Site Occupancy by Mexican Spotted Owls (*Strix occidentalis lucida*) in the US Forest Service Southwestern Region, 2019

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Bird Conservancy of the Rockies
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Bird Conservancy of the Rockies

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Mission: Conserving birds and their habitats through science, education and land stewardship

Vision: Native bird populations are sustained in healthy ecosystems

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2. **Education** is critical to the success of bird conservation.
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3. Contribute to bird population viability and help sustain working lands by partnering with landowners and managers to enhance wildlife habitat.
4. Promote conservation and inform land management decisions by disseminating scientific knowledge and developing tools and recommendations.

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Mexican Spotted Owl by Jennifer Blakesley.

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Executive Summary

The Mexican Spotted Owl (MSO) was listed as threatened under the Endangered Species Act in 1993. A revised recovery plan for MSO was completed in 2012, recommending that the population be monitored via estimating the rate of site occupancy. In August 2013, the US Forest Service Southwestern Region contracted with the Bird Conservancy of the Rockies (formerly the Rocky Mountain Bird Observatory) to refine the site occupancy monitoring protocol recommended in the revised recovery plan, to pilot test the protocol in 2014, and continue monitoring in subsequent years on Forest Service lands in Arizona and New Mexico.

As part of this continued monitoring, we surveyed 199 sites in 2019. These sites were a random subset of sites initially surveyed in 2014 and the same sites surveyed in 2015-2018, except for one site which was inaccessible due to fire. Of the 199 sites, 193 were surveyed twice. Forest fires and fire-related closures prohibited us from completing second surveys in 6 sites. However, our data were still sufficient to estimate occupancy and detection probabilities.

We analyzed the data under a multistate occupancy modeling framework. Using this model we were able to estimate the site occupancy probabilities for MSO in 2014-2019 as well as the probability that an occupied site contained a pair of MSOs. The probability of site occupancy increased from 2014 to 2016 and decreased from 2016 to 2019. The conditional probability that an occupied site contained a pair of MSOs showed a similar, but much less pronounced, pattern and changed very little in the six years of monitoring.

These models also account for imperfect detection. Detection probability was influenced by ordinal date, wind, and noise levels. Unsurprisingly, wind and noise had a negative impact on detection probability. Detection improved as the season progressed in sites with pairs of owls. This is likely due to different behavioral responses of the owls during different stages of the breeding season. We also found that detection probability was higher for pairs than for single owls.

In summary, the sampling frame and survey methods used in 2014 provided the framework needed to continue to monitor site occupancy by Mexican Spotted Owls in the Southwestern Region of the US Forest Service in 2015-2019. This framework may be expanded or adapted for monitoring Mexican Spotted Owls in additional areas of their range. Additional years of data collection will allow us to expand the analysis to answer pertinent questions about what factors drive the occupancy dynamics which will inform management of this sensitive species.

Acknowledgements

The implementation of the 2019 field season and the subsequent analysis of the data would not have been possible without the support and assistance of numerous people.

Karl Malcolm of the US Forest Service Southwestern Region was instrumental in securing the funding as well as making sure we had the support we needed throughout the field season. In addition, Karl and the USFS Southwestern Region supported our survey efforts from 2014-2019.

Numerous Forest Service Forest and District Biologists provided logistical support and invaluable local knowledge as well as making sure our crew remained safe during the field season.

The 2014-2019 Bird Conservancy Spotted Owl crews successfully collected a tremendous amount of data, often in rugged and remote terrain. Their tireless dedication is what makes this work possible.

In addition, this project would not exist without the vision of the MSO Recovery Team. Current Recovery Team members Bill Block and Joe Ganey of the US Forest Service Rocky Mountain Research Station, and Shaula Hedwall of the US Fish and Wildlife Service provided critical guidance in designing and executing this project, as did Karl Malcolm.

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Introduction

The Mexican Spotted Owl (hereafter "MSO" or "owl") is one of three subspecies of Spotted Owl. It was listed as threatened under the Endangered Species Act in 1993. In 1995, the MSO recovery team recommended that the population be monitored via multiple demographic studies randomly located throughout the range of the subspecies (USDI FWS 1995). However, this undertaking proved to be logistically impractical and too expensive. A revised recovery plan was completed in 2012 (USDI FWS 2012), which recommended that the population be monitored by estimating the rate of site occupancy across its range within the United States.

The revised MSO recovery plan outlines two criteria for delisting the subspecies: one pertaining to the owl population trend and the other pertaining to the owl's habitat (USDI FWS 2012). This study addresses the first criterion:

> *"Owl occupancy rates must show a stable or increasing trend after 10 years of monitoring*. The study design to verify this criterion must have a power of 90% (Type II error rate $\beta = 0.10$) to detect a 25% decline in occupancy rate over the 10-year period with a Type I error rate (α) of 0.10."

Occupancy monitoring tracks the proportion of sites occupied by a target species across a region of interest. It is especially useful because it does not involve capturing/banding of individuals and is much easier to implement. In addition it accounts for imperfect detection. Very rarely are organisms detected perfectly; they are often not observed by researchers even when present in the sampling area. Accounting for imperfect detection improves the accuracy and precision of site occupancy estimates (MacKenzie et al. 2002).

The vast majority of the owls in the United States inhabit land administered by the Southwestern Region of the US Forest Service. In 2013, the Forest Service contracted Bird Conservancy of the Rockies (formerly Rocky Mountain Bird Observatory) to refine and implement the site occupancy monitoring protocol recommended by the recovery plan. A pilot study was conducted in 2014. Based on our experiences and results from that pilot study, we adjusted our sample size and field logistics for subsequent years. We currently have six years of data and are able to estimate occupancy and detection probabilities under a multistate occupancy modeling framework.

Objectives

The primary objectives were to:

1. Conduct MSO surveys at 200 randomly located sites throughout the US Forest Service Southwestern Region
2. Analyze the 2014 – 2019 data in a multistate framework to
    a. Estimate site occupancy for each year
    b. Estimate the occupancy rates for pairs of MSOs
    c. Estimate trends in occupancy rates

   d. Estimate detection probabilities and understand the factors that influence our ability to detect owls when they are present
3. Provide recommendations for long-term monitoring of the MSO in the Southwestern Region

Methods

Sampling Area and Design

The geographic area that we sampled in 2019 remained the same as previous years. For details about how we selected our 1 km^2 survey sites, see the 2014 report (Blakesley 2015). Based on results from 2014, we concluded that surveying 200 sites annually would meet the Recovery Plan's monitoring objectives. Those 200 sites were a random subsample of the sites that were surveyed in 2014 and were each surveyed in 2015-2019 (Figure 1). We intended to survey each site twice.

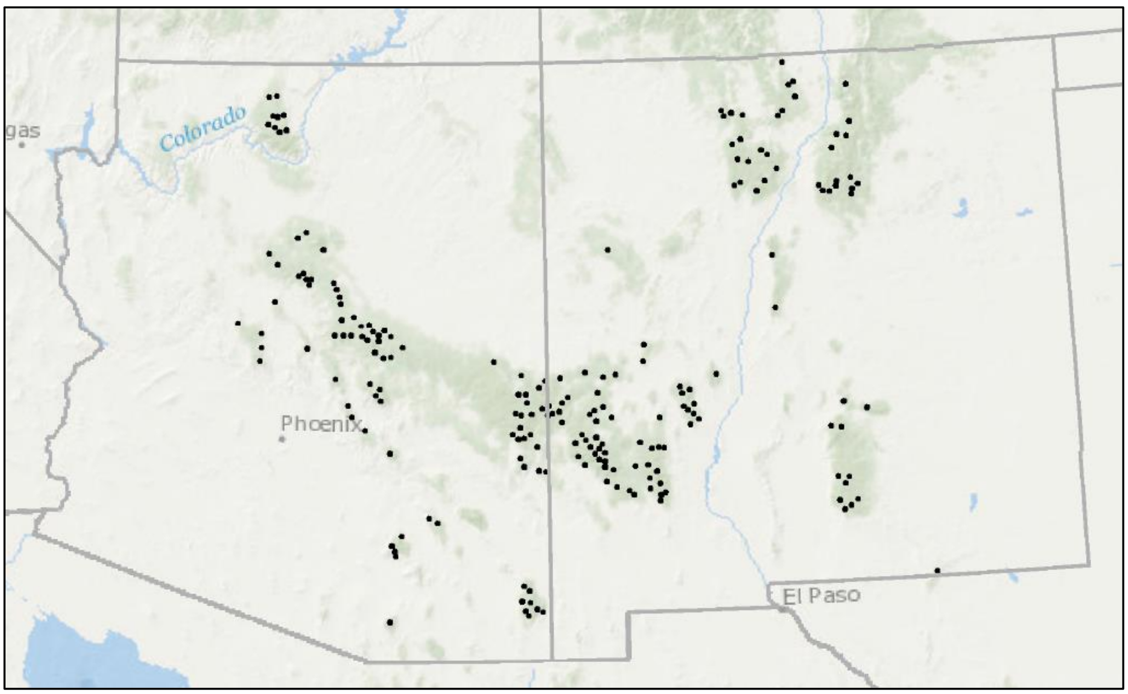

Figure 1. The distribution of sampling units (black dots; *n = 200*) surveyed for Mexican Spotted Owl site occupancy in 2019 in the US Forest Service Southwestern Region.

Each site contained five predetermined survey points. These points were distributed within the site such that there was one point in the center of the site and one point in each of the four quadrants (Figure 2). This ensured full coverage of the site, assuming that conditions allowed the technician to hear owls 250-300 m away. We encouraged technicians to use their discretion to move the survey points to locations that would improve the reach of their calls (e.g. calling from a ridge top rather than the side of a ridge) or to improve their ability to hear any owls (e.g. moving away from a loud stream). However, our technicians were not to move points more than 100 m from their original location in order to maintain full coverage of the site.

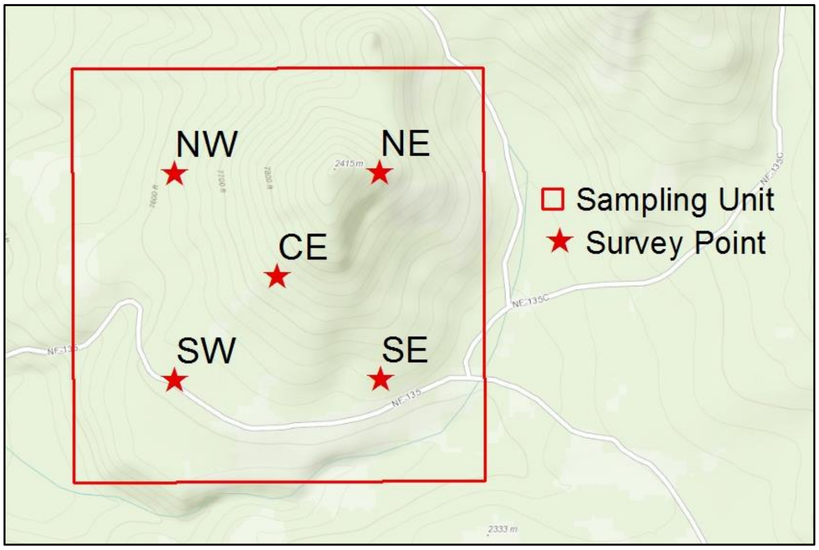

Figure 2. 1-km^2 sampling unit containing five survey points, used to survey for Mexican Spotted Owl site occupancy in 2014-2019 in the US Forest Service Southwestern Region.

<u>Survey Protocol</u>

Survey techniques for Spotted Owls are well-established (Forsman 1983). Spotted Owls are territorial and readily respond to vocalizations of other Spotted Owls, whether they are actual owls calling, recordings of owl calls, or human imitations of owl calls.

Technicians navigated to the survey points using a Garmin eTrex 20 Global Positioning System (GPS) and the geographical coordinates of the survey points. Surveys were conducted no earlier than 30 minutes after sunset. At each survey point within a site, technicians broadcasted prerecorded Spotted Owl calls using a FoxPro NX4. Each prerecorded call file contained 10 minutes of calls with a frequency of about 20 seconds of calling and 20 seconds of silence. Following the 10 minutes of calls, technicians listened in silence for five minutes. We used three different call files: one with a mixture of male and female calls, one with female calls only, and one with male calls only. We began surveying a site with the mixed male and female calls. If a MSO was detected, the technician switched to the recordings of the opposite sex owl for the remainder of that point survey and all subsequent point surveys within that site. Technicians continued to call all points within a site until they detected both a male and female MSO within the site. Occasionally one or two points within a site were not called due to safety concerns, high noise levels, or private property. We required a minimum of three points surveyed to consider a site effectively surveyed.

Once a technician detected an owl, that technician recorded the sex, age class, species, and time of detection of the owl. Adult MSOs have a wide variety of calls whereas juveniles only make a unique begging call, thereby allowing us to differentiate between adults and juveniles. Adult female MSOs have a higher pitched call and this difference in pitch can be used to determine the sex of the calling owl. For other owl species, age and sex were not so easily determined and were recorded as “unknown.” The technician then took a compass bearing towards the owl and estimated the distance to the owl. The technician plotted the bearing and distance on a map and used that to estimate the location in Universal Transverse Mercator (UTM) coordinates of the owl. Occasionally, the technicians were able to walk to where the owl was and then use their GPS units to record more precise coordinates of the owl.

Technicians also collect data on wind (using the Beaufort scale) and noise levels at each call point. For more details regarding our survey protocol and data collection, see Appendix A and Appendix B.

Analysis

Per the MSO recovery plan (USDI FWS 2012), we collected and analyzed our data in an occupancy framework (MacKenzie et al. 2006). In this occupancy framework, the main focus is determining presence or absence of owls in the sample sites. We analyzed the 2014-2019 data using multistate occupancy models (Nichols et al. 2007). The multistate model affords a straightforward way to estimate the rate of occupancy across multiple years as well as analyze a trend in those estimates. This directly supports the goals of the MSO recovery plan. In addition, it allows us to estimate the probability that an occupied site is characterized by additional state variable (e.g. reproductive or social status). In our analysis, we defined this additional state variable as the probability that an occupied site contains a pair of owls, which has strong implications for potential population growth. These probabilities are described by the parameters ψ_{it}^{1} and ψ_{it}^{2} (Table 1).

Like most recently developed occupancy models, this model also accounts for imperfect detection of the target species. The probability of detection is described by two parameters, p_{ij}^{1} and p_{ij}^{2}, differentiated by the occupancy state of the site (Table 1). In addition, the model allows for misclassification of the state variable of interest (in our case, pair occupancy). This probability that an observer would correctly classify the occupancy state (i.e. detect both owls in a site occupied by a pair) is defined by the parameter δ_{ij} (Table 1).

Table 1. Parameters estimated by the multistate model of site occupancy by Mexican Spotted Owls in the US Forest Service Southwestern Region, 2014-2019.

Parameter[1]	**Definition**
$\boldsymbol{\psi_{it}^{1}}$	Probability that site *i* is occupied in year *t* regardless of whether or not there is a pair of owls present
$\boldsymbol{\psi_{it}^{2}}$	Conditional probability that site *i* contains a pair of owls, given that is occupied in year *t*
$\boldsymbol{p_{ij}^{1}}$	Probability that occupancy is detected for site *i* during survey *j*, given that the site does not contain a pair of owls
$\boldsymbol{p_{ij}^{2}}$	Probability that occupancy is detected for site *i* during survey *j*, given that the site contains a pair of owls
$\boldsymbol{\delta_{ij}}$	Probability that the pair of owls is detected in site *i* during survey *j*

[1] In some previous reports we used the parameter notation of MacKenzie et al. (2009); in this report we are using the notation of Nichols et al. (2007).

We can also use the parameters estimated by the model to derive other occupancy parameters of interest such as site occupancy probability for pairs not conditional on occupancy status as well as the site occupancy probability for single owls. The unconditional probability that a site is occupied by a pair of owls for a given year is calculated as:

$$\psi_{it}^{pair} = \psi_{it}^{1} * \psi_{it}^{2}.$$

The probability that a site is occupied by only a single owl is:

$$\psi_{it}^{single} = \psi_{it}^{1} - (\psi_{it}^{1} * \psi_{it}^{2}).$$

Even though this model is structured for data from a single season, we can get year-specific estimates by treating year as a group in the analysis. Thus, we can analyze the overall trend in occupancy as mandated by the recovery plan. Therefore the data contained one season but six groups for each of the years from 2014-2019. Because a third survey was conducted in several sites in 2015, the data contained three survey periods within a season. For sites in which a third survey was not conducted in a given year, which was often the case, a "." denoted the lack of the survey for that period. The model is capable of handling such missing data.

Model Formation and Selection

We considered models that varied in their structures for the occupancy and detection probability parameters. We considered structures where the two occupancy probability parameters, ψ_{it}^{1} and ψ_{it}^{2}, varied by year, were fit to linear trend, fit to a quadratic trend, or were constant across all years (Table 2). We included the trend structures because estimating trends in this population is the ultimate goal of this work as outlined in the MSO 2012 Recovery Plan.

Table 2. Candidate structures for each occupancy parameter and candidate covariates for each detection parameter in the analysis of multistate site occupancy by Mexican Spotted Owls in the US Forest Service Southwestern Region, 2014-2019. Date refers to the ordinal date of the survey. Wind and noise refer to the average conditions during the survey. We fit all possible combinations of the detection covariates to the three detection parameters including a null model with no covariates.

Site Occupancy ψ_{it}^{1}	**Pair Occupancy** ψ_{it}^{2}	**Detection Probability** p_{ij}^{1}, p_{ij}^{2} and δ_{ij}
year	year	year
linear trend	linear trend	date
quadratic trend	quadratic trend	year*date
null	null	noise
		wind
		null

We investigated multiple covariates that may have impacted detection probability by modeling effects of year, ordinal date, noise, wind and an interaction between year and date (Table 2). In addition, we considered a null structure in which detection probability was the same across all surveys. Variation in detection probability by year could reflect annual differences in owl behavior due to population-wide variation in nesting rates. Alternatively, there may have been heterogeneity in detection probability due to possible differences in ability of each year's crew. Ordinal date may impact detection probability as a result of within-season shifts in the owls' vocal or territorial behavior as the breeding season progresses from courtship to nesting to fledgling stages. The timing of behavioral shifts may have varied among years due to the different weather conditions or overall nesting rates each year. Therefore, we included an interaction between year and ordinal date to account for this potential difference. Detection probability may have also improved with technician ability as experience is gained throughout the course of the field season. Wind and noise were both modeled as an average of the conditions at each call point within a site during a given survey, and could have impacted our ability to hear calling owls. We modeled all additive combinations of these four covariates as well as the interaction of year and date for each of the detection probability parameters.

We took a step-wise approach to model formation (Doherty et al. 2009). First, we determined the most supported structure for each detection parameter. During this step, we fit all possible structures to one detection parameter at a time while holding the other detection parameters and occupancy parameters at their most parameterized structure (i.e. allowing the occupancy probabilities to vary by year and allowing the other detection probabilities to vary by wind, noise, and the interaction of year and date). We used Akaike's Information Criterion adjusted for sample size (AIC_c) to rank the models and determine the most supported structure for each detection parameter (Burnham and Anderson 2002). Using the most supported structure for each detection parameter, we then fit models with all possible structures for the occupancy probability parameters and ranked them using AIC_c. This step-wise approach required fitting a total of 76 models as opposed to the 128,000 models that would have resulted fr0om an "all possible models" approach. We fit these models to the MSO data from 2014 - 2019 using Program MARK (White and Burnham 1999).

Results

2019 Summary

We conducted 392 surveys in 199 sites. All 199 sites received at least one survey. We were unable to access one of our original 200 sites due to a wildfire that started early in the field season. In addition, fire and fire-related closures prohibited us from conducting a second survey in six sites. We detected owls during 141 surveys in 88 sites.

Multistate Occupancy Model

Detection Probabilities

The model selection results from the first step of our analysis showed that wind, ordinal date, and noise were important covariates for the detection probabilities. Wind was in the top structure for p_{ij}^1 and p_{ij}^2, ordinal date was in the top structure for p_{ij}^2 and δ_{ij}, and noise was in the top structure for δ_{ij} (Table 3).

Table 3. Most supported structures for the three detection probability parameters for Mexican Spotted Owls in the US Forest Service Southwestern Region, 2014-2019 as determined by initial step of the occupancy analysis. We fit models using a logit link function and estimates for the β coefficients, including the intercept, β_0, are presented along with their standard errors in parentheses. Estimates are from the most parsimonious model from the second step of the analysis.

Parameter	Top Structure	β_0 (SE)	β_{wind} (SE)	β_{date} (SE)	β_{noise} (SE)
p_{ij}^1	wind	0.551 (0.371)	-0.647 (0.253)	--	--
p_{ij}^2	wind + date	0.411 (0.552)	-0.521 (0.110)	0.013 (0.004)	--
δ_{ij}	date + noise	0.010 (0.569)	--	0.015 (0.004)	-0.474 (0.164)

Detection probabilities increased with increasing date and decreased with increasing wind and noise (Table 4; Figures 3, 4, and 5). Detection in sites occupied by a pair, p^2, was considerably higher than in sites occupied by single owls, p^1. However there was little difference between p^2 and δ (Table 4).

Table 4. Model averaged parameter estimates for the different detection probabilities estimated by the single season multistate models of site occupancy by Mexican Spotted Owls in the US Forest Service Southwestern Region, 2014-2019. Estimates are presented for the average values of the covariates of date, wind, and noise. Standard errors appear in parentheses. Parameter definitions appear in Table 1.

	Survey 1	Survey 2	Survey 3
p^1	0.421 (0.068)	0.438 (0.067)	0.543 (0.072)
p^2	0.796 (0.020)	0.877 (0.017)	0.929 (0.015)
δ	0.798 (0.022)	0.876 (0.020)	0.895 (0.023)

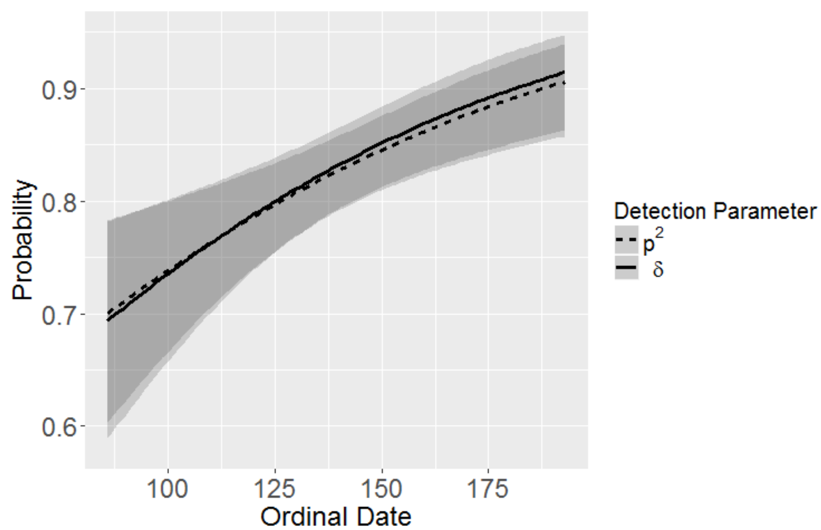

Figure 3. The relationship between date and p^2 and δ based upon model-averaged estimates from an analysis of site occupancy by Mexican Spotted Owls in the US Forest Service Southwestern Region, 2014-2019. The shaded regions represent 95% confidence intervals around the estimate. The ordinal date of April 1 is 100. Delta (δ) is the probability that a pair of owls is detected given that the site contains a pair and p^2 is the probability that occupancy (i.e. at least one owl) is detected given that the site contains a pair of owls. There was little support for an effect of date on p^1 so it is not presented here.

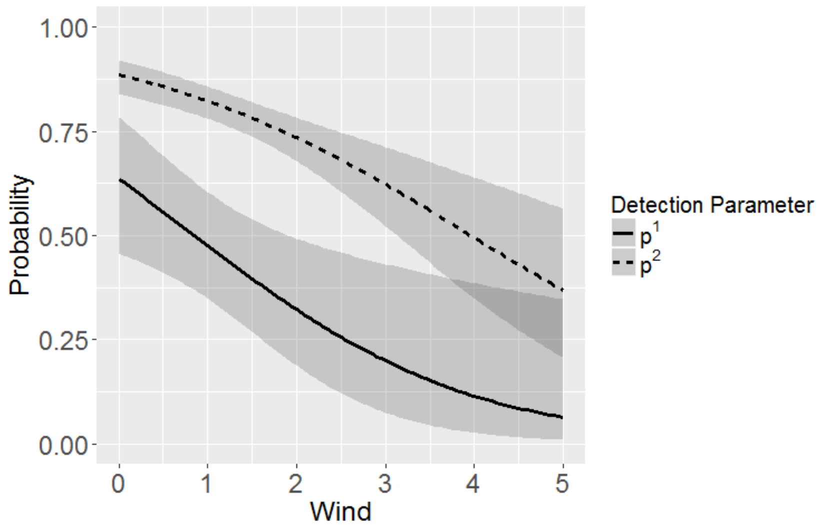

Figure 4. The relationship between wind conditions during a survey and p^1 and p^2 based upon model-averaged estimates from an analysis of site occupancy by Mexican Spotted Owls in the US Forest Service Southwestern Region, 2014-2019. The shaded regions represent 95% confidence intervals around the estimate. p^1 is the probability that occupancy is detected given that the site does not contain a pair of owls and p^2 is the probability that occupancy is detected given that the site contains a pair of owls. There was little support for an effect of wind on δ so it is not presented here.

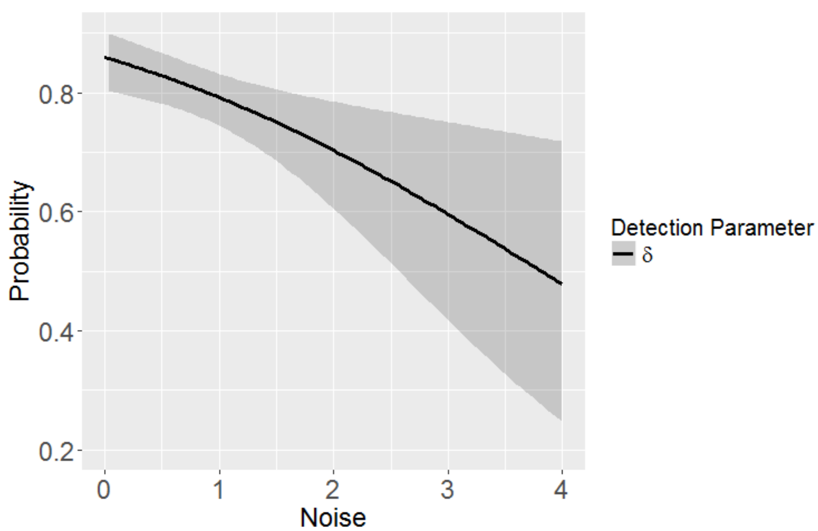

Figure 5. The relationship between noise levels during a survey and δ based upon model-averaged estimates from an analysis of site occupancy by Mexican Spotted Owls in the US Forest Service Southwestern Region, 2014-2019. The shaded regions represent 95% confidence intervals around the estimate. Delta (δ) is the probability that a pair of owls is detected given that the site contains a pair. There was little support for an effect of noise on p^1 and p^2 so it is not presented here.

Occupancy Probabilities

Of the 16 models we fit that contained all possible combinations of structures for the two occupancy probabilities in the second step of the analysis, three had a ΔAIC_c less than two and were considered the top models (Table 5). The most parsimonious model (AIC_c weight = 0.390) contained a quadratic trend on site occupancy, ψ_{it}^{1}, and showed no annual change in the conditional probability that an occupied site contained a pair of MSOs, ψ_{it}^{2}. The quadratic trend on ψ_{it}^{1} was highly supported with a cumulative model weight of 0.670. The next best supported structure was a linear year effect and it only had a cumulative model weight of 0.324. Similarly, the constant structure on ψ_{it}^{2} had a cumulative model weight of 0.587 and was followed by the linear and quadratic structures with cumulative weights of 0.220 and 0.168, respectively.

Table 5. Multistate models of site occupancy by Mexican Spotted Owls in the US Forest Service Southwestern Region, 2014-2019. Log (L) is the log-likelihood, K is the number of parameters, ΔAIC_c is the difference in Akaike's information criterion from the top model, and w_i is the model weight. "Quad" indicates a quadratic trend in occupancy, "linear" indicates a linear trend in occupancy, "year" indicates that occupancy was estimated separately for each year, and "." indicates that occupancy was estimated to be the same across all years. All models contained the same structure for the detection parameters: p^1(wind), p^2(date + wind), δ(date + noise).

Model	log (L)	K	ΔAIC_c	w_i
ψ^1(quad), ψ^2(.)	-1828.626	12	0.000	0.390
ψ^1(year), ψ^2(.)	-1825.839	15	1.366	0.197
ψ^1(quad), ψ^2(linear)	-1828.453	13	1.942	0.148
ψ^1(quad), ψ^2(quad)	-1827.571	14	2.492	0.112
ψ^1(year), ψ^2(linear)	-1825.668	16	3.388	0.072
ψ^1(year), ψ^2(quad)	-1824.794	17	4.031	0.052
ψ^1(quad), ψ^2(year)	-1825.748	17	5.939	0.020
ψ^1(year), ψ^2(year)	-1823.906	20	9.584	0.003
ψ^1(.), ψ^2(quad)	-1833.622	12	9.993	0.003
ψ^1(.), ψ^2(year)	-1830.745	15	11.179	0.001
ψ^1(linear), ψ^2(quad)	-1833.546	13	12.129	0.001
ψ^1(linear), ψ^2(year)	-1830.719	16	13.491	0.000
ψ^1(.), ψ^2(.)	-1838.037	10	14.318	0.000
ψ^1(linear), ψ^2(.)	-1837.740	11	15.964	0.000
ψ^1(.), ψ^2(linear)	-1838.028	11	16.540	0.000
ψ^1(linear), ψ^2(linear)	-1837.640	12	18.029	0.000

To account for model uncertainty, we present model averaged parameter estimates. Overall site occupancy (ψ^1) increased from 2014 to 2016 (ψ_{2014}^{1}= 0.428, SE=0.042; ψ_{2015}^{1}= 0.574, SE=0.043; ψ_{2016}^{1}= 0.613, SE=0.033) then declined between 2016 and 2019 (ψ_{2017}^{1}= 0.609, SE=0.036; ψ_{2018}^{1}= 0.559, SE=0.038; ψ_{2019}^{1}= 0.481, SE=0.043; Figure 6).

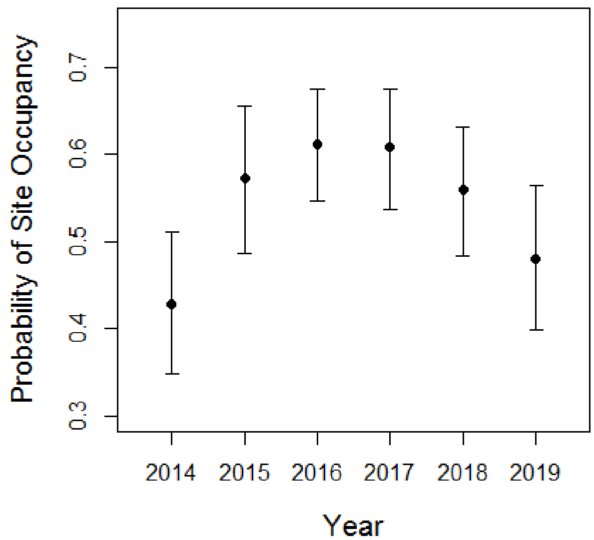

Figure 6. Model-averaged probabilities of site occupancy by Mexican Spotted Owls in the US Forest Service Southwestern Region. Error bars represent 95% confidence intervals.

The conditional probability that an occupied site contained a pair of owls displayed a similar but very muted pattern of increasing slightly from 2014-2016 and decreasing slightly from 2016-2019 with a range from 0.747 (SE=0.048) in 2019 to 0.771 (SE = 0.036) in 2016 (Figure 7).

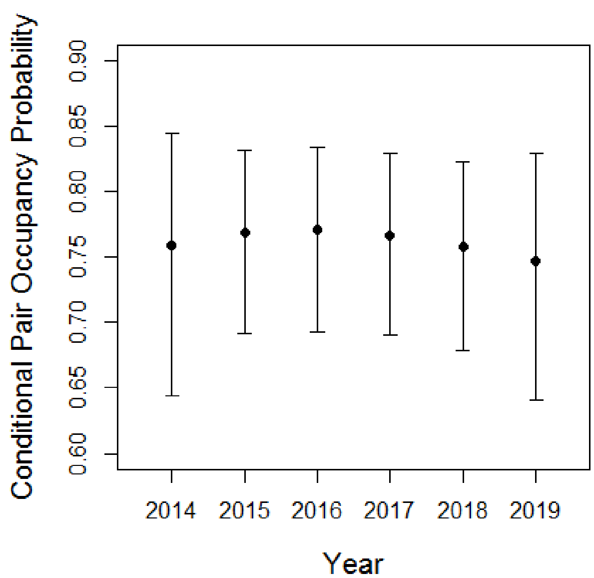

Figure 7. Model-averaged probabilities that a site occupied by Mexican Spotted Owls in the US Forest Service Southwestern Region contains a mated pair. Error bars represent 95% confidence intervals.

Similarly, the unconditional probabilities that a site was occupied by a single owl or a pair of owls followed the same very muted quadratic pattern as the overall site occupancy (Table 6).

Table 6. Derived unconditional probabilities of site occupancy, ψ_{it}, by social status (single or pair) by Mexican Spotted Owls in the US Forest Service Southwestern Region, 2014-2019. Estimates were derived from model-averaged parameter estimates. Standard errors appear in parentheses. Parameter definitions appear in Table 1.

	t=2014	2015	2016	2017	2018	2019
ψ_{it}^{single}	0.103 (0.027)	0.132 (0.024)	0.140 (0.025)	0.142 (0.025)	0.135 (0.025)	0.122 (0.028)
ψ_{it}^{pair}	0.325 (0.032)	0.441 (0.035)	0.472 (0.028)	0.467 (0.029)	0.424 (0.030)	0.359 (0.034)

Discussion

The estimates for the different detection probabilities highlight the different behaviors of single owls verses paired owls. The detection probability for sites with single owls, p^1, was lower than for sites with a pair, p^2. This follows a similar pattern we found in the prior analyses (Lanier and Blakesley 2015, 2016, 2017, 2018) and is likely caused by one or more of the following factors. First, a single owl detected in one survey may have been a transient that was unavailable for detection in the other survey. In this case, the owl's presence could be considered "use" rather than "occupancy" because occupancy assumes that the owl was available for detection in both surveys. Secondly, nonbreeding owls might have larger home ranges (Willey and van Riper 2007) and therefore an owl might not be spatially available for detection during both surveys even if its home range encompassed the survey site. Also, without a breeding territory to defend, a single owl may be less likely to respond to our calls. Lastly, sites occupied by a single owl, by definition, have fewer owls available to respond and be detected than sites with a pair. Therefore, the opportunities for technicians to hear an owl are greater in sites occupied by a pair.

The multistate analysis showed that the probability of detecting both members of a pair in sites occupied by a pair, δ, was high. Therefore, we were likely to detect both members of that pair. There was a low probability of non-detection in sites occupied by a pair (1-p^2) and a similarly low probability of missing one member of a pair (1- δ).

The decrease in detection probability with increasing wind and noise is intuitive as both can make it difficult for observers to hear the owls or for the owls to hear calls broadcasted by the observers. In addition, there could also be a behavioral reason for the low detection during higher winds. Owls might be less likely to respond and exert energy if the wind is coupled with cold temperatures.

The increase in detection probability with increasing date could be due to differential owl response rates during different stages of the breeding season. Owls might be more or less territorial or willing to reveal their location during different stages of the breeding season (e.g. pre-nesting, nesting, dependent fledglings, etc.). This hypothesis is supported by the fact that our model selection did not select date as an important factor for detecting single birds, which are not actively breeding.

It is also encouraging that the effect of year was not an important factor for detection probability. Therefore, the different makeup of each year's crew does not create heterogeneity in detection probability from year to year. This is likely due to our thorough training, relative simplicity of our survey methods, and cooperative nature of Spotted Owls to broadcast surveys.

The multistate occupancy modeling framework allows us to monitor the site occupancy rates as well as parameters of biological interest such as the probability of pair occupancy. The data indicate that site occupancy by Mexican Spotted Owls increased from 2014 to 2016 and decreased from 2016 to 2019. Occupancy estimates for sites with pairs and sites with single owls displayed the same increasing then decreasing trend. Therefore, the factors that are influencing occupancy are impacting all sites regardless of social status. Favorable weather has been shown to positively influence adult survival as well as reproductive output of Mexican Spotted Owls (Seamans et al. 2002). If the decline we observed from 2016-2019 was solely a result of lack of recruitment of young owls into the territorial owl population, it would likely only appear in the occupancy rates of single owls that are often young and still looking for mates. The pattern we observed might be better explained by factors that are indiscriminate of social status such as habitat loss from fires or a combination of factors that impact all social classes (e.g., poor weather that is severe enough to reduce recruitment as well as adult survival). Additional analyses are needed to tease apart the underlying causes of the trends we observed.

Some of our previous reports on this project included a multistate robust design occupancy analysis, which estimated local extinction and colonization probabilities (Lanier and Blakesley 2015 and 2016, MacKenzie et al. 2009). We chose to not include that analysis in this report. On their own, the dynamic parameters of extinction and colonization probability do not offer much more insight into the population than the occupancy estimates that we provide in this report. However, these dynamic parameters could be used in conjunction with habitat and climate covariates in future analyses to determine what drives colonization and local extinction.

With each subsequent year, we amass more valuable data on MSO occupancy. This rich dataset is capable of much more than trend analysis as prescribed by the Recovery Plan. Some potential directions we believe would be of interest to the MSO Recovery Team and land managers within the MSO range include:

1. Using habitat and climate covariates along with a multistate robust design occupancy model to determine what factors contribute to
    a. occupancy of sites, and
    b. local extinction and colonization of sites.
2. Using MSO reproductive data collected by USFS biologists and others in the Southwestern Region as a covariate in analyses to determine
    a. how much variation in site occupancy can be attributed to reproductive output in previous years, and

   b. whether annual reproductive rates influence detection probability.

3. Separating the "single" state into "single male" and "single female" to better understand the behavior and ecology of single owls.
4. Using the data we collect on other owl species during surveys to examine interspecific influences on occupancy and detection of MSOs, especially the influence of Great Horned Owl presence on MSOs.
5. Continuing to explore the efficacy of deploying autonomous recording units at existing survey sites to determine whether acoustic monitoring will be useful in supplementing or replacing broadcast surveys.
6. Using the extinction and colonization estimates from a robust design occupancy model to understand the metapopulation and source-sink dynamics between disjunct areas of habitat in the Southwestern Region.

This sixth year of monitoring continued to demonstrate the ability of the current sampling design and methods to achieve the monitoring goals set out in the 2012 MSO Recovery Plan. We recommend that the Forest Service continue monitoring under the current framework so that we can continue to gain more knowledge about the annual variation in site occupancy by Mexican Spotted Owls. This framework can be expanded to include other areas of the Mexican Spotted Owl's range.

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Appendix A. Mexican Spotted Owl Broadcast Survey Protocol

Bird Conservancy of the Rockies is conducting broadcast surveys for the purpose of estimating occupancy rates and monitoring trends in occupancy rates of the Mexican Spotted Owl on all National Forests in Arizona and New Mexico (USFS Region 3). This project is required under the Mexican Spotted Owl Recovery Plan, First Revision (2012).

The sampling locations were selected using a spatially-balanced sampling algorithm (Generalized Random-Tessellation Stratification), and were essentially a random sample of locations within a sampling frame of potentially suitable Mexican Spotted Owl habitat. It is essential to the validity of the monitoring program that all selected sites are surveyed unless they are unsafe to survey.

Sampling locations (sites) consist of 1-km^2 areas. Each site contains 5 survey points, with one point in the center of the site and one point in the center of each quarter of the site, named according to their location (Figure 1).

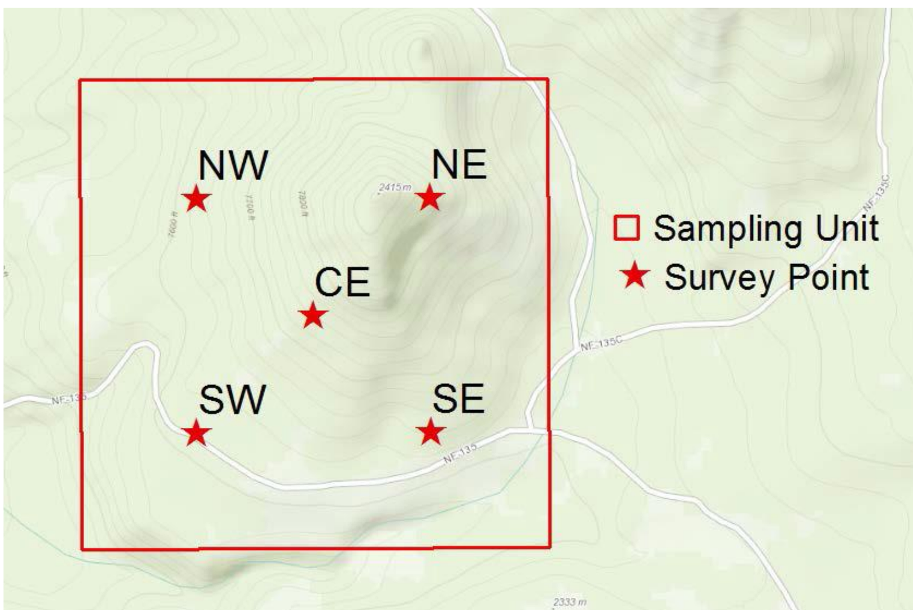

Figure 1. 1-km^2 square sample site containing 5 survey points.

Field technicians will have topographic maps and UTM coordinates of each survey point in their GPS units. Field technicians may use their discretion to move survey points to avoid trespassing on private property, to take advantage of local topography and/or to avoid unsafe terrain; for example, to call from a ridge rather than the side of a slope. In general, call points should not be move more than 100 meters. Field technicians must record the UTMs of the actual location from which they surveyed. A survey point within a site may be skipped if the point lies on private property more than 100 m from Forest Service land or if the technician has concerns about their personal safety (i.e. if the terrain is too dangerous). Safety is of the highest concern; the second highest is conducting thorough and complete surveys.

Surveys are to be conducted no earlier than 30 minutes past sunset (note: the GPS units can be used to determine the exact time of sunset). Each field technician will have a FoxPro NX4 broadcast device to use during surveys. The units contain various recordings of male and female spotted owl calls, with approximately 20 seconds of calls followed by 20 seconds of silence, for 10 minutes. Technicians are to listen for spotted owl responses throughout the survey period. Following the 10 minutes of intermittent calls, the technician will listen for owl responses for 5 additional minutes; the entire time spent at each survey point is 15 minutes (unless a spotted owl responds; see below).

Objectives are to **survey every point until both a male and female spotted owl are detected within the 1-km^2 site, or until all 5 points are surveyed**. If a spotted owl is detected outside of the site, the survey will continue at the remaining survey points. If only one sex of owl is detected within the site from a survey point, the technician will switch from the recording of both sexes of owls (channel zero) to a recording of the opposite sex of owl for the remainder of the 15 minute survey. At this point, it will be up to the technician to turn off the broadcaster at the 10 minute mark and also to keep track of the time during the 5 minutes of silence. For example, if a male owl is detected in survey minute 7, switch to the recording of female calls (channel one) and play this for 3 minutes then listen for 5 minutes; if a female owl is detected in minute 4, switch to the recording of male calls (channel two) for 6 minutes then listen for 5 minutes. All subsequent surveys in the site should use the recordings of the opposite sex. The purpose of this procedure is to avoid excess disturbance to spotted owls detected.

Record the compass bearing from the survey point to the initial location of all owls detected. Plot the bearing on the paper map of the survey site. Use local topography and common sense to estimate the location of the owl (plot on the map) and record the estimate the distance from the call point to the owl.

If you detect an owl while walking between survey points, stop. In the black **Survey Information** section, record your location as Point "99", enter the UTMs of your location and all other information as you would from an established survey point. Then fill out the red **Detection Information** section for the owl you detected. Enter the "Min. to Detect" as "0".

When two technicians are surveying separate points at the same site: Do **NOT** conduct broadcast surveys at more than one point at a time, including the 5 minute listening period. Use walkie-talkies or InReach units to communicate with your field partner to ensure that you do not survey within the same 15-minute period. The purpose of broadcasting spotted owl calls is to entice any spotted owls present to respond because they perceive you as an intruder in their territory. If an owl perceives that there are two intruders in their territory, they may remain silent.

Survey conditions: Do not survey during rainfall more than a light drizzle. Do not survey if wind conditions would prevent you from detecting a calling spotted owl within 250 meters of your survey point (generally greater than 18 mph; see Beaufort wind scale on survey form). Although ridges can be good points to survey from when winds are not strong, during windy conditions it may be better to survey downslope from ridge tops.

Safety: Except in very gentle terrain, technicians should arrive at their survey sites during daylight hours to view the landscape and plan how they are going to navigate between survey sites. Technicians will check in with their crew leaders at least once a day, either in person, by cell phone, or via their DeLorme inReach satellite communication device. The crew leader may request twice-per-day check-in. The crew leader will designate one crew member with whom they will check in daily.

Survey Form details:

SUMMARY INFORMATION (BLUE PORTION OF THE SURVEY FORM)

Site: Each site name contains 3 letters and 4 digits. The letters indicate the National Forest of the site; the numbers indicate the order of the site in the GRTS random sample; for example, "SFE0005".

Date: Follow the example format: 2 digit day, 3 letter month; for example, "01 APR".

Visit number: Each site will be visited 2 times within the season.

Observers 1 and 2: Use 3 initials (or 2 initials if you don't have a middle name).

If two people are surveying separate points within a unit, each person should fill out a form in the field, but after the survey is over, the data from one technician should be copied onto the other technician's form so that only one survey form is turned in for the survey. Destroy the duplicate form that you are not turning in to avoid confusion.

 # Pairs, # Single males, # Single females, # Juveniles: This section should be filled out at the end of the survey, after all points are surveyed for the night. **Enter zeros rather than leaving fields blank.**

Survey Complete? See the codes on the survey form. If a survey is incomplete, an additional visit to the site will be required.

Why survey incomplete? Enter a very short explanation, following the examples given on the form. If survey is complete, put a dash in this field.

SURVEY INFORMATION (BLACK PORTION OF THE SURVEY FORM)

Point: See Figure 1. Use 2 letter codes for surveys from the points or "99" if you detect an owl between survey points.

Wind: See codes.

Noise: Use this field for non-wind noise, such as a creek or traffic. Enter the type of noise in the "Notes" box of the survey form.

Start time: The time you start broadcasting, or the time you heard an owl if you are walking between points or hear the owl before you start broadcasting from a point. Record as 24-hour time; For example, 8:15 PM = 2015. Exact midnight = 2400. 15 minutes after midnight = 0015, NOT 2415.

End time: The time you stop listening for owls.

Survey time: Fill this out after you enter Start Time and End Time. If you do not detect any owls, this will usually be 15 minutes. If you detect a male and female owl, it may be less than 15 minutes. If you need extra time to confirm a detection (or location of a detection), it is ok to spend more than 15 minutes at a point.

UTME and UTMN: Use your GPS unit.

DETECTION INFORMATION (RED PORTION OF THE SURVEY FORM)

Only fill out this section if owls are detected. Most of these fields are obvious and/or have codes on the form.

Min. to Detect: This is the number of minutes that lapse between when you started surveying a point and when you detect the owl. If you detect an owl before you begin broadcasting, enter "0" for Min to Detect. If you detect an owl within a minute of broadcasting, enter "1" even though an entire minute had not lapsed.

Owl Location UTM's: Estimated from where you plotted it on the printed topo maps. Alternatively, if you can see the owl, then walk to where it is and use your GPS to get more accurate UTM's (note: a bearing and distance are still needed in this case).

Bearing and Distance: Unless the owl is perched on top of your head, record a bearing and distance for all owls observed, even the ones that are very close and you can see. Use your compass to take a bearing to the detected owl. Use your common sense to estimate a distance to it.

Unique Bird ID: This field is used to keep track of the same owl detected from multiple points. Use the same code to indicate the same individual spotted owl detected from more than one point. Start with M1, F1, U1. For example, if you hear the same male owl from NE and NW points, record its location and data for each detection on separate lines, and enter "M1" as the ID on both lines. If you then hear a second male owl from the NW point, record its location on a new line and enter "M2". If only one owl of each sex is detected, there is no need to use the Unique Bird ID field. Example:

Point	Species (see codes)	Sex (M,F,U)	Age (A,J,U)	How (see codes)	Time Detected				Min. to Detect	Bearing (degrees)	Distance (meters)	Unique Bird ID	Inside/ Outside*
NE	SPOW	M	A	HO	2	1	3	5	5	225	300	M1	I
NW	SPOW	M	A	HO	2	2	0	7	2	135	250	M1	I
NW	SPOW	M	A	HS	2	2	1	2	7	352	75	M2	I

Inside/Outside: Enter I or O to indicate whether the owl is inside or outside of the 1-km^2 survey site.

Appendix B. Spotted Owl Broadcast Survey Form

SPOTTED OWL BROADCAST SURVEY FORM

Page ____ of ____

Site: ________________ (e.g., SFE0005)

Date: ____/______/ 2018 (e.g., 01 / APR / 2018)

Visit #: _____

Observer 1: __________ (INITIALS)

Observer 2: _________ (INITIALS)

Survey Complete? ______
Y Yes; 5 pts surveyed OR SPOW pair in sampling unit
P Partial; 3-4 pts surveyed AND no SPOW pair
N No; < 3 points surveyed AND no SPOW detected

MSO Summary:
Pairs ____ # Single Males ____ # Single Females ____ # Unk. Sex ____ # Juveniles ______

Why Survey Incomplete? ___________
Bear, Fire, Mt Lion, People, Priv Prop, Rain, Snow, Space Aliens, Tech Error, Terrain, Wind

Survey Information:

Point	Wind (see codes)	Noise (see codes)	Start Time	End Time	Survey Minutes	Observer Location UTME	Observer Location UTMN

Beaufort Wind Scale

Code:	mph	Description
0	0	smoke rises vertically
1	1-3	smoke drifts
2	4-7	wind felt on face
3	8-12	leaves in constant motion
4	13-18	raises dust; branches sway
5	18-24	small trees sway

Noise codes
0 – no noise
1 – some noise, but can hear very well
2 – moderate noise; can still hear to 200 m
3 – loud noise; affecting ability to detect owls
4 – very loud stream or other noise (move!)

Detection Information:

Point	Species (see codes)	Sex (M,F,U)	Age (A,J,U)	How (see codes)	Time Detected	Min. to Detect	Owl Location UTME	Owl Location UTMN	Bearing (degrees)	Distance (meters)	Unique Bird ID	Inside/ Outside*

Notes:

Species codes

BDOW	Barred Owl
BNOW	Barn Owl
ELOW	Elf Owl
FEPO	Ferruginous Pygmy-Owl
FLOW	Flammulated Owl
GHOW	Great Horned Owl
LEOW	Long-eared Owl
NOPO	Northern Pygmy-Owl
NSW0	Northern Saw-whet Owl
SPOW	Spotted Owl
WESO	Western Screech-Owl
WHSO	Whiskered Screech-Owl

How detected codes

HO	Heard Only
HS	Heard, then Seen
SO	Seen Only
SH	Seen, then Heard

*Inside (I) or Outside (O) sampling unit

3/20/2017

IF FOUND, PLEASE RETURN TO: Bird Conservancy of the Rockies; 230 Cherry Street; Fort Collins, CO 80521