Plateau Ecological Management Unit (EMU) (USDI 2012). In this region, we identified four independent study areas each comprising 12 contiguous U.S. Geological Survey 7.5-min series quadrangle maps (Fig. 1). We selected the study areas because each had a history of field surveys and were occupied historically by at least three nonoverlapping Mexican Spotted Owl territories (Willey 1998). Thus, the study areas contained known Mexican Spotted Owl use sites and locations where no Mexican Spotted Owls were detected during repeated surveys. In addition, these study areas represented potential habitat variation described for the region (USDI 1995).

The Paria River study area (Paria) was located 45 km east of Kanab, Utah, and included steep sandstone tributary canyons that surrounded the deeply entrenched upper Paria River Gorge, where elevations ranged from 1345–1729 m (Fig. 1). The Manti study area was located 35 km west of Blanding, Utah, on a prominent north-south oriented high plateau with deep canyons along its flanks, where elevations ranged from 1529–2445 m. The Dirty Devil River (Dirty) study area included a deeply entrenched canyon system that forms a prominent tributary of the Colorado River 45 km east of Hanksville, Utah, where elevations ranged from 1280–1646 m. The Desolation Canyon study area

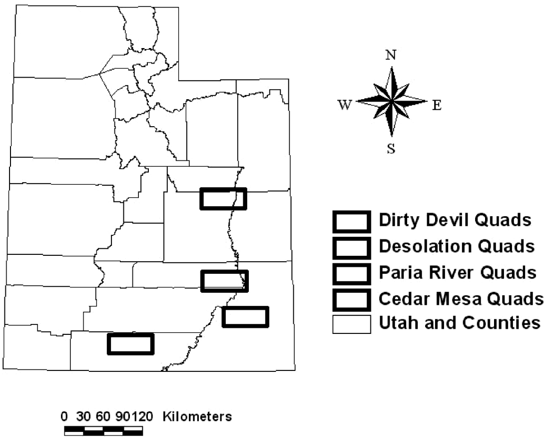

Figure 1. Location of four study areas used for modeling Mexican Spotted Owl probability of occurrence in rocky canyon habitat, southern Utah.

Table 1. Explanatory habitat variables measured in 300-m-radius plots used to describe potential Mexican Spotted Owl habitat in southern Utah, U.S.A.

VARIABLE NAME	VARIABLE DESCRIPTION
DEMR	Elevation range within the buffers
DEMS	Ruggedness and surface complexity
SLOP	Index to percent slope (terrain steepness)
ASP	Slope orientation in degrees (an index to temperature)
CURV	Planimetric slope-curvature (measure of complexity)
TH1	Landsat-7 thermal band (surface radiation)
TCA2	Tasseled-cap band 2 (vegetation greenness)
T2TX	Tasseled-cap band 2, kernel texture (vegetation edge)
MSVI	Soil-adjusted vegetation cover
MTEX	MSVI kernel texture (vegetation complexity)
GEO	Cliff formation substrates (surface geology)

(Desolation), located 35 km north of Interstate 70 in central Utah, encompassed a central gorge that rivals the Grand Canyon in Arizona in terms of depth and width, and was the northernmost study area in Utah. Elevation ranged from 1220–2730 m in Desolation Canyon. In all study areas, vegetation communities were diverse and depended strongly on topography and surface geology (Brown 1982, Thornbury 1965). Canyon floors with intermittent surface water contained small scattered patches of riparian vegetation, typically including a mix of willow species (*Salix* spp.), box elder (*Acer negundo*), bigtooth maple (*A. grandidentatum*), Fremont cottonwood (*Populus fremontii*), and various forbes (e.g., *Mimulus*). In relatively cool microsites, often near riparian communities, were small patches of mixed-conifer forest including Douglas-fir (*Pseudotsuga menziesii*) and white fir (*Abies concolor*), and often ponderosa pine (*Pinus ponderosa*). Forest patches often included bigtooth maple, Gambel's oak (*Quercus gambelii*), and Great Basin sage (*Artemisia tridentata*) in the understory. In more xeric canyon bottoms, desert scrub or pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus utahensis*) were often present, but bare rock dominated these locations. Desert scrub included blackbrush (*Coleogyne ramosissima*), curl-leaf mahogany (*Cercocarpus ledifolius*), various cacti (*Opuntia* spp.), and scattered bunch-grasses [e.g., Indian ricegrass (*Stipa hymenoides*)]. Above the steep cliffs overlooking canyon bottoms, terraced slopes were dominated by pinyon-juniper woodland or desert scrub. All four study areas were part of the high plateaus subsection of the Colorado Plateau Physiographic Province (Thornbury 1965), where total annual precipitation typically averages 17 cm, and summer temperatures can exceed 44°C (Willey 1998).

Habitat Variables. We used results from previous studies of Mexican Spotted Owls conducted in rocky canyon terrain to identify important habitat characteristics. Our set of potentially relevant variables included: (1) landscape complexity and slope (Rinkevich 1991, Willey 1998); (2) surface temperatures (Barrows 1981, Ganey et al. 1993); and (3) vegetation cover, which provides roost sites and habitat for prey species (Willey and Willey 2010, USDI 2012). We predicted Mexican Spotted Owls were likely to be found in: (1) steep, rocky canyons as opposed to terraced, relatively exposed uplands; (2) canyons that possessed relatively cool micro-sites because the owls may be heat sensitive (e.g., Barrows 1981, Ganey et al. 1993), and (3) canyons with vegetative cover provided by riparian or forest vegetation types that augment rocky cliffs to enhance roost habitat (Ward 2001). We represented each of the identified habitat components with GIS-based covariates (Table 1).

Within each of our four study areas (Fig. 1), we randomly selected locations with confirmed Mexican Spotted Owl presence or absence determined during field surveys conducted during 1992 to 1997 (Willey 1998), where the number of sample points for each category (i.e., presence or absence) was equal to approximately half the total number of known owl locations in each study area. The number of historical owl territories present in each study area ranged from three to six, and we limited our sample to approximately half the known locations per owl within each territory because we were concerned about pseudoreplication and biases associated with repeated sampling of the same territory. Our sample across all four study areas included 81 presence and 81 absence locations for modeling habitat. At each presence and absence point, we established a 300-m-radius circular sampling buffer (28-ha area) using ArcMap 9.1 (ESRI 2007). We used this 28-ha size based on Willey and van Riper (2007), who reported a mean home-range size of 288 ha; thus, our buffer was designed to sample a relatively fine-grained measurement unit within a home range (Johnson 1980). In each 300-m buffer, we measured a suite of GIS-based habitat covariates (Table 1). We derived covariates from digital elevation models (DEM), Landsat-7 satellite imagery (30-m resolution), and a geologic map of the region (Utah Division of Natural Resources, SGID database). We derived percent slope (SLOP) from the digital elevation models of each study area to represent terrain steepness and identify potential cliff habitat (Table 1). We derived an index to slope aspect (ASP) to represent compass orientation and create an index of potential surface temperature. Previous studies (Rinkevich 1991, Willey 1998) suggested that relatively north-facing aspects provided relatively shaded roost and nest sites so owls could avoid high summer temperatures. We converted slope aspect into an index (ASP) related to potential daytime surface temperatures by calculating the number of degrees from due South (180°) to each pixel's compass orientation. We reasoned that more north-facing slopes would possess relatively cooler daytime temperatures than relatively south-facing aspects. We calculated ASP as the number of degrees northward from due South; for example, an aspect of 180° was converted to 0 degrees North, whereas aspects of 320° (a northwest-facing slope) or 40° (a northeast-facing slope) were each converted to 140 degrees North. We reasoned that more northerly facing slopes represented cooler, shaded microsites (Willey 1998). In addition, we used the Landsat thermal band (TH1) to derive a layer that represented surface radiation and create another index to microclimate. We derived a measure of planimetric slope curvature (CURV) to represent terrain complexity, where CURV represents the ruggedness of slope profile (Willey and Spotskey 2000). To further describe geomorphology, we hypothesized that comparing the range of DEM values (DEMR, Table 1) between buffers would better represent the extent of topographic change within a buffer than the mean value for each buffer. We selected standard deviation of values within the buffers (DEMS) to represent the complexity of the topography within those buffers by showing the relative spread of values around a central tendency for each buffer. We used the Tasseled-cap band 2 (TCA2) transformation (Kauth and Thomas 1976) to represent ''greenness'' of vegetation and create an index of vegetation cover (Crist and Kauth 1986), and we also used a soil-vegetation index (MSVI, Table 1) to minimize variations in greenness due to soil brightness to describe vegetation density (Huerte 1988, Lawrence and Ripple 1998). We used both the Landsat-derived Tasseled-cap band 2 Texture (T2TX) and Soil-vegetation adjusted index (MTEX) to create spatial variables that described vegetation characteristics. We selected T2TX from Landsat ETM+ imagery as a habitat variable to create an index of vegetation intensity. We used MTEX in our models to describe vegetation density for the study area. Following Haralick et al. (1973), we derived a measure of Landsat image texture from the tasseled-cap and soil-vegetation indices to represent vegetation boundaries. We calculated texture for the vegetation indices using a window size of 3 × 3 and used the co-occurrence displacement of (1, 1) to calculate mean values. We calculated texture variance for the selected scenes as our final measure of image texture from vegetation index layers. We calculated texture variance using:

$$\sigma_i^2 = \sum_{i,j=0}^{N-1} P_{i,j}(i-\mu_i)^2 \qquad (1)$$

Where μ_i represented the modeled mean for each co-occurrence window. Texture measures calculated in this manner represented locations of vegetation change and therefore boundaries of vegetation components for a given scene. Our version of MTEX did not require a soil line function to be empirically derived (Lawrence and Ripple 1998); thus, MSVI in our models represented a soil-adjusted index of vegetation density for the study areas, defined by the following equation:

Table 2. Candidate models representing relationships among explanatory variables and the predicted occurrence of Mexican Spotted Owls in rocky canyon environments, Utah, U.S.A. (see Table 1 for variable definitions).

MODEL ID	MODEL DESCRIPTION	MODEL STRUCTURE
M1	Complex and steep terrain	b_0 + CURV + SLOP + DEMS
M2	Complex and steep terrain, temperature-shade	b_0 + CURV + SLOP + DEMS + ASP + TH1
M3	Complex and steep terrain, surface geology	b_0 + CURV + SLOP + GEO
M4	Steep terrain, plant-soils index	b_0 + SLOP + DEMR + MSVI
M5	Steep terrain, plant cover (greenness)	b_0 + SLOP + DEMR + TCA2
M6	Steep terrain, plant-soils index, temperature	b_0 + SLOP + DEMR + MSVI + TH1
M7	Complex and steep terrain, plant texture (complexity)	b_0 + CURV + DEMS + MTEX
M8	Complex and steep terrain, plant community edges	b_0 + CURV + SLOP + MTEX + T2TX
M9	Complex and steep terrain, temperature, plant-edge	b_0 + CURV + SLOP + TH1 + MTEX + T2TX
M10	Complex and steep terrain, temperature-shade, plant-edge	b_0 + CURV + SLOP + TH1 + ASP + MTEX

$$MSAVI_2 = \frac{(2*Band4)+1-\sqrt{((2*Band4)+1)^2+(8*(Band4-Band3))}}{2} \quad (2)$$

Band 4 represents the near-infrared range of the spectrum collected by the Landsat ETM+ sensor and Band 3 represents the visible red range of the spectrum. We created texture images in RSE ENVI 4.1 (RIS-ENVI, Inc., Boulder, CO). Finally, we exported each buffered area as a shape file using ArcMap 9.1, and then used Hawth's Analysis Tool (Beyer 2004) to estimate mean values for each continuous habitat variable in the 300-m buffers. To derive an index of surface geology, we assigned each geologic formation (n = 10 types) a unique value, from 1–10 (representing relatively soft to hard cliff-forming substrates), and used the average of this variable within the buffer. Higher values of this variable were associated with greater tendency for the presence of large cliffs that contained ledges and caves suitable for roost or nest sites (Willey 1998).

Statistical Analyses. We investigated associations between the response variable, the probability of owl occurrence, and the habitat covariates using logistic regression (Neter et al. 1996). We evaluated potential habitat associations by constructing an *a priori* set of regression models using combinations of our covariates (Table 2). We modeled the logarithm of the odds ratio of Mexican Spotted Owl occupancy as a linear function of the explanatory variables (Horssen et al. 2002). We determined maximum likelihood estimates of model coefficients (β_i) for each regression model, and we used an inverse transform of the logit to produce estimates of the probability of owl occurrence spatially for each study area. We used Akaike's Information Criteria (AIC) to rank the candidate models, constructed a global model, calculated goodness-of-fit, and estimated over-dispersion (Burnham and Anderson 2002). We inspected covariates within a variance-covariance matrix and we observed relatively low correlation among variables (i.e., <0.045). We used model-averaging to produce a composite habitat model with averaged parameter estimates to account for model-selection uncertainty. We estimated unconditional prediction variances (Burnham and Anderson 2002, Powell 2007) and used the estimated sampling variances for spatially explicit predictions. We estimated 95% confidence intervals for mapping our spatial predictions from the logistic regression models. We calculated the lower 95% confidence limit for probability of owl occurrence for each pixel within the study areas and used that value to create probability maps. These maps represented a conservative approach to depict owl habitat by minimizing potential errors of omission in our prediction areas along the fringe of suitable habitat.

Model Validation. From a list of 7.5-min USGS quadrangle maps that encompassed the entire Colorado Plateau EMU but omitting maps within our modeling study areas, we randomly selected six maps for field validation surveys. These maps were then defined as our six validation quadrats. Across each quadrat, we overlaid a sampling frame using 1-km^2 grid cells, and systematically identified up to 20 1-km^2 plots, with each plot spaced $\geq$2 km apart to achieve independence among our test plots (Ganey et al. 1999). Within these plots we conducted surveys for Mexican Spotted Owls during May–July 2006, a time period associated with the nestling through fledging phase of the breeding season

Table 3. Three best-supported *a priori* models for predicting probability of occurrence for Mexican Spotted Owls in rocky canyon environments, Utah, U.S.A., showing number of parameters (K), Akaike's Information Criterion (AIC), change in AIC (ΔAIC), and model weights (w).

MODEL	K	AIC	ΔAIC	w
M5: b_0 + SLOP + DEMR + TCA2	4	106.7	0.0	0.48
M4: b_0 + SLOP + DEMR + MSVI	4	107.7	0.6	0.36
M6: b_0 + SLOP + DEMR + MSVI + TH1	5	109.0	2.3	0.16

(Willey 1998). We selected plot size based on work conducted by Ganey et al. (1999), who suggested that 1-km^2 plots could be surveyed with a reasonable amount of effort and represented a size relevant to the owl's territorial behavior. We located study plots in the field using a global positioning device and 7.5-min maps. Within each plot, we established four calling stations, one at each plot corner, to achieve complete coverage of the plot (Forsman 1983). Once we located a call point, a trained observer called for Mexican Spotted Owls for 30 min using voiced-produced imitations of the 4-note location call and contact calls (Ganey 1990) following the standardized survey protocol (Forsman 1983), and alternating calling and listening in 5-min intervals. We conducted all surveys at night between dawn and dusk, and visited each plot twice during the survey period. If we detected an owl in a plot, we estimated the owl's position as a Universal Transverse Mercator (UTM) point location.

Willey (1998) conducted standardized surveys for Mexican Spotted Owls and located 21 territories in Zion National Park and nine territories in Capitol Reef National Park. Both Zion and Capitol Reef national parks are located outside the study areas we used to generate our predictive habitat model. We used the UTM locations of known nest sites or primary roosting sites within each of these 30 territories as a final step in model assessment. We created 300-m buffers around each owl use location (i.e., a nest or roost site) and estimated the probability of occurrence using a single, weighted-average composite habitat model.

RESULTS

We examined 10 regression models in our candidate list (Table 2), generated each model's AIC value, and evaluated a global model containing all covariates. Correlation coefficients among variables was low (i.e., <0.045), a goodness-of-fit test indicated the global model fit the data (P = 0.94), and over-dispersion was modest ($\hat{c}$ = 1.38). Among the *a priori* models, two were closely ranked (M5, M4) as top-approximating models, and three models received substantial support (Table 3). Seven other models had AIC weights near zero, and therefore did not contribute to our estimation of the probability of owl occurrence. We used the three models with substantial AIC weights to generate model-averaged prediction coefficients and create a composite habitat model. In our composite model, percent slope showed a positive relationship with the probability of owl occurrence (Table 4). Several other covariates showed weak negative associations with probability of owl occurrence; however, for these covariates the 95% confidence intervals spanned zero. Using the composite habitat model parameter estimates, we constructed predictive maps that depicted well-defined areas with high probability of owl occurrence (Fig. 2).

We completed field validation surveys within six study quadrats (Table 5) during 2006, including 138 1-km^2 plots with 448 calling stations. We detected Mexican Spotted Owls in five quadrats (83%) and confirmed owl presence in 22 plots. Based on our composite habitat model, the estimated probability of occurrence of plots with Mexican Spotted Owls was 0.68 (SE = 0.03, 95% CI = 0.62, 0.74) versus 0.38 (SE = 0.02, 95% CI = 0.34, 0.42) for plots (n = 116) with no owl detections (Fig. 3). The average probability of occurrence for plots with

Table 4. Multivariate logistic regression model coefficients estimated by model-averaging across the three best-supported models describing Mexican Spotted Owl occurrence.

PARAMETER	β	95% CI
Intercept (b_0)	−3.779	−10.616, 3.058
SLOP (% slope)	0.241	0.164, 0.318
DEMR (elevation range)	−0.043	−0.060, −0.026
MSVI (soil-plant index)	−0.684	−2.349, 0.981
TCA2 (greenness)	−0.005	−0.010, 0.000
TH1 (thermal)	−0.004	−0.036, 0.028

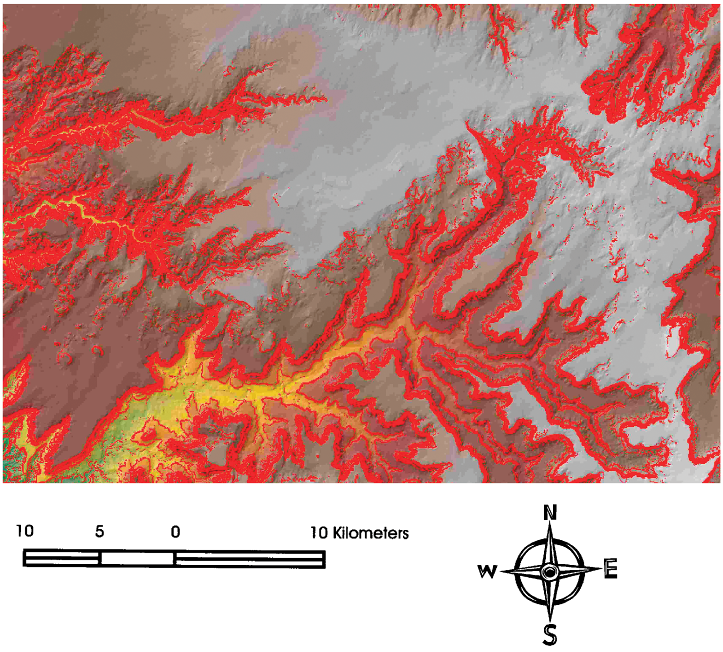

Figure 2. Mexican Spotted Owl habitat (red pixels) in a portion of the DIRTY study area. Red pixels show the 95% lower confidence limit for the 99% probability of occurrence, and additional colors show topography using shaded relief across the landscape.

Mexican Spotted Owls was 0.63 (SE = 0.03), and 0.79 (SE = 0.05) for Black Steer and Kolob Arch quadrats, respectively (Table 5). The Hunts Draw quadrat had no owl detections within the plots we surveyed, and showed moderate estimated probability of occurrence (i.e., mean = 0.50, SE = 0.09).

For our analysis of model performance among 300-m GIS sample buffers centered at known use sites (i.e., nest or roosts) within Mexican Spotted Owl territories located in Capitol Reef and Zion, we calculated an overall mean probability of occurrence of 0.78 (95% CI = 0.71, 0.81), and probability

Table 5. Results of validation surveys for Mexican Spotted Owls within six 7.5-min series quadrangle maps during May–July 2006, southern Utah, U.S.A. Shown are map names, number of 1-km^2 plots, stations per plot, and unique owl detections.

QUAD NAME	PLOTS	CALLING STATIONS	PLOTS WITH OWL DETECTIONS
Black Steer Canyon	20	80	8
Bull Valley Gorge	20	80	1
Calf Creek	20	80	2
Kolob Arch	18	70	7
Snow Flat Spring Cave	20	76	4
Hunts Draw	20	62	0
Total values	138	448	22

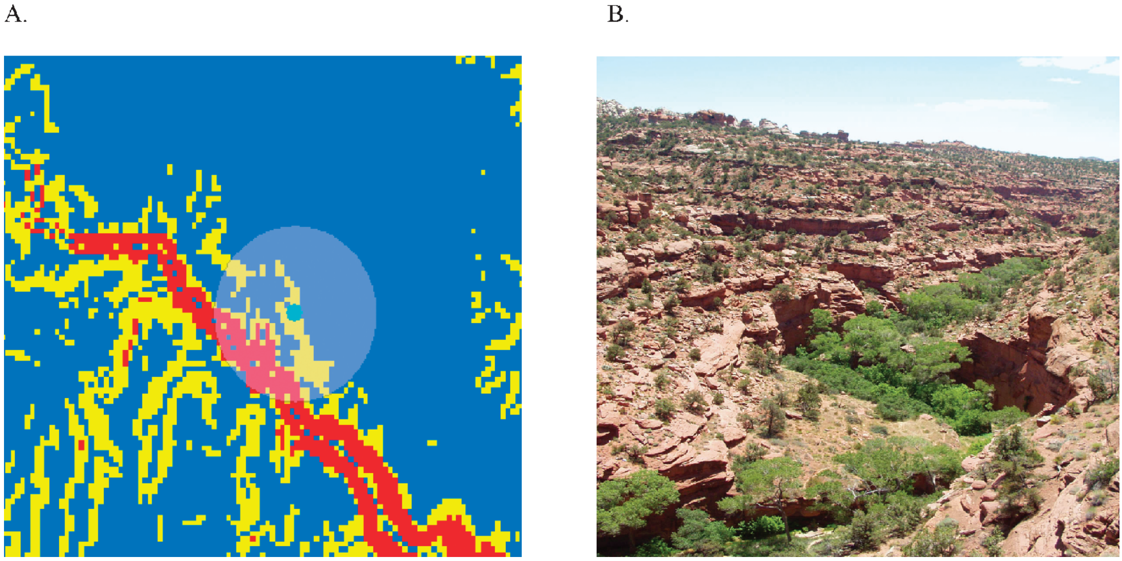

Figure 3. (A) Probability of occurrence map for Mexican Spotted Owls for a 1-km² plot in the PARIA study area. The mean probability of occurrence = 0.39 within the circular buffer centered outside the canyon rim. Pixel colors correspond to the follow occurrence probabilities: red = 0.99–1.0; yellow = 0.50–0.98; and blue <0.50. (B) Photograph of the 1-km² plot shown in (A), with steep cliff habitat (center) bordered by terraced benchlands in the background.

ranged from 0.54–0.90 among sites. Twenty-five owl use sites showed estimated probability of occurrence >0.70, and only one site had an estimated probability of occurrence <0.62 (the lower bound of our 95% confidence interval).

DISCUSSION

We developed a suite of *a priori* models and evaluated their ability to explain variation in Mexican Spotted Owl presence within rocky canyon habitat. Our best-supported models indicated that areas with high probability of owl occurrence were characterized by canyon reaches dominated by steep parallel-sided cliffs in southern Utah's canyonlands (Fig. 1). Our results indicated that percent slope was a key predictive variable that had a strong positive relationship with probability of owl occupancy (Table 4); thus, canyons lined by relatively large steep cliffs were associated with Spotted Owl use sites in our study. The correlation we identified between probability of occurrence and steep cliffs is consistent with other studies in canyon environments where Mexican Spotted Owl habitat was associated with canyons lined by steep cliffs (Rinkevich 1991, Willey and van Riper 2007, Bowden 2008). Our results also indicated a potentially negative association between Mexican Spotted Owl occupancy and warmer slope aspects (Table 3), providing some support for the influence of heat sensitivity on habitat selection (Barrows 1981, Ganey 2004).

We observed negative, although relatively weak, associations among vegetation indices and estimated probability of owl occurrence despite the presence of small stands of riparian forest and mixed-conifer vegetation in canyons used by Mexican Spotted Owls (Table 4, Fig. 3). We observed *post hoc*, after viewing the model-based predictive maps, that topography of non-use sites outside of canyons was frequently dominated by stair-stepped benchlands terminating in flat mesas. Benchlands and mesa-tops possessed relatively high vegetation cover comprised of desert scrub and pinyon-juniper communities (Willey and van Riper 2007), whereas inner canyon habitats were dominated by cliff faces, talus slopes, and intermittent small patches of vegetation (Fig. 3B; Rinkevich 1991, Willey 1998). Although vegetation patches within canyons likely influence habitat suitability, these features may occur at a scale too fine to be detected by the 30-×-30 m remotely sensed data we used in our analysis (Loyn et al. 2001, Hatten and Paradzick 2003). Furthermore, Mullet and Ward (2010) provided evidence that in some settings, vegetation played a larger role in Mexican Spotted Owl habitat use than adjacent cliff faces, especially when cliffs possessed relatively few caves or ledges, or where canyons had substantially more forest cover compared to our study areas in Utah.

Our model validation surveys for Mexican Spotted Owls indicated that plots with owl detections had mean estimated probability of occurrence equal to 0.68 (95% CI = 0.62, 0.74), and for plots with no detections, only 8.6% (10 of 116 total plots) had mean probability of occurrence >0.62 (equal to the lower bound of the 95% confidence interval for plots with owls). In addition, our composite habitat model performed well in two study areas (Zion and Capitol Reef national parks) with known Mexican Spotted Owl territories in southern Utah. For example, the model predicted >0.70 probability of occurrence for 83% of the historical territories (25 of 30 sites), and predicted occurrence for only one territory in the two parks fell below the lower bound of the 95% confidence interval estimated from our composite model.

Our results represent the first effort to use an information-theoretic approach to create and field-validate a GIS-based habitat model to predict the distribution of habitat for Mexican Spotted Owls in arid canyon environments in the Colorado Plateau EMU. Conservation efforts in this region need to be guided by ecologically based habitat information, and our results provide initial information that will help wildlife managers identify suitable Mexican Spotted Owl habitat. Our results indicate that conservation efforts for Mexican Spotted Owls in southern Utah focus on topography dominated by deeply entrenched rocky canyons with extensive sections of steep cliffs. Although selection of habitat by Mexican Spotted Owls depends on a complex set of cues, we think our composite habitat model can be used with confidence to identify rocky canyon landscapes with high potential for occupancy by Mexican Spotted Owls in Utah.

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