Owl occupancy in three of El Salvador’s protected areas from 2003 to 2013

Jane West and Althea Archer

1/11/2021

# Abstract

# Introduction

Owls are a keystone species in many ecosystems, and as such are an important bioindicator of ecosystem health. Top predators such as owls affect communities through their top-down control on biodiversity and their presence or absence can cause trophic cascades. However, owls are also cryptic, nocturnal predators that are difficult to accurately census. The Mexican Spotted Owl (*Strix occidentalis*) and its sub-species have long been studied as an indicator species for the interactions between anthropogenic and environmental forces, demonstrating that even various sub-species of spotted owls have complex and often contrasting responses to environmental land use and management (e.g., White et al. 2013, Wan et al. 2018).

Neotropical owls are less well-studied than temperate species, and we have limited understanding of their ecological requirements, population dynamics, reproductive behavior, or conservation status (Clark et al. 1978, Enríquez et al. 2006, Pérez-Léon et al. 2017, Rangel-Salazar and Enríquez 2017). Yet, neotropical owls are reliant upon ecosystems under tremendous anthropogenic pressure and rapid and unpredictable responses to climate change (Corlett 2012). In the tropics, particularly in rain and cloud forests, owl studies are even more difficult than in temperate regions, regardless of denser populations (König and Weick 1999). In general, while our knowledge about the conservation status of neotropical populations is limited, we do know that owl abundance and distribution is decreasing in several regions where species have been added to endangered species lists or have become locally extirpated (Enríquez et al. 2006).

The vocalization of crepuscular and cryptic animals such as owls are often leveraged for surveying, and vocal patterns are often considered more important than coloration as an aid to identification (**???**, **???**, König and Weick 1999). *springer 1978 and forsman 1983 are not cited on previous ms draft xxx* Owls vocalize to communicate with the same species, threaten or provoke other species, or to delimit territory (Johnsgard 1988). Spontaneous and provocation listening are two methods that researchers use with increasing frequency during acoustic surveys of nocturnal birds of prey (e.g., Baumgardt et al. 2019). Spontaneous or passive surveys are based off of listening for animal calls with no prior stimulus whereas provocation surveys are conducted by listening after a period of playing animal vocalizations or “broadcast calls.” One benefit of auditory surveys, whether spontaneous or broadcast, is being able to identify multiple species during the same survey period. Adding in provocation to auditory surveys can increase the detection probability of owls, although intra- and inter-species interactions can play a role whether owls are more likely or less likely to call in response to a vocalization simulus (Enrı́quez and Salazar 1997, Baumgardt et al. 2019).

The objective of our study was to monitor population dynamics of El Salvador owls through time to determine both individual species’ population dynamics and community composition. El Salvador is located in the heart of the Mesoamerican Biodiversity Hotspot (Myers and Mittermeier 2000), and we selected the three survey areas to represent ecosystem diversity across El Salvador. We set up two routes in each protected area to further represent the habitats diversity of this heterogeneous country. We conducted nighttime foot surveys using passive listening and broadcast calls during the breeding season for three weeks each year from 2003 through 2013.

# Methods

## Study area

El Salvador is the smallest and most densely populated Central American country with 13.6% of its land forested (Central Intelligence Agency 2020). It is bordered by the Pacific Ocean, Guatemala and Honduras (Fig. 1XXX). We conducted surveys in three protected natural areas located at different elevations (high, mid and low elevations) and in different types of forest vegetation (alluvial, deciduous, semi-deciduous, pine-oak and cloud forest) that are representative of the country’s diverse ecosystems (Fig. 1xxx, Table 1XXX).

El Imposible National Park (NP) was located 119 km southwest of San Salvador (Fig. 1XXX, Table 1XXX). Its elevation ranged from 250 to 1425 m above sea level. It was the largest NP in the country, covering 3792 ha. The topography was extremely steep and broken, with many cliffs (Álvarez and Komar 2003). The area contained deciduous and semi-deciduous forest, secondary growth vegetation on the edges, and former pasture areas that were reforested with native species in 1997. We set up one survey route (EI-1) in the western portion of El Imposible in an area of reforestation and at a low elevation. We set up the other survey route (EI-2) in an area of semi-deciduous forest.

Montecristo NP was located 125 km northwest of San Salvador (Fig. 1XXX; Table 1XXX). Its altitude ranged from 730 to 2418 m above sea level, and the NP covered 1973 ha (Ministerio de Medio Ambiente y Recursos Naturales 2010). The higher elevations contained cloud forest, middle elevations contained pine/oak forest (with some pine and cypress plantations) and the lower elevations contained a semi-deciduous tropical forest (Ministerio de Medio Ambiente y Recursos Naturales 2015a). This NP was part of the Montecristo Tri-national Protected Area which included extensive adjoining natural areas in Guatemala and Honduras (Komar 2010). In this NP, one survey route (M-1) was set up in a cloud forest and another (M-2) was located at a moderate elevation in a pine/oak forest.

Nancuchiname Forest, a Protected Natural Area, was located 95 km southeast of San Salvador in the coastal alluvial plain along the Lempa River (Fig. 1XXX). Its elevation ranged from 5 to 12 m above sea level and the protected area covered 797 ha. Nancuchiname Forest represented the largest remaining patch of tropical forest on the alluvial plain of the country (**???**)xxx **we can’t site a geocities website**. The area contained deciduous and semi-deciduous forest, second growth vegetation, native species reforestation and a dike. In Nancuchiname Forest, we set up one survey route (N-1) in alluvial forest along the dike, which was surrounded by secondary growth, and we set up the other route (N-2) in a semi-deciduous alluvial forest.

*Table 1XX. Route locations and habitats. Owl surveys were conducted from 2003 to 2013 in three different protected areas within El Salvador: El Imposible National Park (EI-1 and EI-2), Montecristo National Park (M-1 and M-2) and Nancuchiname Forest (N-1 and N-2).*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Route | Latitude | Longitude | Elevation | Habitat |
| EI-1 | xxx | xxx | xxx | Reforested Deciduous Forest |
| EI-2 | XXX | XXX | xxx | Semi-Deciduous Forest |
| M-1 | XXX | XXX | xxx | Cloud Forest |
| M-2 | XXX | XXX | xxx | Pine/Oak Forest |
| N-1 | XXX | XXX | xxx | Alluvial Forest with Secondary Growth |
| N-2 | XXX | XXX | xxx | Alluvial Forest |

## Survey methods

We conducted foot surveys following the Guidelines for Nocturnaal Owl Monitoring (Takats et al. 2001), a similar protocol developed for Costa Rica (Enrı́quez and Rangel-Salazar 2001), and other raptor research guidelines (Fuller and Mosher 1987). This study’s survey protocol was an extension of previous research completed in the western half of El Imposible NP (West 1988). For our surveys, we created six 2-km long survey routes (transects) that each included 10 permanent survey stations set at 200 m intervals. Two routes were established in each protected area (Table 1xxx).

Surveys began at local twilight and took approximately five hours to complete. At each station, we measured and recorded environmental conditions (Brunton Sherpa, Brunton Incorporated) including temperature, precipitation, cloud cover, fog cover, wind speed, barometric pressure, moon phase, and noise level. The survey then began with passive listening for two minutes, followed by a three-minute broadcast call, and then seven minutes of silent listening. We recorded local owl vocalizations and used them for broadcast calls whenever possible. If an owl vocalized during broadcast playback, we stopped the broadcast and recorded the owl’s vocalization. When we detected an owl, we noted its location and angle relative to the station, and we tracked when the same owl was identified at consecutive stations. The broadcast calls varied between routes, but were consistent at each route and station across years. Specifically, we broadcasted the vocalizations of Pacific Screech-Owls, Mottled Owls, Crested Owls, Black-and-white Owls, Spectacled Owls, Pacific Screech-Owls, Mottled Owls, Crested Owls, Black-and-white Owls, and Spectacled Owls at stations 1 through 10, respectively, in all routes in El Imposible NP (EI-1 and EI-2) and Nancuchiname Forest (N-1 and N-2). We broadcasted the vocalizations of Whiskered Owls, Mottled Owls, Fulvous Owls, Stygian Owls, Great Horned Owls, Whiskered Owls, Mottled Owls, Fulvous Owls, Stygian Owls, and Great Horned Owls at stations 1 through 10, respectively, in both routes of Montecristo NP (M-1 and M-2). Surveys were repeated at each route up to three times a year from 2003 through 2013, depending on site access and weather. We did not conduct any surveys in 2006. We georeferenced the owl detections for each survey and route to eliminate double counting of individual owl observations.

*Table 2XX. Species detection records by route. Owl surveys were conducted from 2003 to 2013 in three different protected areas within El Salvador, although specific survey years varied by route.*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Name | EI-1 | EI-2 | M-1 | M-2 | N-1 | N-2 |
| Barn Owl | 0 | 0 | 0 | 0 | 8 | 2 |
| (Tyto alba) |  |  |  |  |  |  |
| Whiskered Screech-Owl | 0 | 0 | 0 | 2 | 0 | 0 |
| (Megascops trichopsis) |  |  |  |  |  |  |
| Pacific Screech-Owl | 11 | 1 | 0 | 0 | 6 | 9 |
| (Megascops cooperi) |  |  |  |  |  |  |
| Crested Owl | 0 | 0 | 0 | 0 | 0 | 0 |
| (Lophostrix cristata) |  |  |  |  |  |  |
| Spectacled Owl\*\* | 1 | 1 | 0 | 1 | 59 | 75 |
| (Pulsatrix perspicillata) |  |  |  |  |  |  |
| Great Horned Owl | 0 | 0 | 3 | 0 | 0 | 0 |
| (Bubo virginianus) |  |  |  |  |  |  |
| Ferruginous Pygmy-Owl | 4 | 0 | 0 | 0 | 82 | 98 |
| (Glaucidium brasilianum) |  |  |  |  |  |  |
| Burrowing Owl | 0 | 0 | 0 | 0 | 0 | 0 |
| (Athene cunicularia) |  |  |  |  |  |  |
| Mottled Owl | 214 | 117 | 1 | 22 | 62 | 114 |
| (Ciccaba virgata) |  |  |  |  |  |  |
| Black-and-white Owl\*\* | 0 | 0 | 0 | 0 | 0 | 0 |
| (Ciccaba nigrolineata) |  |  |  |  |  |  |
| Fulvous Owl\* | 0 | 0 | 17 | 0 | 0 | 0 |
| (Strix fulvescens) |  |  |  |  |  |  |
| c.f. Stygian Owl | 0 | 0 | 0 | 1 | 0 | 0 |
| (Asio stygius) |  |  |  |  |  |  |
| Striped Owl | 0 | 0 | 0 | 0 | 0 | 0 |
| (Pseudoscops clamator) |  |  |  |  |  |  |
| Unspotted Saw-whet Owl | 0 | 0 | 0 | 0 | 0 | 0 |
| (Aegolius ridgwayi) |  |  |  |  |  |  |

*Note: \*\* = Endangered and \* = Threatened (Ministerio de Medio Ambiente y Recursos Naturales 2015b)*

## Single-species occupancy model framework

We modeled occupancy within each route, year, and survey assuming that the probability of occupancy would be closed across surveys of a given route in a given year. In other words, for any single species of owl, we assumed that the probability of a route being occupied would not change between surveys within a year but could vary between years. Let:

We assumed that occupancy in each individual survey () was the outcome of Bernoulli trials with a probability of occupancy, , which we allowed to vary by year and route:

with hyperpriors for and such that the expected value of :

We assumed that detecting an owl depended on an owl being present during that survey () and the probability of detection, , which was related to the species-specific broadcast call ():

where, generally, , or more specifically:

This model provided a consistent probability of detection for all surveys in the first two minutes of each observation period, before the broadcast call was played (). Then, the probability of detection for each post-broadcast time period depended which call had been played. This allowed species-specific behavior in response to the different broadcast calls (Baumgardt et al. 2019). We used means parameterization for the logistic regression model such that the coefficients were interpretable as the effect of that specific broadcast call (including the pre-broadcast time frame). The priors for every logistic model coefficient were chosen to be near uniform as recommended in Gelman et al. (2008): .

## Richness model framework

To model species richness at each route in each year, we assumed that there were 14 possible species present in El Salvador. This included the 9 species observed during our surveys and an additional 5 species that we never observed (Table 2XX). This upper limit to expected species richness related directly to the 13 species known to inhabit El Salvador (Dickey and van Rossem 1938) plus one species we identified (c.f. Stygian owl), which was previously undocumented in El Salvador. We thus augmented our owl detection data with 5 additional potential species with all-zero detection records (Royle 2007).

For each species (where ), was a binary indicator of whether that owl species was present in each route based on the probability of species presence in that route, (Broms et al. 2016):

We used prior distributions for : (Broms et al. 2016, Guillera-Arroita et al. 2019).

In the richness model, the presence of an owl species in any year, route, and survey, , was conditional on the probability of occupancy for that route, year, and species *and* that species belonging to that route’s community that year ():

To share information about occupancy amongst species, we incorporated random effects into the parameterization of :

This parameterization allowed us to borrow strength across species in determining the mean probability of occupancy () for each route and year (Guillera-Arroita et al. 2019).

Richness of each route was conditional on each species’ presence and was estimated as the sum of owl species present in that route:

We also estimated year-to-year richness () by route by adding up the number of unique species that were present in each route, year, and survey. We first determined if a species was present in any of that route and year’s set of surveys with a species-specific binary indicator where if in any of that route’s surveys that year. Then, we summed up the number of species present in each year and route:

Consistent with our approach for the occupancy models, we assumed that detecting an owl depended on an individual of that species being present during that survey () and the species-specific probability of detection , which was related to the broadcast call:

where generally for each broadcast call as described above. The coefficients of the detection model were thus assumed to be consistent for all owl species, which allowed us to borrow information about the detection process for undetected owl species from those that were detected.

### Model implementation

We used the R2jags package in R (R Development Core Team 2014) (Plummer 2013) to implement the Bayesian models. We verified that R-hats were lower than 1.3 and visually inspected traceplots to verify that chains mixed well (Supplemental information S1-3xx).

We applied the single-species occupancy model for three owl species that had sufficient positive detections for analysis: Mottled Owl, Spectacled Owl, and Ferruginous Pygmy-Owl (Table 2XX). Based on our understanding of owl ecology, we assumed that Spectacled and Ferruginous Pygmy owls would not occupy route M-1 in Montecristo, so we removed M-1 from those species’ occupancy analyses. For all three of the single-species occupancy models, we ran 3 chains for 10,000 iterations and 1000 iterations discarded as burn-in, for a total of 27,000 iterations comprising the posterior distributions for each model parameter. Initial values for were equivalent to one if an owl was detected in that survey and otherwise zero.

To implement the richness model, we ran 3 chains for 20,000 iterations with 2000 iterations discarded as burn-in and a thinning rate of 2, for a total of 27,000 iterations comprising the posterior distributions for each model parameter. Initial values for were equivalent to one if that species of owl was detected in that survey and otherwise zero. Similarly, initial values for whether a species belonged to a route’s community () were equivalent to one if that species of owl was ever detected in that route and otherwise zero.

# Results

A total of 86 surveys were conducted between March and May from 2003 through 2005 and 2007 through 2013. No surveys were conducted in 2006.

We detected nine species of owls during our surveys: Barn Owl, Whiskered Screech-Owl, Pacific Screech-Owl, Spectacled Owl, Great Horned Owl, Ferruginous Pygmy-Owl, Mottled Owl, Fulvous Owl, and c.f. Stygian Owl (Table 2xXX). We identified Whiskered Screech-Owls in Montecristo NP, which had previously been undocumented in that protected area. We also identified a c.f. Stygian Owl in Montecristo NP, which was a species not previously documented in the entire country of El Salvador. The c.f. Stygian Owl requires further investigation to determine true presence of that owl in El Salvador.

## Single-species occupancy model results

Mottled Owls, Spectacled Owls, and Ferruginous Pygmy-Owls had 542, 137, and 187 positive detections over the 11 year period, respectively (Table 2XX). No other owl species had enough detections to analyze species-specific occupancy (Table 2XX). Averaged across years, we found that the probability of occupancy was somewhat higher for Mottled Owls than for Ferruginous Pygmy-owls or Spectacled Owls in both routes of El Imposible and in M-2 route of Montecristo (Fig. 1X). Occupancy probabilities were relatively high across all three species for both routes of Nancuchiname (Fig. 2XX). We found that the probability of occupancy for Mottled Owls was relatively consistent across time in the El Imposible routes and in N-2 (Fig. 3XX), but that it seemed to increase in the last approximately 6 years in M-2 and N-1 (Fig. 3XX). The probability of occupancy in M-1 seemed to have decreased through time for Mottled Owls (Fig. 3XX).

For routes EI-1, EI-2, and M-2, the probability of occupancy for Ferruginous Pygmy-owls and Spectacled Owls stayed relatively low across time other than a higher probability of occupancy for Ferruginous Pygmy-owl in EI-1 in the early years of the surveys (Fig. 3XX). The probability of occupancy for Ferruginous Pygmy-owls was relatively high in both routes of Nancuchaname except in 2008 and 2009 (Fig. 3XX), and the probability of occupancy for the Spectacled Owl fluctuated slightly from year to year in the Nancuchaname routes (Fig. 3XX).

## Richness model results

Our estimates of each route’s community richness () and 90% credible intervals were 4 (4,4), 5 (4,5), 3 (3,4), 4 (4,5), 5 (5,5), and 5 (5,5) for EI-1, EI-2, M-1, M-2, N-1, and N-2, respectively. These median values were equivalent to the number of species detected in each route (Table 2XX), indicating that the probability of occupancy for undetected species was low and no additional species were predicted to be present in a route’s community, other than those that were detected.

When analyzed by year, median species richness () varied from 0 to 5, depending on route and year (Fig. 4XXX). At most, the median species richness was one species higher than the number of species detected at any single route and year; however, the 90% credible intervals of richness added up to 4 new undetected species (e.g., in M-2 during 2004 where we detected zero species (Fig. 4XXX).

## Detection results

Including all detected species into one richness model increased the precision of the estimates of the effect of broadcast calls on detection probability (i.e., compare All Species with individual occupancy results in Fig. 5XXX). When incorporating all owl species, broadcasting calls from Mottled Owls, Pacific Screech-owls, Crested Owls, Black-and-white Owls, and Spectacled Owls increased detection probability; whereas broadcasting the Great Horned Owl calls decreased detection (Fig. 5XXX).

The probability of detection when analyzed with single-species occupancy models varied little during the timeframe before broadcast recordings were played (Pre-broadcast); however, the probability of detecting owls after broadcast calls were played varied by call and between Mottled Owls, Ferruginous Pygmy-owls, and Spectacled Owls (Fig. 5XX). The probability of detecting Mottled Owls increased after broadcasting Mottled Owl, Pacific Screech-owl, Crested Owl, Black-and-white Owl, or Spectacled Owl calls. The probability of detecting Ferruginous Pygmy-owls increased after broadcasting Mottled Owl and Pacific Owl calls, and the probability of detecting Spectacled Owls increased after broadcasting Pacific Screech-owl, Black-and-white Owl, and Spectacled Owl calls (Fig. 5XX).

# Discussion

The goal of this long-term project was to complete two survey passes at each route for each year from 2003 through 2013. However, that was not always possible due to weather conditions, such as strong winds or rain. Access to the routes also precluded us from surveys in some instances. Rain and high winds diminish the vocalizations of owls as well as the ability for surveyors to detect any owl calls (Takats et al. 2001, Andersen 2007). The survey was initially set up for 10 years based on recommendations from Mexican Spotted Owls researchers who stated that a monitoring period of 10 years would provide adequate information about population trends (United States Fish and Wildlife Service 1995).

An estimated 75% of the nearly 250 surviving species of owls are associated with dense and undisturbed forests (Mikkola 2012). Pérez-Léon et al. (2017) stated that within El Salvador, natural ecosystems were the most diverse, specifically natural habitats of cloud, deciduous, riparian and pine-oak forests. In El Salvador, 13.6% of its land is forested (Central Intelligence Agency 2020). The country has continued with the traditional shade-growing coffee farming, which helps maintain forest cover. Coffee plantations account for around 7% of its forested land because of the intensive use of shade-cover farming practices (Silva 2016). Silva (2016) also stated that almost all primary or closed forest is surrounded by coffee farms, which act as a buffer zone against land use change. Pérez-Léon et al. (2017) stated that coffee plantations are the most important agroecosystem for owl communities’ survival in El Salvador.

In Central America, the Mottled Owl is the most common and widespread owl (Vallely and Dyer 2018). Pérez-Léon et al. (2017) stated that habitat loss has restricted the distribution of several owl species, but that populations of Barn Owls, Pacific Screech-owls, Mottled Owls, and Ferruginous Pygmy-owls have survived the fragmentation processes in El Salvador relative to other Neotropical species. Contrarily, Enrı́quez and Rangel-Salazar (2001) stated that Mottled Owl populations in La Selva may have decreased during the past 30 years. The results of this study indicated that Mottled Owls are still fairly common at each of the protected areas, although there seemed to be a downward trend in occupancy in M-2 (Fig 3XX).

Ferruginous Pygmy-owls were the second most-often detected owls in this study. Ferruginous Pygmy-owls were often detected at the beginning of survey routes, often closer to sunset than later at night, and Ferruginous Pygmy-owls demonstrated fairly low occupancy rates in El Imposible routes, other than in the first couple years of the survey in EI-1. Ferruginous Pygmy-owls prefer open habitats with a lot of edge. West (1988) observed that the lower elevation areas of El Imposible had been grazed and dotted with houses. The activities and vegetation structure of the area has changed overtime, and native species re-vegetation efforts began in that area in 1997. It is possible that Ferruginous Pygmy-owls are responding to the decrease in edge habitat in this park, and we recommend further surveys to determine the risk to Ferruginous Pygmy-owls in response to revegetation management.

Stygian Owl was listed as an expected owl in El Salvador [Pérez-Léon et al. (2017)). On 26 March 2002, after listening to recordings and viewing photographs, the Montecristo NP guards stated that they thought c.f. Stygian owl was present in the park (personal communication). While there was only one c.f. Stygian Owl detected during the course of our surveys, we did also hear a c.f. Stygian Owl between the survey stations on 25 April XXXXyear. We also heard c.f. Stygian Owl twice on M-2 between station points on 20 March 2005 and once between stations in 2007. We did not record any of these vocalizations by c.f. Stygian Owls. Detections that occurred between stations or away from survey routes were not included in our results. So while we are confident that c.f. Stygian Owls are present in Montecristo NP, we believe that further documentation of the species would be beneficial for confirmation of the species in El Salvador.

During 1979-1981, in the western portion of El Imposible NP, West (1988) heard or observed six owl species, including two that were not detected during this study (Barn Owls and Black-and-white Owls) in that NP. In 1980, Barn Owls nested in a cave of Loma de Paja Mountain (opposite this study’s El Imposible routes). An 5 April 2002, Barn Owls were detected in that same location (Vidal Campos Aguirre, personal communication). Vidal Campos Aguirre also stated that Black-and-white Owls were observed in two areas of the Mistepe River Valley in that same timeframe. It is likely, then, that these two owls still occur in El Imposible, though we were not able to detect them. We also observed a Barn Owl nesting near the N-1 route; however, again, we did not include any visual or auditory detections of owls outside of the survey stations. Barn Owls were detected in both Nancuchiname routes, but Black-and-white Owls were not detected in any routes during our surveys.

Nancuchiname Forest was the richest in diversity of our three protected areas; however, many of the more specialist species were only detected in Montecristo NP (e.g., Whiskered Owl, Great Horned Owl, Fulvous Owl, and c.f. Stygian Owl). The 2002 Nancuchiname Forest Management Plan only listed one owl, Ferruginous Pygmy-owl, as being present (Zepeda 1995)xx \*why does year not match\*\*, but we confirmed the presence of four additional owl species in that NP. Fulvous Owl is one of El Salvador’s 18 endemic bird species (Komar 2002), and it was detected numerous times in the cloud forest of Montecristo NP (M-1). Fulvous Owl has also been recently photographed in Montecristo NP (Gonzalez et al. 2017).

Distinguishing individuals by non-invasive means, such as vocal traits, is preferable when species are rare, sensitive to handling, elusive, or when other techniques are unfeasible (Terry et al. 2005). Overall, the probability of detection was fairly low for all species (median values , even though we used locally recorded owl vocalizations when possible. In Guatemala, Gerhardt (1989) found that a series of vocalizations obtained from a non-local ornithological laboratory, which were identified as vocalizations of the Mottled Owl, could not generate a response from Guatemalan owls. We found that the probability of detecting most owls increased after we broadcasted the vocalizations of Mottled Owls, Pacific Screech-owls, Crested Owls, and Spectacled Owls. On the other hand, owls were less likely to call or be detected after we played Great Horned Owl calls. Because owls, like many birds of prey, are sensitive to interactions with other owls (Enrı́quez and Salazar 1997, Baumgardt et al. 2019), we recommend that surveyors carefully consider the intra- and inter-species interactions that may affect detectability after playing specific bird vocalizations.

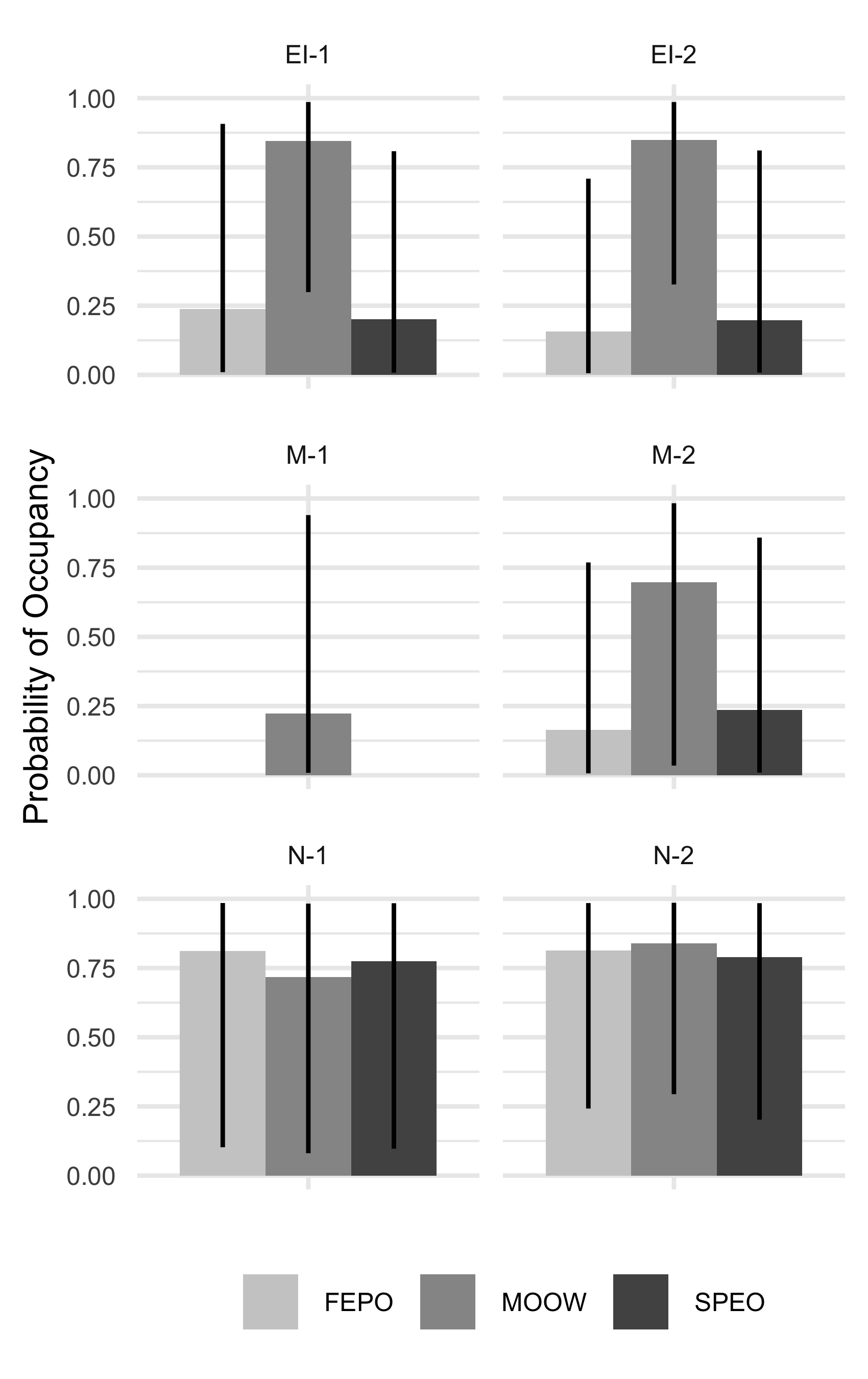
We did not use spectogram analysis to determine any of the specific individuals of owls that we detected. Spectograms of acoustic signals, such as owl vocalizations, are capable of not only recognizing differences between species, but even potentially individual owls of the same species or owl gender (**???**, **???**, **???**, Rognan et al. 2009). *xx can’t find Eakle 1989, Farquahar 1993, Galeotii 1993* Identifying individuals within a population can improve census estimates and provide useful information on demographics, life history traits, and behavior–all of which often influence management decisions (Terry et al. 2005). Spectogram analysis could help future owl researchers in El Salvadar determine more accurate population sizes of the more rare species we detected, such as Whiskered Screech-owls, c.f. Stygian Owls, and Great Horned Owls.

Pérez-Léon et al. (2017) stated that there are human activities affecting owl populations in El Salvador, including illegal hunting, trapping, persecution, killing, and wildlife trade. They also stated that, of eight species of owls confiscated from local markets in 1995 to 2008, the most frequent were Mottled Owls and Ferruginous Pygmy-owls.

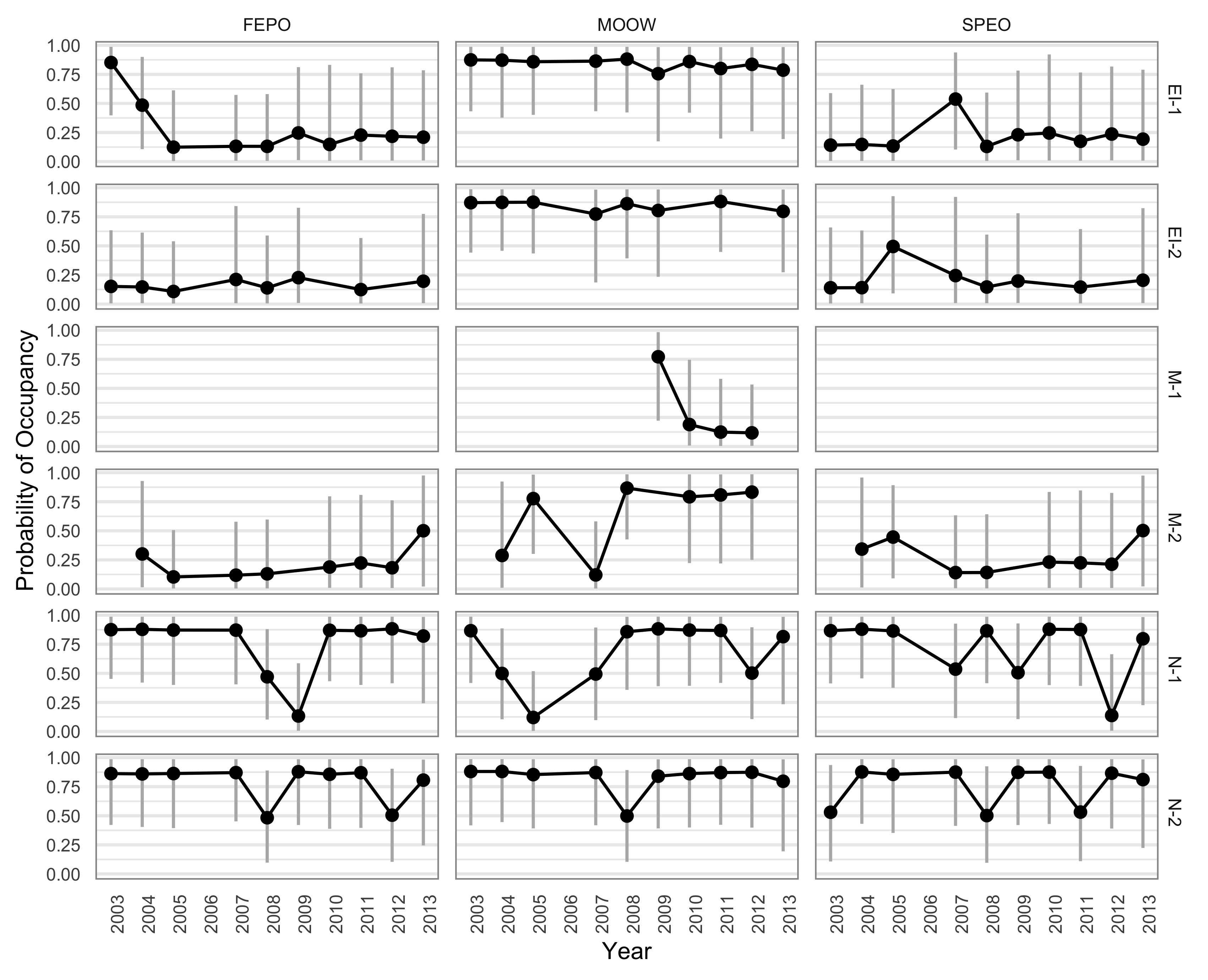
# Figures

1XX. Map of El Salvador. Owl surveys were conducted from 2003 to 2013 in three different protected areas within El Salvador: El Imposible National Park (EI-1 and EI-2), Montecristo National Park (M-1 and M-2) and Nancuchiname Forest (N-1 and N-2).

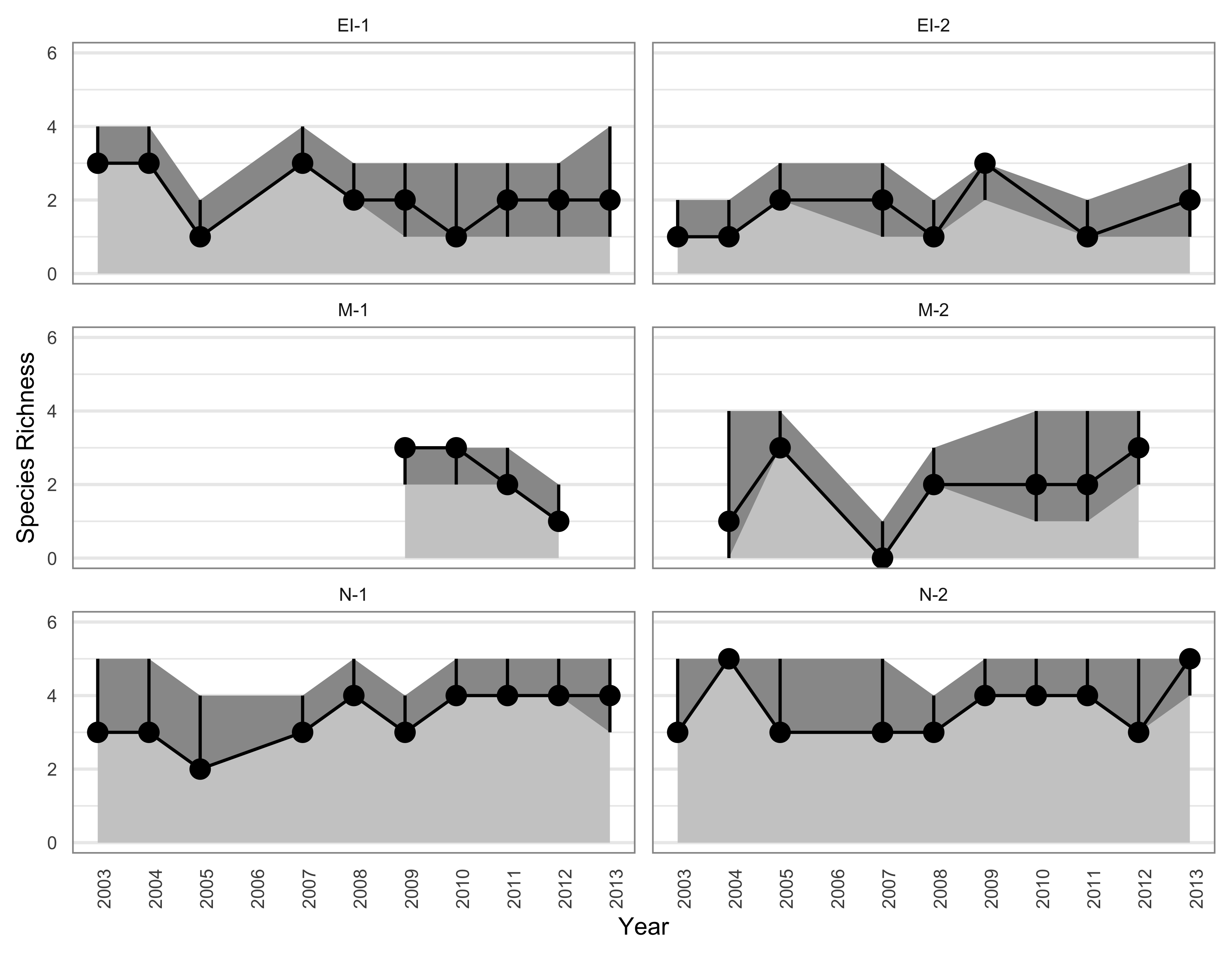
1XX. Map of El Salvador. Owl surveys were conducted from 2003 to 2013 in three different protected areas within El Salvador: El Imposible National Park (EI-1 and EI-2), Montecristo National Park (M-1 and M-2) and Nancuchiname Forest (N-1 and N-2).



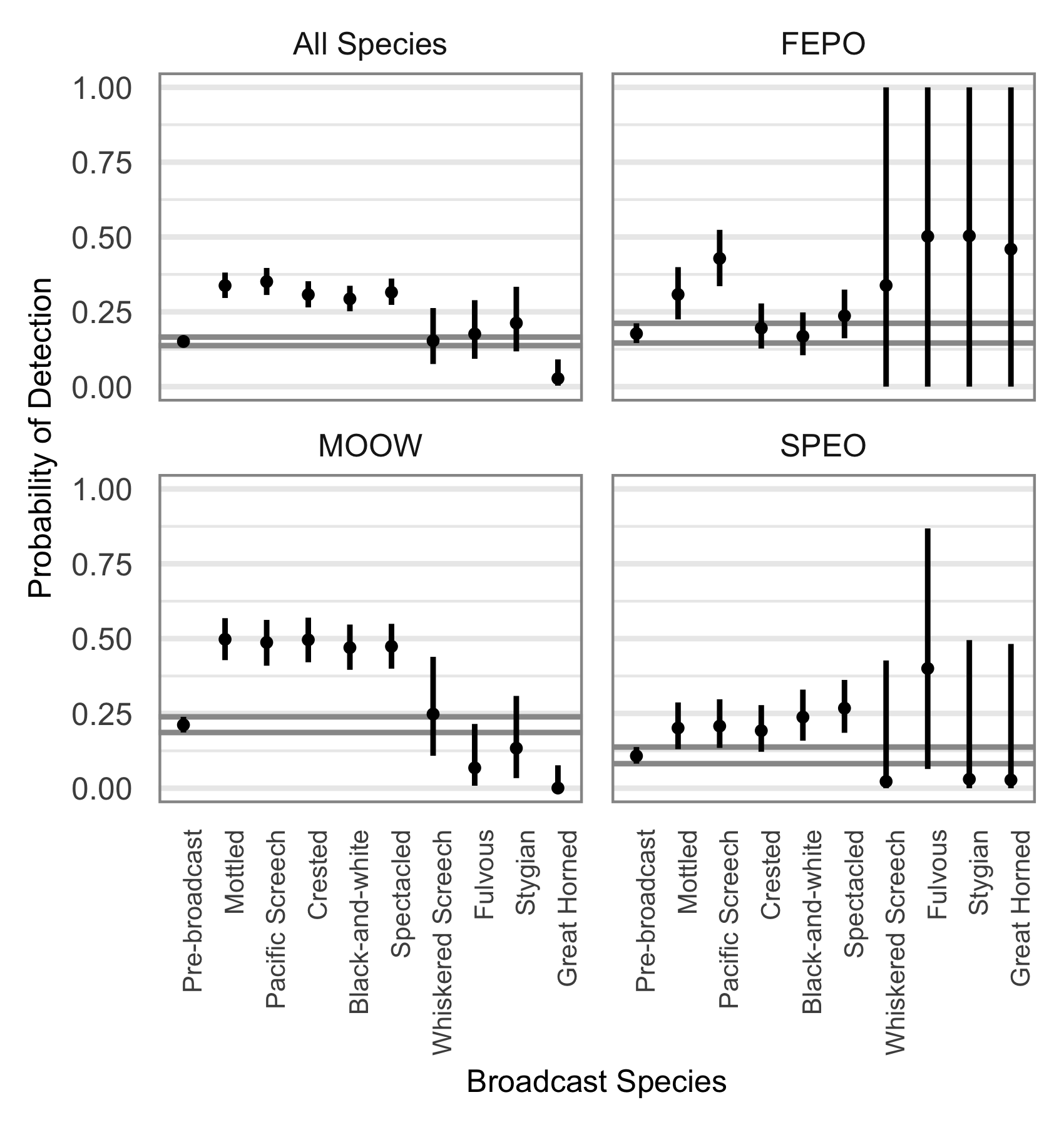
2XX. Probability of occupancy () averaged by route for Ferruginous Pygmy-owl (FEPO), Mottled Owl (MOOW), and Spectacled Owl (SPEO). Owl surveys were conducted from 2003 to 2013 in three different protected areas within El Salvador: El Imposible National Park (EI-1 and EI-2), Montecristo National Park (M-1 and M-2) and Nancuchiname Forest (N-1 and N-2). Posteriors were summarized with median 90% credible intervals.



3XX. Probability of occupancy by route and year for Ferruginous Pygmy-owl (FEPO), Mottled Owl (MOOW), and Spectacled Owl (SPEO). Owl surveys were conducted from 2003 to 2013 in three different protected areas within El Salvador: El Imposible National Park (EI-1 and EI-2), Montecristo National Park (M-1 and M-2) and Nancuchiname Forest (N-1 and N-2). Posteriors were summarized with median 90% credible intervals.



4XX. Species richness (Richness\*) by route and year. Owl surveys were conducted from 2003 to 2013 in three different protected areas within El Salvador: El Imposible National Park (EI-1 and EI-2), Montecristo National Park (M-1 and M-2) and Nancuchiname Forest (N-1 and N-2). Posteriors were summarized with median (black dot) 90% credible intervals (dark grey shading and vertical black lines). The number of owl species detected at each route and year is indicated with the light grey area.



5XX. The probabiliity of detecting owls during spontaneous surveys (i.e., pre-broadcast) and after broadcast, depending on the species of owl used for broadcast vocalization. These logistic regression coefficients were evaluated from the richness model, which combined all detected species (All Species) and the single-species occupancy models for Ferruginous Pygmy-owls (FEPO), Mottled Owls (MOOW), and Spectacled Owls (SPEO). Owl surveys were conducted from 2003 to 2013 in three different protected areas within El Salvador. Posteriors were summarized with median 90% credible intervals.

# References

Andersen, D. E. 2007. Survey techniques. Pages 89–100 *in* D. M. Bird and K. L. Bildstein, editors. Raptor research and management techniques. Hancock House Publishers, Blaine, WA USA.

Álvarez, J. M., and O. Komar. 2003. El parque nacional el imposible y su vida silvestre. Salva Natura y Ministerio de Medio Ambiente y Recursos Naturales.

Baumgardt, J. A., M. L. Morrison, L. A. Brennan, and T. A. Campbell. 2019. Effects of broadcasting calls on detection probability in occupancy analyses of multiple raptor species. Western North American Naturalist 79:185–194.

Broms, K. M., M. B. Hooten, and R. M. Fitzpatrick. 2016. Model selection and assessment for multi-species occupancy models. Ecology 97:1759–1770.

Central Intelligence Agency. 2020. The world factbook. www.cia.gov/the-world-factbook.

Clark, R. J., D. G. Smith, and L. H. Kelso. 1978. Working bibliography of owls of the world. National Wildlife Federation Scientific and Technical Series.

Corlett, R. T. 2012. Climate change in the tropics: The end of the world as we know it? Biological Conservation 151:22–25.

Dickey, D. R., and A. J. van Rossem. 1938. The birds of El Salvador. Field Museum of Natural History.

Enrı́quez, P. L., and J. L. R. Salazar. 1997. Intra-and interspecific calling in a tropical owl community. *in* In: Duncan, james r.; johnson, david h.; nicholls, thomas h., eds. Biology and conservation of owls of the northern hemisphere: 2nd international symposium. Gen. Tech. Rep. NC-190. St. Paul, mn: US dept. Of agriculture, forest service, north central forest experiment station. 525-532.

Enrı́quez, P., and J. Rangel-Salazar. 2001. Owl occurrence and calling behavior in a tropical rain forest. Journal of Raptor Research 35:107–114.

Enríquez, P. L., D. H. Johnson, and J. L. Rangel-Salazar. 2006. Taxonomy, distribution and conservation of owls in the Neotropics: A review. Pages 254–307 *in* R. Rodríguez-Estrella, editor. Current Raptor Studies in México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad.

Fuller, M. R., and J. A. Mosher. 1987. Raptor survey techniques. *in* Raptor research techniques manual. US Fish and Wildlife Service.

Gelman, A., A. Jakulin, M. G. Pittau, and Y.-S. Su. 2008. A weakly informative default prior distribution for logistic and other regression models. The Annals of Applied Statistics 2:1360–1383.

Gerhardt, R. P. 1989. Response of the Mottled Owl (*Ciccaba virgata*) to broadcast of conspecific call. *in* W. A. Burnham, J. P. Jenny, and C. W. Turley, editors. Maya project: Use of raptors as environmental indices for design and management of protected areas and for building local capacity for conservation in latin america. The Peregrine Fund, Inc., World Center for Birds of Prey.

Gonzalez, R., R. Pineda, and L. Pineda. 2017. Photographic documentation of Fulvous Owl (*Strix fulvescens* in Montecristo National Park, El Salvador. Spizaetus Neotropical Raptor Network Newsletter. 24:16–21.

Guillera-Arroita, G., M. Kéry, and J. J. Lohoz-Monfort. 2019. Inferring species richness using multispecies occupancy modeling: Estimation performance and interpretation. Ecology and Evolution 9:780–792.

Johnsgard, P. A. 1988. North american owls: Biology and natural history. Yale University Press, New Haven, CT.

Komar, O. 2002. Priority conservation areas for birds in El Salvador. Animal Conservation 5:173–183.

Komar, O. 2010. Research stewardship strategy for Montecristo National Park, El Salvador. Technical report, USAID.

König, C., and F. Weick. 1999. Owls: A guide to owls of the world. Yale University Press, New Haven, CT.

Mikkola, H. 2012. Owls of the world-a photographic guide. Firefly Books, Buffalo, New York, NY, USA.

Ministerio de Medio Ambiente y Recursos Naturales. 2010. Guía de Aves Parque Nacional Montecristo. Guías de la Biodiversidad del Parque Nacíonal Montecristo. San Salvador, El Salvador.

Ministerio de Medio Ambiente y Recursos Naturales. 2015a. La guía de aves del Parque Nacíonal Montecristo. Parte de la serie de guías de la biodiversidad del Parque Nacíonal Montecristo. San Salvador, El Salvador.

Ministerio de Medio Ambiente y Recursos Naturales. 2015b. Acuerdo No. 74 Listado oficial de especíes de vida silvestre amenazadas o en peligro de extinción. San Salvador, El Salvador.

Myers, N., and R. A. Mittermeier. 2000. Biodiversity hotspots for conservation priorities. Nature 403:853.

Pérez-Léon, R., I. Vega, and N. Herrera. 2017. The owls of El Salvador. Pages 397–418 *in* P. L. Enríquez, editor. Neotropical owls: Diversity and Conservation. Springer International Publishing AG, Cham, Switzerland.

Plummer, M. 2013. JAGS Version 3.4.0 user manual.

Rangel-Salazar, J. L., and P. L. Enríquez. 2017. Introduction: The birds in the neotropical region. Pages 1–6 *in* Neotropical owls. Springer.

R Development Core Team. 2014. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Rognan, C. B., J. M. Szewczak, and M. L. Morrison. 2009. Vocal individuality of Great Gray Owls in the Sierra Nevada. The Journal of Wildlife Management 73:755–760.

Royle, J. A. 2007. Analysis of multinomial models with unknown index using data augmentation. Journal of Computational and Graphical Statistics 16:67–85.

Silva, R. O. 2016. Country coffee profile: El Salvador. Technical report, International Coffee Organization.

Takats, D. L., C. M. Francis, G. L. Holroyd, J. R. Duncan, K. M. Mazur, R. J. Cannings, W. Harris, and D. Holt. 2001. Guidelines for nocturnal owl monitoring in North America. Beaverhill Bird Observatory and Bird Studies Canada.

Terry, A. M., T. M. Peake, and P. K. McGregor. 2005. The role of vocal individuality in conservation. Frontiers in Zoology 2:10.

United States Fish and Wildlife Service. 1995. Recovery plan for the Mexican Spotted Owl. Technical report, United States Department of the Interior.

Vallely, A. C., and D. Dyer. 2018. Birds Of Central America: BELIZE, GUATEMALA, HONDURAS, EL SALVADOR, NICARAGUA, COSTA RICA, and PANAMA. Princeton University Press, Princeton, NJ, USA.

Wan, H. Y., J. L. Ganey, C. D. Vojta, and S. A. Cushman. 2018. Managing emerging threats to spotted owls. The Journal of Wildlife Management 82:682–697.

West, J. N. 1988. Raptors of El Imposible Forest, El Salvador. Masters thesis, Central Washington University, Ellensburg, WA.

White, A. M., E. F. Zipkin, P. N. Manley, and M. D. Schlesinger. 2013. Conservation of avian diversity in the Sierra Nevada: Moving beyond a single-species management focus. PLoS ONE 8:e63088.

Zepeda, L. 1995. Plan de manejo del área natural silvestre Nancuchiname. Anexo 4 - listado preliminar de las aves del área, San Salvador, El Salvador.