OWL OCCUPANCY IN THREE OF EL SALVADOR’S PROTECTED AREAS FROM 2003 THROUGH 2013

Jane Noll West 1

1120 Sidney Road, Washburn, ND 58577 USA

Althea A. Archer

Department of Biological Sciences, St. Cloud State University, St. Cloud, MN 56301 USA

1 Email address: buhobay@protonmail.com

Phone: 612-869-0721

Owl Occupancy in El Salvador

# Abstract

Neotropical owls are a priority for conservation but are relatively understudied compared to their temperate kin. In the first long-term study of owls in the country, we conducted 10 years of owl surveys in three protected areas of El Salvador (El Imposible National Park, Montecristo National Park and Nancuchiname Forest) to assess occurrence, species richness, and abundance using occupancy modeling. We chose two surveys routes per protected area to represent the landscape diversity of the country. During our acoustic surveys, we used passive listening and broadcasted calls of several species, and we repeated surveys two times a year, when possible. We analyzed data with hierarchical Bayesian occupancy models, including three single-species models for Mottled Owls (*Ciccaba virgata*), Ferruginous Pygmy-Owls (*Glaucidium brasilianum*), and Spectacled Owls (*Pulsatrix perspicillata*), and a multispecies richness model for all El Salvador owls. We completed 86 surveys between March and May from 2003 through 2013, although no surveys were conducted in 2006. We detected nine species of owls during our surveys, including c.f. Stygian Owl (*Asio stygius*), which was previously undocumented in El Salvador. We recorded multiple vocalizations for eight owl species and documented 1,211 owl observations in the three protected areas. Occupancy and richness patterns were relatively stable across time and broadcasted calls significantly affected the probability of detecting owls. Our study supports the importance of protected areas in conserving Neotropical owls in a heterogenous landscape in Central America.

Key Words: El Salvador; Neotropical owl surveys; occupancy modeling; protected areas

As apex predators, owls are an important bioindicator of ecosystem health, although much current understanding of owl ecology comes from temperate systems (White et al. 2013, Wan et al. 2018, Buechley et al. 2019) and its application to the Neotropics is not clear. The Neotropics were recently identified as a priority area for owl research because the high conservation risk for Neotropical owls has not resulted in research necessary to inform conservation (Buechley et al. 2019). In part, that may be because studying owls in tropical rain and cloud forests is difficult compared to studying owls in many temperate regions, regardless of potentially denser populations in the Neotropics (König et al. 1999). As a result, there is limited understanding of Neotropical owl distribution, ecological requirements, population dynamics, and reproductive behavior (Clark et al. 1978, Enríquez et al. 2006, Pérez-Léon et al. 2017, Rangel-Salazar and Enríquez 2017). This lack of information poses a challenge for proactive conservation. In general, although information about the status and trends of Neotropical owl populations is limited, owl abundance and distribution is known to be decreasing in several regions where species have been added to endangered species lists or have become locally extirpated (Enríquez et al. 2006).

The vocal patterns of nocturnal or crepuscular species are in general much more important than plumage as an aid to identification (König et al. 1999). The majority of owl species are active during the night and it is easier to hear them than see them. Generally, the most reliable way of detecting owls is to hear them and count their vocalizations (Springer 1978, Forsman 1983, Smith 1987 in Enríquez and Rangel-Salazar 2001). However, knowledge of the vocalizations of tropical owls is incomplete (König et al. 1999).

El Salvador is located on the western side of the Central American isthmus and is the smallest and most densely populated Central American country (Fig. 1; Central Intelligence Agency 2021). Overall, 13.6% of El Salvador’s 20,721 km of land is forested, and 74.7% is used for agricultural purposes (Central Intelligence Agency 2021). A common agroecosystem in El Salvador is shade-grown coffee, which supports forested cover on otherwise agricultural land. Approximately 7% of El Salvador’s forested land is comprised of shade-grown coffee, which may be providing an important land-use buffer around El Salvador’s protected natural areas (Silva 2016, Pérez-Léon et al. 2017). Although shade-grown coffee systems are potentially reducing the effects of land-use on forest-dependent owls in El Salvador (e.g., Pérez-Léon et al. 2017), there is a lack of information about the long-term dynamics of these populations. Concerns about habitat availability are not the only challenge facing owls in El Salvador. Pérez-Léon et al. (2017) identified several human activities affecting owl populations in El Salvador, in addition to deforestation caused by changes in land use, that include: illegal hunting, trapping, persecution, killing, and wildlife trade.

The objectives of our study were to assess the occurrence, abundance, and community composition of owls in El Salvador, and to evaluate trends in owl abundance through time. We conducted nocturnal surveys for owls to determine the trends in abundance and spatial distribution of species in three targeted protected areas; El Imposible National Park, Montecristo National Park, and Nancuchiname Forest. El Salvador is located in the heart of the Mesoamerican Biodiversity Hotspot (Myers and Mittermeier 2000), and we selected these survey areas in protected landscapes to represent the breadth of ecosystem diversity across the country and Central America. We used occupancy modeling to evaluate abundance and trends in abundance through time. Ours was the first long-term study of owls in El Salvador, and provides information about Neotropical owl communities that can help guide conservation.

Methods

**Study Area**

We conducted surveys in three protected natural areas in El Salvador (El Imposible National Park, Montecristo National Park, and Nancuchiname Forest) 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 represent a portion of the country’s diverse ecosystems (Fig. 1, Table 1).

El Imposible National Park (NP) is located 119 km southwest of San Salvador (Fig. 1; Table 1). Its elevation ranges from 250 to 1,425 m above sea level (a.s.l.) and is the largest NP in the country, covering 3,792 ha. The topography of El Imposible is extremely steep and broken, with many cliffs (Alvarez and Komar 2003). The area contains deciduous and semi-deciduous forest, secondary growth vegetation on the edges, and former pasture areas that were reforested with native species in 1997. In the western portion of El Imposible NP we established one survey route (EI-1) at a lower elevation in secondary growth and reforestation, and a second survey route (EI-2) in an area of semi-deciduous forest.

Montecristo NP (1973 ha) is located 125 km northwest of San Salvador (Fig. 1; Table 1) and its elevation ranges from 730 to 2,418 m a.s.l. (Ministerio de Medio Ambiente y Recursos Naturales 2015b). High elevations of Montecristo NP contain cloud forest, middle elevations contain pine-oak forest (with some pine and cypress plantations) and the lower elevations contain a semi-deciduous tropical forest (Ministerio de Medio Ambiente y Recursos Naturales 2015b). This NP is part of the Montecristo Tri-national Protected Area, which includes extensive adjoining natural areas in Guatemala and Honduras (Komar 2010). Within Montecristo NP, we established one survey route (M-1) in a cloud forest and another (M-2) in the middle elevation pine-oak forest.

Nancuchiname Forest (797 ha) is a Protected Natural Area located 95 km southeast of San Salvador in the coastal alluvial plain along the Lempa River (Fig. 1; Table 1). Its elevation ranges from sea level to 12 m a.s.l. The area contains deciduous and semi-deciduous forest, second-growth vegetation, native species reforestation, and a dike surrounded by secondary growth. In Nancuchiname Forest, we established one survey route (N-1) in alluvial forest along the dike and the other route (N-2) in a semi-deciduous alluvial forest.

**Survey Methods**

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To access almost any terrestrial cover type in areas with limited number of roads, we modified standardized vehicle-based roadside surveys (Takats et al. 2001) to surveys on foot (Fuller and Mosher 1987) and adapted parts of a survey protocol used in Costa Rica (Enrı́quez and Rangel-Salazar 2001). This study was an extension of previous research completed in the western half of El Imposible NP (West 1988).

We created six 2-km-long survey routes (transects) that each included 10 permanent survey points at 200-m intervals. We established two of these routes, representing different cover types, in each protected area (Table 1). For each of the 60 permanent points, we took detailed vegetative descriptions, elevation readings, photo points, and GPS readings and the points were marked with flagging.

Each survey began at local twilight during the breeding season (March to May) and took approximately five hours to complete. At each station, we measured and recorded environmental conditions including precipitation, cloud cover, fog cover, moon phase, and noise level, and used a Brunton Sherpa (Brunton Co., Riverton, WY, USA) for measurements of temperature, wind speed, and barometric pressure.

We began each acoustic survey with passive listening for two minutes, followed by a three-minute broadcasted call, and ending with seven minutes of silent listening. When we detected an owl(s), we recorded the number of owls, species spontaneously vocalizing, species vocalization broadcasted, species responses to broadcasted vocalizations, estimated distance, and direction.

To broadcast owl vocalizations, we used a Sony Walkman Sports (model WM-FS221, Sony Corp., Oradell, NJ, USA) cassette tape player (2002-2005) and a CD player (Sony Portable CD Player, model D-NS707F, Sony Electronics Inc., San Diego, CA, USA) (2007-2013) with a hand-held mini amplifier/speaker (Radio Shack, Fort Worth, TX, USA) (speaker frequency response: 100-10,000Hz; which includes the call frequency of the owls). The players were connected to the speaker with an audio dubbing cable (Gold Series 42-2607, Radio Shack, Fort Worth, TX, USA). We measured the playback levels with a VLIKE sound level meter (Gungzhoul Like Technologies Co. Inc., Guangdong, China) and at 1 m from the speaker the SPL was \_\_\_\_\_ ±1.5 dB.

As much as possible we used owl vocalizations recorded locally owl as the source for broadcasted calls to maximize owl response (Gerhardt 1989) and throughout the study we recorded owl vocalizations for species verification. If an owl closely approached the speaker used to broadcast vocalizations during a survey and vocalized, we stopped broadcasting and recorded the owl’s vocalization.

We recorded vocalizations with a cassette recorder (Marantz PMD222, Superscope Technologies Inc., Aurora, IL, USA), an omnidirectional microphone (Electro-Voice 635A Dynamic Omni, F01U118054, Bosch Security Systems Inc., Burnsville, MN, USA), and a parabolic sensor (Sony PBR-330, Crouse-Kimzey Co., Fort Worth, TX, USA). From 2007 to 2013, we used an omnidirectional microphone (Sennheisser ME62, Sennheiser Electronic GmbH & Co. KG, Wedemark, Germany) and a parabolic sensor (Telinga Pro Universal, Tobo, Sweden). We used TDK 60-minute tapes (IECIV/TYPE IV, and IECII/TYPE II) for recordings.

Broadcasted calls varied between routes, but were consistent at each route and survey point across years. Specifically, we broadcasted vocalizations of Pacific Screech-Owls (*Megascops cooperi*), Mottled Owls (*Ciccaba virgata*), Crested Owls (*Lophostrix cristata*), Black-and-white Owls (*C. nigrolineata*), Spectacled Owls (*Pulsatrix perspicillata*), Pacific Screech-Owls, Mottled Owls, Crested Owls, Black-and-white Owls, and Spectacled Owls at survey points 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 vocalizations of Whiskered Screech-Owls (*Megascops trichopsis*), Mottled Owls, Fulvous Owls (*Strix fulvescens*), Stygian Owls (*Asio stygius*), Great Horned Owls (*Bubo virginianus*), Whiskered Screech-Owls, Mottled Owls, Fulvous Owls, Stygian Owls, and Great Horned Owls at survey points 1 through 10, respectively, in both routes of Montecristo NP (M-1 and M-2).

We repeated surveys at each route two times a year from 2003 through 2013, depending on site access and weather conditions. We did not conduct surveys in 2006.

After returning from the field we: 1) eliminated the potential of over counting vocalizations by georeferencing the location and species in a Geographic Information System, 2) entered the information from the field survey forms into a database for future analysis, and 3) transferred recordings of owl vocalizations to a computer via an audio editing program.

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## 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 broadcasted 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 call was broadcasted (). Then, the probability of detection for each post-broadcast period depended on which call had been broadcasted. This allowed species-specific behavior in response to the different broadcasted 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 broadcasted 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 owl species present in El Salvador. This included the 9 species observed during our surveys and an additional 5 species that we never observed (Table 2). This upper limit to expected species richness related directly to the 13 species known to inhabit El Salvador (Pérez-Léon et al. 2017) 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 summing 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’s 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 the number of species present in each year and route:

Consistent with our approach for 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 broadcasted 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 2017, Plummer 2017) 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. Archer and West (2021) provide all analysis data and code necessary to reproduce are results in an online archive.

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 2). 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 1,000 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 2,000 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

We conducted 86 surveys between March and May from 2003 through 2005 and 2007 through 2013. No surveys were conducted in 2006. We documented 1,211 owl observations in the three study areas; with 911 owls documented during the period that we surveyed owls at each point, 163 owls documented incidentally at transects (outside of the survey protocol, but noted on the survey forms), and 137 owls documented from field notes made while at study areas.

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 2). 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 El Salvador (see Discussion for additional information). The Nancuchiname Forest Management Plan (Zepda 1995) only listed Ferruginous Pygmy-Owl as occurring in the forest; however, we found four additional species of owls (Table 2) in that protected area.

We recorded multiple vocalizations for eight species of owls: Barn Owl*,* Whiskered Screech-Owl*,* Pacific Screech-Owl*,* Spectacled Owl, Great Horned Owl*,* Ferruginous Pygmy-Owl*,* Mottled Owl, and Fulvous Owl (Table 2). These recordings were used as a verifiable method of species identification and as locally recorded vocalizations for broadcasts (as suggested by Gerhardt 1989). The most common Mottled Owl vocalizations (uttered by both males and females) we heard in the study areas were the territorial calls of two to three lower volume muffled secondary hoots followed by three separated primary hoots. The variation of these hoots allowed us to identify individual Mottled Owls. We were able to identify between male and female territorial vocalizations because the female vocalizations were higher pitched than the male vocalizations. The cat-like yowls given by females (food solicitation calls) were also frequently heard. The Mottled Owl vocalizations we heard support the descriptions of the vocalizations heard in Tikal NP, Guatemala (Gerhardt and Gerhardt 2012).

## Single-species occupancy model results

Mottled Owls, Spectacled Owls, and Ferruginous Pygmy-Owls had 530, 137, and 184 positive detections over the 11-year period, respectively (Table 2). No other owl species had enough detections to analyze species-specific occupancy. Averaged across years, 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. 1). Occupancy probabilities were relatively high across all three species for both routes of Nancuchiname (Fig. 2). The probability of occupancy for Mottled Owls was relatively consistent across time in both El Imposible routes and in N-2 (Fig. 3), but it seemed to increase in the last approximately 6 years in M-2 and N-1 (Fig. 3). The probability of occupancy in M-1 seemed to have decreased through time for Mottled Owls (Fig. 3).

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. 3). The probability of occupancy for Ferruginous Pygmy-Owls was relatively high in both routes of Nancuchaname except in 2008 and 2009 (Fig. 3), and the probability of occupancy for the Spectacled Owls fluctuated slightly from year to year in the Nancuchaname routes (Fig. 3).

## Richness Model Results

Our estimates of each route’s community richness () and 90% credible intervals were 4 (4,4), 3 (3,3), 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 2), 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 and route, median species richness () varied from 0 to 5 (Fig. 4). 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. 4).

## Detection Results

Including all detected species in 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. 5). 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 Great Horned Owl calls decreased detection probability (Fig. 5).

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

Discussion

To assess owl abundance, distribution, and population trends in El Salvador, we established survey routes within three protected natural areas in disparate ecological regions (alluvial plain, forested, cloud forests) and attempted to complete two surveys passes per route each year from 2003 through 2013. Our surveys were not always completed twice per year in each route because of issues with site access or poor weather, which decreases owl vocalizations and detection (Takats et al. 2001, Andersen 2007). Overall, our surveys yielded sufficient data to analyze occupancy patterns for three species of interest: Mottled Owl, Ferruginous Pygmy-Owl, and Spectacled Owl.

Mottled Owls were the most frequently detected owl during our surveys. Mottled Owls are the most common and widespread large owl in Central America (Vallely and Dyer 2018), and they have been documented in a wide range of land-cover types and elevations in Mexico (Enríquez-Rocha et al. 1993). Dickey and van Rossem (1938) considered Mottled Owls to be typically woods owls and frequent, both day and night, the thickest parts of the forest. The majority of Mottled Owls we observed were observed in primary forest and to a lesser degree in coffee plantations in the western portion of El Imposible NP in 1979-1981 (West 1988). A recent study indicated that Mottled Owl populations in El Salvador have persisted despite habitat loss that has restricted the distribution of several other owl species (Pérez-Léon et al. 2017). In contrast, Enrı́quez and Rangel-Salazar (2001) reported that Mottled Owl populations in La Selva may have decreased during the past 30 years. Our results indicated that Mottled Owls are still relatively common at each of our study areas, although there seemed to be a downward trend in occupancy in M-2 that could warrant further monitoring.

Ferruginous Pygmy-Owls were the second most-often detected owls in our study and they vocalized more closer to sunset than later in the evening. This species exhibited relatively low occupancy rates in El Imposible routes, other than in the first two years in EI-1. Ferruginous Pygmy-Owls tend to prefer open cover types with a lot of edge, such as the flooded forests of Amazonia (Borges et al. 2004) and heterogenous forests in central Argentina (Campioni et al. 2013). Furthermore, the diet of Ferruginous Pygmy-Owls varies based on forest density (Sarasola and Santillán 2014). Lower elevation areas of the western portion of El Imposible NP were grazed and dotted with houses in the early 1980s, and this mixed agrarian landscape may have provided suitable forest edge, which has decreased resulting from vegetation changes and the 1997 reforestation. It is possible that Ferruginous Pygmy-Owls are responding to a decrease in forest edge within El Salvador, and we recommend further surveys to determine the risk to Ferruginous Pygmy-Owls in response to vegetation management. Poaching may also be a risk for these owls: of eight species of owls confiscated from local markets in 1995 to 2008, the most frequent were Mottled Owls and Ferruginous Pygmy-Owls (Pérez-Léon et al. 2017).

Spectacled Owls followed similar occupancy patterns to those of Ferruginous Pygmy-Owls, with highest occupancy in the alluvial Nancuchiname Forest. Spectacled Owls can be found in a range of forest types and land uses, including coffee plantations and urban parks (Marín-Gómez et al. 2017), and they tend to prefer lowland forests below 1,000 m a.s.l. (Enríquez-Rocha et al. 1993, Orihuela-Torres et al. 2018). In 1979-1981 in the western portion of El Imposible NP, Spectacled Owls were observed in lower elevations of primary forest near El Imposible River and its small tributaries (West 1988). Spectacled owls were detected in each of the routes located at low to moderate elevation; however, we also detected Spectacled Owls in Montecristo National Park, in a valley below transect M-2 (1,755 m a.s.l.), which is potentially near the maximum of their elevation tolerance range. Spectacled Owls have been reported to prefer mammalian prey over reptiles or arthropods (Orihuela-Torres et al. 2018) and preferentially hunt near fallen logs where small mammals often seek refuge (Esclarski and Cintra 2014), but we were unable to test for micro-habitat occupancy in our study. Further assessment of Spectacled Owl habitat selection would provide better understand of their ecology and distribution in the Neotropics, and specifically, El Salvador.

Nancuchiname Forest was the richest in owl diversity of the three protected areas we included in our study; however, many of the owl species recognized as habitat specialists were only detected in Montecristo NP (e.g., Whiskered Screech-Owl, Great Horned Owl, Fulvous Owl, and c.f. Stygian Owl). Fulvous Owls are one of El Salvador’s 18 endemic bird species (Komar 2002), and were detected numerous times in the cloud forest of Montecristo NP (M-1). A Fulvous Owl has also been recently photographed in Montecristo NP (Gonzalez et al. 2017).

Stygian Owls, which often inhabit dense cloud forests (from 1,500-3,000 m elevation) (Enríquez-Rocha et al. 1993), were listed as an owl species expected to reside in El Salvador (Pérez-Léon et al. 2017) but have been previously undetected in the country. On 26 March 2002, after listening to recordings and viewing photographs, the Montecristo NP guards indicated that they thought c.f. Stygian owls were present in the park (personal communication). Although there was only one c.f. Stygian Owl detected on our survey routes (on 21 March 2005), we also heard a c.f. Stygian Owl twice on M-2 between different survey points on 20 March 2005 and once between M-2 survey points on 25 April 2007. We did not record any of these vocalizations by c.f. Stygian Owls, and detections that occurred between stations or away from survey routes were not included in our analyses. So, while we are confident that c.f. Stygian Owls are present in Montecristo NP, we believe that further documentation of the species is necessary to understand its distribution and abundance in El Salvador.

During 1979-1981, in the western portion of El Imposible NP, West (1988) observed six species of owls, including two that were not detected during this study (Barn Owls and Black-and-white Owls). In 2002, Barn Owls were detected in a cave of Loma de Paja Mountain, which is the other side of the ridge from this study’s El Imposible routes (V. Campos Aguirre pers. comm.). V. Campos Aguirre also indicated that in 2002, Black-and-white Owls were observed in two areas of the Mistepe River Valley. It is likely, then, that these two owl species still occur in El Imposible, though we did not detect them during our surveys.

Like many owl species, Neotropical owls are difficult to survey due to their cryptic nature and nocturnal habits. Positive visual identifications are relatively rare, and many owl surveys rely on aural detections. Distinguishing individuals by non-invasive means, such as vocal traits, is also preferable when species are rare, sensitive to handling, elusive, or when other techniques are unfeasible (Terry et al. 2005). Owls vocalize to communicate with the same species, to threaten or provoke other species, and to delimit territory (Johnsgard 2002). Our surveys involved periods of passive listening followed by broadcasting vocalizations designed to trigger vocalization from owls as a means of increasing the probability of detection. Overall, the probability of detection was lower during passive listening periods pre-broadcast. Owls are sensitive to interactions with other owls (Enrı́quez and Rangel-Salazar 1997, Baumgardt et al. 2019) and may change their response to broadcasted calls depending on their life stage (e.g., nesting versus courtship; Flesch and Steidl 2007). We found that specific owl vocalizations affected responsiveness and detection probability for multiple species within our study system, and we recommend that future studies targeting Neotropical owls take this into account.

Globally, an estimated 75% of the nearly 250 species of owls are associated with dense and undisturbed forests (Mikkola 2012). Pérez-Léon et al. (2017) reported that within El Salvador, natural ecosystems such as cloud forest, deciduous, riparian, and pine-oak forests had the most diverse owl populations, and we calculated richness to be from 3 to 5 species across the protected areas of our study, which were all relatively intact natural areas. Our results highlight the importance of maintaining protected areas in El Salvador and demonstrate the importance of maintaining natural forested areas and diverse land-cover heterogeneity in a country under considerable pressures.

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[22March 2021]

TABLES

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*: 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), although s*

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*aVocalizations recorded; bThreatened; c*

# Figures

Figure 1. Map of El Salvador. Owl surveys were conducted from 2003 to 2013 in three different protected areas within El Salvador: El Imposible National Park (EINP), Montecristo National Park (MNP) and Nancuchiname Forest (NF). Map coordinates are in decimal degrees.

Figure 2. Probability of occupancy () summarized by route for Ferruginous Pygmy-Owls, Mottled Owls, and Spectacled Owls. 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.

Figure 3. Probability of occupancy by route and year for Ferruginous Pygmy-Owls, Mottled Owls, and Spectacled Owls. 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.

Figure 4. 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 of Richness 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 were indicated with the light grey area.

Figure 5. The probability of detecting owls during spontaneous surveys (i.e., pre-broadcast) and after broadcasting vocalizations, depending on the species vocalization broadcasted. 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, Mottled Owls, and Spectacled Owls. Owl surveys were conducted from 2003 to 2013 in three different protected areas within El Salvador. Posteriors were summarized with median 90% credible intervals. The pre-broadcast effect size’s credible intervals are represented with two grey horizontal lines on each graph.