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Open-File Report 2023–1012

U.S. Department of the Interior
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Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F = (1.8 × °C) + 32.

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83_Albers).

Abbreviations

AIC_c	Akaike's information criteria, corrected for small sample sizes
BO	barred owl
CAS	South Cascades
CI	confidence interval
CLE	Cle Elum
COA	Coast Ranges
GDR	Green Diamond Resources
HJA	HJ Andrews
HUP	Hoopa
KLA	Klamath
NSO	northern spotted owl
NWC	Northwest California
OLY	Olympic
RAI	Rainier
SE	standard error
TYE	Tyee
USFWS	U.S. Fish and Wildlife Service

Estimating Northern Spotted Owl (*Strix occidentalis caurina*) Pair Detection Probabilities Based on Call-Back Surveys Associated with Long-Term Mark-Recapture Studies, 1993–2018

Katie M. Dugger [1], Alan B. Franklin[2], Damon B. Lesmeister[3], Raymond J. Davis[3], J. David Wiens[1], Gary C. White[4], James D. Nichols[5], James E. Hines[1], Charles B. Yackulic[1], Carl J. Schwarz[6], Steven H. Ackers[7], L. Steven Andrews[7], Larissa L. Bailey[4], Robin Bown[8], Jesse Burgher[3], Kenneth P. Burnham[4], Peter C. Carlson[4], Tara Chestnut[9], Mary M. Conner[10], Krista E. Dilione[1], Eric D. Forsman[3], Scott A. Gremel[9], Keith A. Hamm[11], Dale R. Herter[12], J. Mark Higley[13], Rob B. Horn[14], Julianna M. Jenkins[3], William L. Kendall[1], David W. Lamphear[11], Christopher McCafferty[3], Trent L. McDonald[15], Janice A. Reid[3], Jeremy T. Rockweit[7], David C. Simon[1], Stan G. Sovern[7], James K. Swingle[3], and Heather Wise[14]

Abstract

The northern spotted owl (*Strix occidentalis caurina*; hereinafter NSO) was listed as “threatened” under the Endangered Species Act in 1990 and population declines have continued since that listing. Given the species’ protected status, any proposed activities on Federal lands that might impact NSO require consultation with U.S. Fish and Wildlife Service and part of that consultation often includes surveys to determine presence and occupancy status of the species in the proposed activity area. The objective of this report is to present study-area specific estimates of the probability of detection for NSO pairs from twelve 2-week seasonal survey periods using data from a recent range-wide meta-analysis. These estimates were a by-product of pair occupancy modeling but might provide insight into potential changes in the effect of the invasive barred owl on NSO detection rates. We used two-species multi-season occupancy models to estimate the probability of detection for NSOs on each of 11 study areas for each 2-week survey period and relative to the range-wide effect of barred owl presence or absence. Detection probabilities within the season generally increased from the earliest surveys in March through mid-season, decreasing again in the late season on five study areas. For three other study areas, detection rates were highest during the earliest survey periods in late March or early April. Estimates of cumulative seasonal detection of NSO (across a maximum of six within-season surveys) were less than 0.90 when barred owls (BO) were present on all but one study area, regardless of when surveys were conducted within a season. However, despite low detection rates, the probability that a territory was occupied when an NSO pair was not detected over six within-season surveys was also very low. When BO are not present on a territory, a six-survey protocol had a high probability of detecting an NSO pair at least once during the season on all study areas, except for the very lowest per-survey estimates. Conducting most surveys earlier in the season, when the probability of detecting pairs is highest (through May on most areas) could improve seasonal detection rates. However, alternative methods of population monitoring—such as the use of passive acoustic recorders—may be needed to continue monitoring NSO for research and management.

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[1]U.S. Geological Survey

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[12]Raedeke Associates

[13]Hoopa Tribal Council

[14]Bureau of Land Management

[15]McDonald Data Sciences LLC

Introduction

The northern spotted owl (*Strix occidentalis caurina*; hereinafter NSO) was listed as "threatened" under the Endangered Species Act in 1990 (U.S. Fish and Wildlife Service, 1990). Because of continued population declines, the U.S. Fish and Wildlife Service (hereinafter USFWS) recently determined that uplisting NSO to "endangered" status was "warranted but precluded" by other listing priorities (U.S. Fish and Wildlife Service, 2020). Given the species' protected status, any proposed activities on Federal lands that might impact NSO require consultation with USFWS, and part of that consultation often includes surveys to determine presence and occupancy status of this threatened species in the area of the proposed activity (U.S. Fish and Wildlife Service, 1992, 2012).

Detection of NSOs in forest stands incorporates two processes: (1) the probability that the territory is occupied (in other words, one or more NSO are present on the territory) and (2) the probability that if an NSO is present on the territory, it is detected. Thus, survey protocols and analyses that allow these two probabilities to be estimated separately provide the best estimates of territory occupancy and are important for documenting when planned management activities will negatively impact resident NSOs through habitat modifications or disruption to essential breeding activities. The primary method of surveying for NSOs in long-term demography studies includes as much as six call-back surveys conducted at fixed points along a route at night, or during walk-ins to previously occupied territory centers during the day (Franklin and others, 1996; Yackulic and others, 2012). As has been documented for some time, the invasive barred owl (*Strix varia*; hereinafter BO) suppresses NSO response rates to traditional call-back surveys (Olson and others, 2005; Crozier and others, 2006; Duchac and others, 2020). Barred owl presence on a territory also negatively impacts occupancy dynamics of NSO in the landscape (for example, Olson and others, 2005; Kroll and others, 2010; Dugger and others, 2011, 2016; Franklin and others, 2021). Therefore, NSO surveys that account for the probability of detection and BO presence provide the most robust estimates of NSO site occupancy.

Previously published estimates of NSO detection rates were based on per-visit detections (Olson and others, 2005; Kroll and others, 2010; Dugger and others, 2011), rather than equal-length survey periods that might include multiple territory visits (Yackulic and others, 2014; Dugger and others, 2016; Franklin and others, 2021). Early estimates also included detections of any owl—single or pair—and these per-visit detection rates were generally higher than detections of pairs only (Olson and others, 2005; Kroll and others, 2010). However, an owl pair is the ecological unit required to maintain viable populations so pair occupancy is vitally important to understanding population status and trends (Dugger and others, 2011). Recent efforts to understand occupancy dynamics of NSO have focused on detections of NSO pairs only (Yackulic and others, 2012, 2014, 2019; Dugger and others, 2011, 2016; Franklin and others, 2021). In these analyses, the estimation and modeling of NSO pair occupancy dynamics (for example, colonization, local extinction, annual occupancy) were the primary objective, so although the probability of detection was also always modeled, it was often not reported (for example, Dugger and others, 2016; Franklin and others, 2021).

The objective of this report is to present study-area specific estimates of the probability of detection for NSO pairs from twelve 2-week seasonal survey periods ("survey-specific") using data from a recent meta-analysis of 11 NSO demographic study areas across the species range (Franklin and others, 2021). The NSO meta-analysis was not focused on estimating the probability of detecting NSO pairs, but such estimates were generated as a by-product of the pair occupancy modeling and might provide insight into potential changes into the continued effects of BOs on NSO detection rates. Since these estimates were not provided in Franklin and others (2021), they are presented in this report.

Study Areas

Populations of NSO that occurred on Federal and non-Federal lands within the range of the species were the basis of this analysis. To address our objectives, we used detection/non-detection survey data from historically monitored territories on 11 NSO demography studies included in the most recent meta-analysis evaluating population status and trends (table 1; fig. 1; Franklin and others, 2021). This analysis included three study areas in Washington (Cle Elum [CLE], Rainier [RAI], Olympic Peninsula [OLY]), five study areas in Oregon (Coast Ranges [COA], HJ Andrews [HJA], Tyee [TYE], Klamath [KLA], and South Cascades [CAS]), and three study areas in Northern California (Northwest California [NWC], Hoopa [HUP], Green Diamond Resources [GDR]; fig. 1). These study areas primarily represent lands under Federal administration, but some private, Tribal, and mixed ownership lands are also included (table 1). Detailed descriptions of each study area are available in Anthony and others (2006).

Table 1. General characteristics of 11 study areas used to estimate probability of detection of northern spotted owl (*Strix occidentalis caurina*) pairs in Washington, Oregon and California, 1993–2018.

[WA Douglas-fir refers to *Pseudotsuga menziesii*. **Abbreviations:** NW, Northwest; WA, Washington; OR, Oregon; CA, California; OR-CA, Oregon–California; km^2, square kilometers]

Study area	Acronym	Area (km^2)	Landowner	Ecological region
		Washington		
Cle Elum	CLE	1,784	Mixed	WA mixed conifer
Rainier	RAI	2,167	Mixed	WA Douglas-fir
Olympic	OLY	2,230	Federal	WA Douglas-fir
		Oregon		
Coast Ranges	COA	3,922	Mixed	OR coastal Douglas-fir
HJ Andrews	HJA	1,604	Federal	OR Cascades Douglas-fir
Tyee	TYE	1,026	Mixed	OR coastal Douglas-fir
Klamath	KLA	1,422	Mixed	OR-CA mixed conifer
South Cascades	CAS	[1]2,372	Federal	OR Cascades Douglas-fir
		California		
NW California	NWC	460	Federal	OR-CA mixed conifer
Hoopa	HUP	356	Tribal	OR-CA mixed conifer
Green Diamond Resources	GDR	1,340	Private	CA coast
Total		18,683		

[1]Study area size was 3,377 km^2 in 2014 meta-analysis.

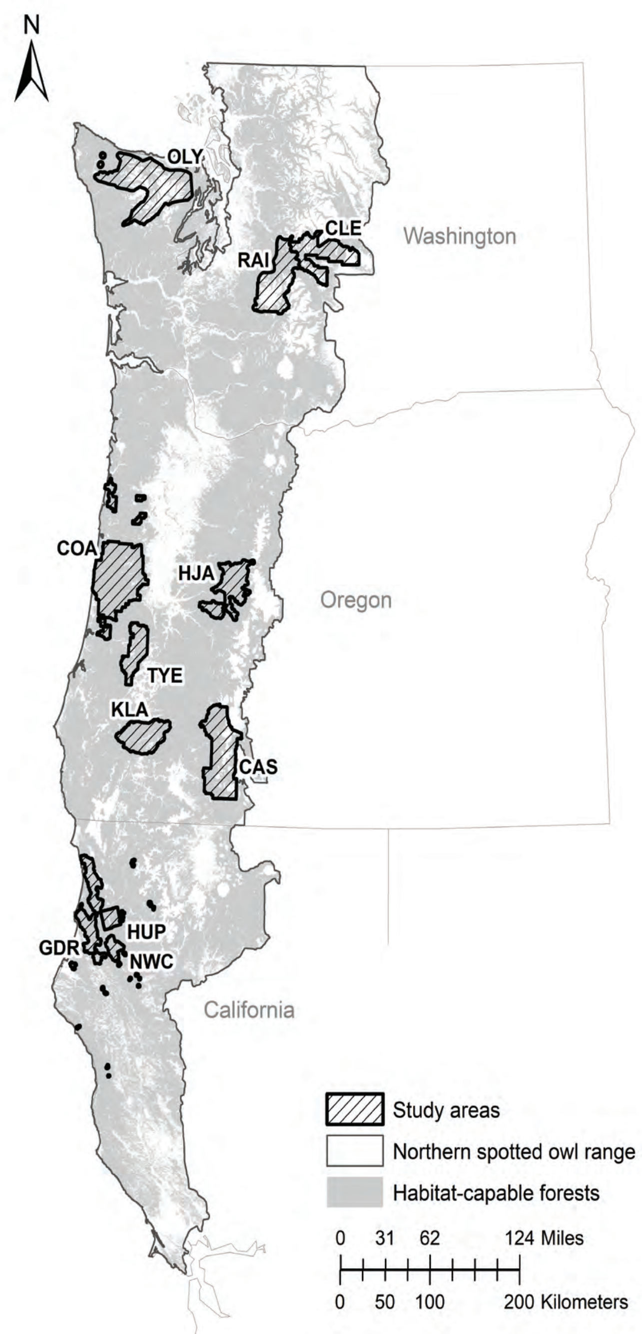


Figure 1. Locations of 11 study areas used to estimate per survey estimates of the probability of detection for northern spotted owl (*Strix occidentalis caurina*) pairs, Washington, Oregon, and California, 1993–2018. Figure is taken from Dugger and others (2016).

Methods

Survey Data

Detection/non-detection data were collected annually for both NSO and BO across 26 years (1993–2018) on 9 study areas, 21 years (1993–2013) for HUP, and 16 years (1993–2008) for GDR. The total number of surveyed territories included in this analysis declined on two study areas (CLE, COA) in the last 4 years because we excluded territories involved in a concurrent BO removal study (for example, Wiens and others, 2021). Vocal lure (in other words, "callback") surveys and daytime walk-in visits to previously used territory centers or nest trees were used to systematically search each study area for territorial NSOs (Franklin and others, 1996). The minimum number of visits per season ranged from three to six depending on the study area (Franklin and others, 1996). A detailed description of survey protocols associated with the NSO effectiveness monitoring program is available in appendix A of Lint and others (1999). Incidental detections (auditory and visual) of BOs were recorded as well as NSO detections. We grouped the results of territory visits into twelve 2-week survey periods (starting on March 1 and ending on August 31 of each year) that included detections of one or more BO and the distinction between single NSO and NSO pair detections during each survey period. Most study areas began surveys in early or late March of each year (period 1 or 2), but NWC began surveys in April (survey period 3) of each year. An NSO pair detection was defined as the detection of both the male and female NSO at some point during the 2-week survey period, the detection of a male NSO with a nest, or the detection of a single NSO of either sex with fledged young. We then summarized detection data within 2-week survey periods into encounter histories for any BO (singles or pairs) and NSO pairs only. Thus, to focus on detections of NSO pairs, detections of NSO singles were replaced with "0" (representing no detection of a pair) and "1" for pairs during a survey period, resulting in encounter histories that included four types of detections:

1. No owls were detected.
2. BOs only were detected.
3. NSO pairs only were detected.
4. Both BOs and an NSO pair were detected.

We used "dots" to denote missing data (in other words, no survey conducted within the 2-week survey period).

Analyses

Estimates of the probability of detection for NSOs were generated from two-species multi-season occupancy models (MacKenzie and others, 2018) using a hybrid of the approaches of Richmond and others (2010) and Yackulic and others (2014). For parameters modeled using the approach of Richmond and others (2010), we considered BOs the dominant species (coded as “A”) because of their prevalence and competitive advantage, and NSOs were the subordinate species (coded as “B”). The ecological process parameters were modeled as in Richmond and others (2010) and included initial occupancy (ψ_1), colonization (γ_i), and local extinction (ε_i) for each species. These parameters are year-specific (subscript *i* denotes primary sampling period “year”) and were modeled for BO as independent of NSO presence. For NSO, these parameters were modeled as conditional on whether BO were present or not. The probabilities of detection were survey-specific (*j*) within years (*i*) for each species (p_{ij}) and were conditional on the presence (or not) of the other species as in Yackulic and others (2014), with estimates of the probability of detecting NSO pairs the focus of this report. We generated model parameter estimates as part of a meta-analysis effort that was focused on NSO demographics and included data from all 11 study areas (Franklin and others, 2021). We used program R-PRESENCE (https://www.mbr-pwrc.usgs.gov/software/presence.html) to build models and generate parameter estimates and model selection results. Detection probability (p_{ij}) was estimated for each survey *j* (secondary samples within seasons) within primary sampling periods *i* (years) based on the model structure used in the meta-analysis (excluding the trap response; Franklin and others, 2021). We identified our best model for NSO pair detection rates using an information theoretics approach and AIC_c (Akaike’s Information Criteria corrected for small sample size) model selection results, with the model containing the lowest AIC_c generally considered to have the most support (Burnham and Anderson, 2002). The best probability of NSO pair detection model from our analysis included a study-area specific covariate, plus a study area-specific quadratic function reflecting within-season variation, and the additive effect of the presence of BOs that was shared across all study areas. No between season variation (denoted by the “.”) was included in the best model, only within-season variation ($p_{.j}$). We used the following equation to estimate the probability of detection of NSO pairs when BO were present:

$$logit(\hat{p}_{.j}) = \hat{B}_{Study\ Area} + \hat{B}_{Study\ Area(j)} \times (j) + \hat{B}_{Study\ Area(j^2)} \times (j^2) + \hat{B}_{BO\ presence} \quad (1)$$

We used the following equation to estimate the probability of detection of NSO pairs when BO were absent:

$$logit(\hat{p}_{.j}) = \hat{B}_{Study\ Area} + \hat{B}_{Study\ Area(j)} \times (j) + \hat{B}_{Study\ Area(j^2)} \times (j^2). \quad (2)$$

The survey period ($j = 1 - 12$) was standardized $[(j-6)/6]$ and we used the resulting estimates of model coefficients (table 2) and the associated variance-covariance matrix to calculate survey-specific $p_{.j}$ estimates that were constant across all years. We used the delta method (Cooch and White, 2021, Appendix B) and the embdbook package (v1.3.12; Bolker, 2008) in R 4.0.4 (R Core Team, 2021) to calculate standard errors (SE) and 95-percent confidence limits for these estimates. For more detail on the methodology and results relative to other model parameters, see Franklin and others (2021).

We also used p_j estimates to calculate a cumulative seasonal detection rate (p^*), or the probability of detecting a NSO pair one time or more over the course of the season based on six surveys within a year (in other words, the highest minimum number of visits conducted per year on some study areas). We estimated p^* under a robust design framework for each study area as follows:

$$p^* = 1 - \begin{bmatrix}(1-\hat{p}_{.1}) \times (1-\hat{p}_{.2}) \times (1-\hat{p}_{.3}) \times \\ (1-\hat{p}_{.4}) \times (1-\hat{p}_{.5}) \times (1-\hat{p}_{.6})\end{bmatrix}. \quad (3)$$

We used four different combinations of $p_{.j}$ estimates to calculate p^*, including:

1. the single highest;
2. the single lowest;
3. the sixth highest (corresponding to the “peak” of the quadratic function); and
4. $p_{.j}$ estimates from surveys 2, 4, 6, 8, 10, and 12, to reflect consistent survey effort over the 6-month NSO breeding season, for territories where BOs was present and territories where they were absent.

We also estimated the probability that NSO pairs were present even though they were never detected on any of six surveys conducted at a site within a season, for territories where BOs were present and territories where BOs were absent using Bayes’ Theorem (MacKenzie and others, 2018) as follows:

$$\hat{\psi}_{condl} = \frac{\hat{\psi}\,(1-\hat{p}_{.j})^k}{1-\hat{\psi}\left[1-(1-\hat{p}_{ij})^k\right]}. \quad (4)$$

We calculated closed conditional probability of occupancy ($\hat{\psi}_{condl}$) based on six surveys per season ($k = 6$) for territories with BOs present and territories with BOs absent. We used estimates of the probability of NSO pair territory occupancy in 2018 for each study area ($\hat{\psi}_{2018}$) and (1) the single highest and (2) six survey-specific detection probabilities ($\hat{p}_{.j}$) from surveys evenly spread across the season (in other words, surveys 2, 4, 6, 8, 10, 12) when BOs were present and when BOs were absent.

Table 2. Model coefficients and standard errors from the model structure used to estimate survey-specific probability of detection for northern spotted owl (*Strix occidentalis caurina*) pairs on 11 study areas in Washington, Oregon, and California, 1993–2018.

[The model included individual study area effects and the quadratic structure of survey occasion (j, j^2) for each study area, with the effect of barred owl (*Strix varia*) presence consistent across all season-specific surveys and study areas. There were twelve 2-week survey occasions (j), and they were standardized [$(j-6)/6$] before inclusion in the model. **Abbreviations:** OLY, Olympic; CLE, Cle Elum; RAI, Rainier; COA, Coast Ranges; HJA, HJ Andrews; TYE, Tyee; KLA, Klamath; CAS, South Cascades; HUP, Hoopa; GDR, Green Diamond; NWC, Northwest California; SE, standard error; $\hat{\beta}$, model coefficients]

Study area	Description	$\hat{\beta}$	SE
Cle Elum	Study area–CLE	0.569	0.085
	j	–0.582	0.135
	j^2	–1.127	0.251
Rainier	Study area–RAI	–0.401	0.088
	j	–0.707	0.120
	j^2	–0.027	0.226
Olympic	Study area–OLY	–0.787	0.057
	j	–0.369	0.080
	j^2	–0.807	0.164
Coast Ranges	Study area–COA	–0.404	0.044
	j	–0.693	0.050
	j^2	–0.554	0.098
HJ Andrews	Study area–HJA	–0.399	0.039
	j	–0.434	0.065
	j^2	–0.899	0.116
Tyee	Study area–TYE	–0.372	0.055
	j	–0.654	0.062
	j^2	–0.596	0.114
Klamath	Study area–KLA	–0.188	0.042
	j	–0.378	0.056
	j^2	–1.035	0.108
South Cascades	Study area–CAS	–0.170	0.044
	j	–0.253	0.090
	j^2	–1.008	0.134
Northwest California	Study area–NWC	–0.375	0.059
	j	–0.563	0.109
	j^2	–0.249	0.204
Hoopa	Study area–HUP	–0.793	0.063
	j	–0.562	0.102
	j^2	0.075	0.176
Green Diamond Resources	Study area–GDR	–0.622	0.041
	j	–0.648	0.046
	j^2	0.040	0.087
All study areas	Barred owl presence	–1.256	0.034

Results

Detection probabilities for within-season surveys for NSO pairs generally indicated a quadratic pattern, increasing from the earliest surveys in March through mid-season (May–June), decreasing again late in the season for five study areas (CLE, OLY, HJA, KLA, CAS; table 3; fig. 2). The pattern for COA and TYE was quadratic but the highest detection rates occurred earlier in the season, in late March or early April, and then decreased through the rest of the season (table 3; fig. 2). For the three California study areas (NWC, HUP, GDR) and one study area in Washington (RAI), the highest per-survey pair detection rates occurred during the earliest surveys in March and April and then decreased through the season to lows in August (fig. 2B, I–K). The additive effect of BO was negative for all study areas, with substantial reductions in per-survey NSO pair detection rates on all areas when BOs were present (table 3; fig. 2).

Estimates of cumulative seasonal detection of NSO pairs ($\hat{p}^*$) from a maximum of six surveys were highest when based on either the single highest estimate or the six highest estimates. However, only CLE achieved p^* greater than (>) 0.90 and represented the highest estimates of per-survey probability of detection when BOs were present (table 4). For most study areas the estimates of p^* based on the six highest $p_{.j}$ estimates varied from 0.60 to 0.75, but a low of 0.51 was observed on OLY and a high of 0.91 on CLE when BOs were present (table 4). In contrast, estimates of p^* based on six surveys were >0.90 when BOs were not present on a territory for all $p_{.j}$ configurations except for the lowest estimates (table 5), or when surveys 2,4,6,8,10, and 12 were used on OLY and HUP (table 5).

Despite low detection rates when BOs were present on a territory, conditional estimates of occupancy for territories where NSO pairs were never detected generally were also very low, particularly for the lowest per-survey pair detection rates and unconditional probability of occupancy for NSO pairs from 2018 when BOs were present (table 6). The probability that a territory was occupied when an NSO was not detected over six surveys was highest for study areas with the highest NSO pair occupancy rates and the lowest per-survey pair detection rates within seasons for both territories with and without BOs (table 6).

Table 3. Estimates with standard errors and 95-percent confidence limits of the probability of detecting a northern spotted owl (*Strix occidentalis caurina*) pair on a territory if it is present when one or more barred owls (BO) are present, and when no barred owls (*Strix varia*) are present for twelve 2-week periods surveyed each year from March 1 to August 31 for Cle Elum, Rainier, Olympic, Coast Ranges, HJ Andrews, Tyee, Klamath, South Cascades, Northwest California, Hoopa, and Green Diamond Resources study areas, in Washington, Oregon, and California, 1993–2018.

[Detection rates presented are from the best model, which does not include variation between years, only variation between surveys within years. The highest per-survey detection rates within a season are shown in **bold** type. **Abbreviations:** $\hat{p}_{.j}$, estimates; SE, standard errors; 95% CI, 95-pecent confidence limits; --, no data]

Survey	BO present			BO not present		
	$\hat{p}_{.j}$	SE	95%CI	$\hat{p}_{.j}$	SE	95%CI
Cle Elum						
1	0.272	0.168	0.194–0.367	0.568	0.585	0.459–0.670
2	0.31	0.142	0.248–0.380	0.612	0.492	0.538–0.682
3	0.337	0.113	0.290–0.387	0.641	0.388	0.590–0.688
4	0.35	0.094	0.313–0.390	0.654	0.322	0.616–0.691
5	0.35	0.089	0.314–0.388	0.654	0.307	0.617–0.689
6	0.335	0.087	0.298–0.374	0.639	0.301	0.599–0.676
7	0.307	0.078	0.271–0.345	0.608	0.271	0.567–0.658
8	0.268	0.063	0.236–0.302	0.562	0.22	0.521–0.603
9	0.221	0.049	0.194–0.251	0.499	0.17	0.458–0.541
10	0.171	0.04	0.146–0.200	0.421	0.14	0.375–0.467
11	0.124	0.037	0.099–0.154	0.332	0.128	0.279–0.390
12	0.084	0.033	0.060–0.115	0.242	0.117	0.183–0.314
Rainier						
1	--	--	--	--	--	--
2	0.232	0.081	0.188–0.282	0.515	0.287	0.449–0.580
3	0.213	0.054	0.182–0.247	0.487	0.191	0.438–0.536
4	0.194	0.041	0.169–0.221	0.458	0.145	0.417–0.500
5	0.177	0.036	0.154–0.202	0.43	0.128	0.389–0.471
6	0.16	0.033	0.139–0.185	0.401	0.118	0.360–0.443
7	0.145	0.03	0.125–0.168	0.373	0.107	0.333–0.415
8	0.131	0.027	0.112–0.152	0.345	0.096	0.306–0.387
9	0.118	0.025	0.100–0.138	0.318	0.089	0.279–0.360
10	0.105	0.026	0.087–0.128	0.292	0.092	0.249–0.340
11	0.094	0.03	0.073–0.121	0.267	0.107	0.215–0.327
12	0.084	0.036	0.059–0.199	0.243	0.128	0.179–0.322
Olympic						
1	0.092	0.024	0.074–0.113	0.261	0.083	0.220–0.308
2	0.104	0.02	0.089–0.121	0.289	0.067	0.257–0.323
3	0.113	0.017	0.101–0.127	0.309	0.054	0.284–0.335
4	0.118	0.016	0.107–0.131	0.32	0.051	0.298–0.344
5	0.119	0.016	0.107–0.132	0.321	0.052	0.298–0.345
6	0.115	0.016	0.103–0.128	0.313	0.052	0.290–0.337
7	0.107	0.015	0.096–0.119	0.295	0.048	0.272–0.319
8	0.095	0.013	0.085–0.106	0.269	0.043	0.247–0.292
9	0.081	0.012	0.072–0.092	0.236	0.04	0.214–0.260
10	0.066	0.012	0.056–0.077	0.199	0.041	0.174–0.226

Table 3. Estimates with standard errors and 95-percent confidence limits of the probability of detecting a northern spotted owl (*Strix occidentalis caurina*) pair on a territory if it is present when one or more barred owls (BO) are present, and when no barred owls (*Strix varia*) are present for twelve 2-week periods surveyed each year from March 1 to August 31 for Cle Elum, Rainier, Olympic, Coast Ranges, HJ Andrews, Tyee, Klamath, South Cascades, Northwest California, Hoopa, and Green Diamond Resources study areas, in Washington, Oregon, and California, 1993–2018.—Continued

[Detection rates presented are from the best model, which does not include variation between years, only variation between surveys within years. The highest per-survey detection rates within a season are shown in **bold** type. **Abbreviations:** $\hat{p}_{.j}$, estimates; SE, standard errors; 95% CI, 95-pecent confidence limits; --, no data]

Survey	BO present			BO not present		
	$\hat{p}_{.j}$	SE	95%CI	$\hat{p}_{.j}$	SE	95%CI
Olympic—Continued						
11	0.052	0.013	0.042–0.042	0.161	0.044	0.132–0.193
12	0.039	0.013	0.028–0.052	0.123	0.045	0.093–0.161
Coast Ranges						
1	0.187	0.032	0.168–0.209	0.447	0.105	0.416–0.479
2	0.191	0.024	0.176–0.207	0.453	0.078	0.430–0.476
3	0.19	0.02	0.177–0.203	0.451	0.064	0.432–0.470
4	0.184	0.019	0.172–0.197	0.442	0.061	0.423–0.460
5	0.174	0.019	0.161–0.187	0.425	0.062	0.405–0.445
6	0.16	0.018	0.148–0.173	0.4	0.059	0.380–0.421
7	0.143	0.016	0.132–0.155	0.369	0.053	0.349–0.390
8	0.124	0.014	0.114–0.135	0.333	0.046	0.313–0.353
9	0.105	0.012	0.096–0.115	0.291	0.04	0.272–0.312
10	0.086	0.011	0.077–0.095	0.247	0.038	0.227–0.269
11	0.068	0.011	0.059–0.078	0.203	0.038	0.181–0.228
12	0.052	0.011	0.043–0.062	0.161	0.038	0.136–0.189
HJ Andrews						
1	0.128	0.033	0.105–0.155	0.34	0.115	0.293–0.391
2	0.146	0.028	0.128–0.167	0.375	0.094	0.340–0.412
3	0.159	0.022	0.145–0.175	0.4	0.072	0.375–0.425
4	0.167	0.018	0.155–0.179	0.412	0.057	0.393–0.432
5	0.167	0.017	0.156–0.179	0.413	0.052	0.396–0.431
6	0.161	0.016	0.150–0.172	0.402	0.052	0.383–0.420
7	0.148	0.015	0.137–0.159	0.378	0.05	0.360–0.397
8	0.13	0.013	0.121–0.140	0.345	0.044	0.326–0.363
9	0.109	0.011	0.101–0.118	0.301	0.036	0.284–0.319
10	0.088	0.009	0.080–0.096	0.252	0.032	0.235–0.270
11	0.067	0.009	0.059–0.075	0.2	0.031	0.182–0.220
12	0.048	0.009	0.041–0.056	0.15	0.03	0.130–0.173
Tyee						
1	0.183	0.03	0.164–0.203	0.44	0.098	0.410–0.470
2	0.189	0.024	0.174–0.205	0.45	0.077	0.427–0.473
3	0.19	0.022	0.176–0.205	0.452	0.073	0.430–0.473
4	0.186	0.023	0.172–0.201	0.445	0.076	0.422–0.468
5	0.177	0.023	0.162–0.193	0.431	0.078	0.406–0.456
6	0.164	0.022	0.150–0.180	0.408	0.075	0.382–0.434

Table 3. Estimates with standard errors and 95-percent confidence limits of the probability of detecting a northern spotted owl (*Strix occidentalis caurina*) pair on a territory if it is present when one or more barred owls (BO) are present, and when no barred owls (*Strix varia*) are present for twelve 2-week periods surveyed each year from March 1 to August 31 for Cle Elum, Rainier, Olympic, Coast Ranges, HJ Andrews, Tyee, Klamath, South Cascades, Northwest California, Hoopa, and Green Diamond Resources study areas, in Washington, Oregon, and California, 1993–2018.—Continued

[Detection rates presented are from the best model, which does not include variation between years, only variation between surveys within years. The highest per-survey detection rates within a season are shown in **bold** type. **Abbreviations:** $\hat{p}_{.j}$, estimates; SE, standard errors; 95% CI, 95-pecent confidence limits; --, no data]

Survey	BO present			BO not present		
	$\hat{p}_{.j}$	SE	95%CI	$\hat{p}_{.j}$	SE	95%CI
			Tyee—Continued			
7	0.148	0.02	0.134–0.162	0.378	0.068	0.353–0.404
8	0.129	0.017	0.116–0.142	0.342	0.06	0.316–0.368
9	0.109	0.016	0.097–0.122	0.3	0.055	0.274–0.327
10	0.089	0.015	0.077–0.102	0.255	0.054	0.226–0.285
11	0.07	0.015	0.058–0.084	0.209	0.054	0.178–0.244
12	0.053	0.015	0.041–0.068	0.165	0.053	0.132–0.205
			Klamath			
1	0.136	0.027	0.118–0.157	0.356	0.088	0.321–0.393
2	0.161	0.024	0.145–0.178	0.402	0.074	0.377–0.428
3	0.18	0.022	0.167–0.195	0.436	0.062	0.417–0.455
4	0.193	0.021	0.179–0.207	0.456	0.06	0.438–0.474
5	0.196	0.023	0.182–0.211	0.462	0.066	0.443–0.481
6	0.191	0.023	0.177–0.206	0.453	0.07	0.433–0.474
7	0.177	0.022	0.163–0.192	0.43	0.066	0.410–0.452
8	0.157	0.019	0.144–0.170	0.394	0.058	0.374–0.416
9	0.131	0.016	0.120–0.143	0.346	0.05	0.326–0.368
10	0.104	0.014	0.093–0.115	0.289	0.045	0.267–0.312
11	0.078	0.013	0.068–0.089	0.228	0.043	0.204–0.254
12	0.054	0.012	0.045–0.065	0.168	0.04	0.143–0.197
			South Cascades			
1	--	--	--	--	--	--
2	0.154	0.04	0.128–0.184	0.389	0.137	0.341–0.440
3	0.175	0.033	0.154–0.198	0.427	0.111	0.391–0.463
4	0.189	0.027	0.173–0.208	0.451	0.086	0.425–0.476
5	0.196	0.024	0.181–0.212	0.461	0.075	0.440–0.482
6	0.194	0.023	0.179–0.209	0.458	0.074	0.436–0.479
7	0.183	0.023	0.169–0.198	0.44	0.072	0.418–0.462
8	0.165	0.02	0.152–0.179	0.409	0.065	0.387–0.432
9	0.141	0.017	0.130–0.154	0.366	0.054	0.345–0.388
10	0.115	0.013	0.105–0.126	0.313	0.044	0.293–0.334
11	0.088	0.012	0.079–0.098	0.253	0.04	0.232–0.276
12	0.064	0.011	0.055–0.074	0.193	0.038	0.170–0.218
			Northwest California			
1	--	--	--	--	--	--
2	--	--	--	--	--	--
3	0.196	0.044	0.170–0.225	0.461	0.147	0.419–0.503

Table 3. Estimates with standard errors and 95-percent confidence limits of the probability of detecting a northern spotted owl (*Strix occidentalis caurina*) pair on a territory if it is present when one or more barred owls (BO) are present, and when no barred owls (*Strix varia*) are present for twelve 2-week periods surveyed each year from March 1 to August 31 for Cle Elum, Rainier, Olympic, Coast Ranges, HJ Andrews, Tyee, Klamath, South Cascades, Northwest California, Hoopa, and Green Diamond Resources study areas, in Washington, Oregon, and California, 1993–2018.—Continued

[Detection rates presented are from the best model, which does not include variation between years, only variation between surveys within years. The highest per-survey detection rates within a season are shown in **bold** type. **Abbreviations:** $\hat{p}_{\cdot j}$, estimates; SE, standard errors; 95% CI, 95-pecent confidence limits; --, no data]

Survey	BO present			BO not present		
	$\hat{p}_{\cdot j}$	SE	95%CI	$\hat{p}_{\cdot j}$	SE	95%CI
			Northwest California—Continued			
4	0.187	0.03	0.168–0.207	0.446	0.098	0.417–0.476
5	0.176	0.025	0.160–0.193	0.428	0.082	0.402–0.455
6	0.164	0.024	0.148–0.181	0.407	0.081	0.380–0.435
7	0.15	0.023	0.135–0.167	0.383	0.078	0.355–0.413
8	0.136	0.02	0.122–0.152	0.357	0.07	0.329–0.386
9	0.122	0.018	0.109–0.136	0.328	0.063	0.300–0.356
10	0.107	0.018	0.094–0.122	0.297	0.063	0.268–0.328
11	0.093	0.021	0.078–0.111	0.266	0.072	0.229–0.306
12	0.08	0.025	0.062–0.103	0.234	0.087	0.188–0.287
			Hoopa			
1	0.178	0.074	0.134–0.232	0.432	0.255	0.354–0.514
2	0.162	0.047	0.133–0.197	0.405	0.161	0.350–0.462
3	0.148	0.03	0.128–0.171	0.379	0.101	0.342–0.418
4	0.135	0.021	0.121–0.152	0.355	0.07	0.327–0.384
5	0.124	0.018	0.111–0.139	0.332	0.06	0.307–0.359
6	0.114	0.017	0.102–0.128	0.311	0.057	0.285–0.339
7	0.105	0.016	0.093–0.118	0.292	0.054	0.266–0.320
8	0.097	0.014	0.086–0.109	0.274	0.049	0.250–0.301
9	0.09	0.013	0.080–0.101	0.258	0.044	0.235–0.283
10	0.084	0.013	0.074–0.095	0.243	0.043	0.220–0.268
11	0.078	0.014	0.067–0.091	0.23	0.05	0.202–0.260
12	0.073	0.018	0.059–0.091	0.218	0.064	0.181–0.259
			Green Diamond Resources			
1	0.212	0.038	0.190–0.237	0.486	0.121	0.455–0.518
2	0.193	0.026	0.177–0.211	0.457	0.078	0.435–0.480
3	0.176	0.02	0.163–0.190	0.428	0.056	0.411–0.446
4	0.16	0.017	0.149–0.172	0.401	0.048	0.384–0.418
5	0.146	0.016	0.135–0.158	0.375	0.046	0.357–0.392
6	0.133	0.015	0.122–0.144	0.349	0.044	0.331–0.368
7	0.121	0.013	0.111–0.131	0.325	0.04	0.308–0.344
8	0.11	0.012	0.101–0.120	0.303	0.036	0.286–0.320
9	0.101	0.011	0.092–0.110	0.282	0.032	0.266–0.298
10	0.092	0.011	0.084–0.101	0.262	0.032	0.245–0.280
11	0.084	0.012	0.075–0.094	0.244	0.037	0.223–0.265
12	0.077	0.014	0.066–0.089	0.226	0.045	0.201–0.254

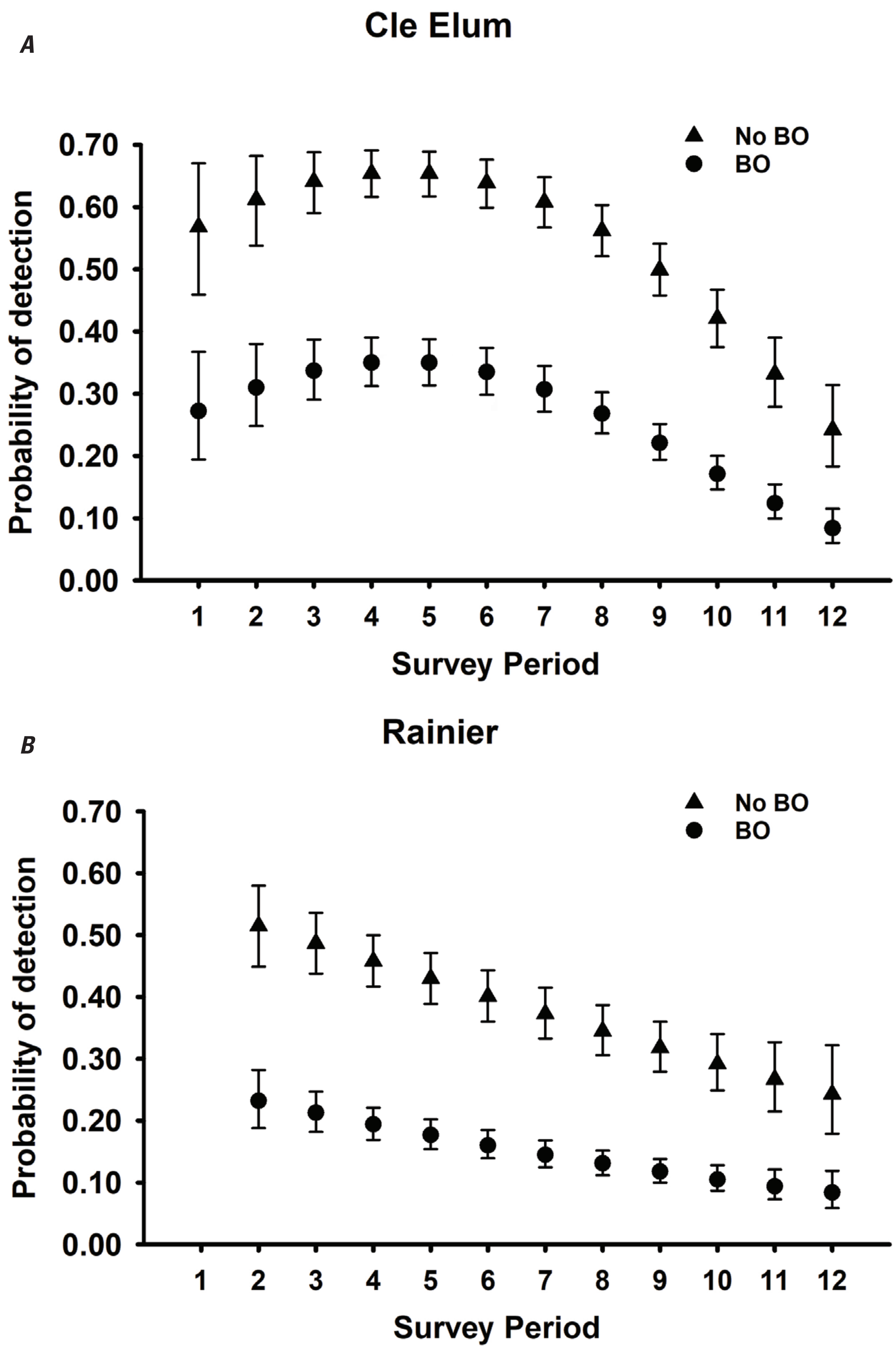
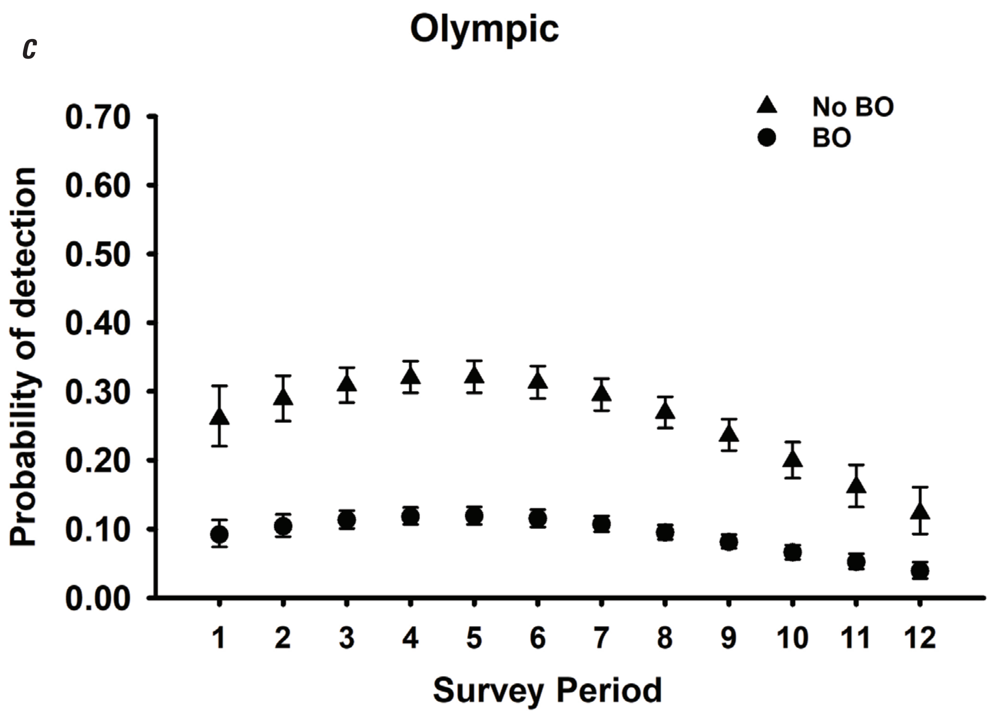


Figure 2. Estimates of detection probabilities with 95-percent confidence limits for northern spotted owl (*Strix occidentalis caurina*) pairs when barred owls (*Strix varia*; BO) are detected and when they are not across all twelve 2-week survey periods (March 1–August 31) conducted within seasons for Cle Elum (*A*), Rainier (*B*), Olympic (*C*), Coast Ranges (*D*), HJ Andrews (*E*), Tyee (*F*), Klamath (*G*), South Cascades (*H*), Northwest California (*I*), Hoopa (*J*), and Green Diamond Resources (*K*) study areas, Washington, Oregon, and California, 1993–2018. Surveys during period 1 in Rainier and South Cascades, and periods 1 and 2 in Northwest California were not conducted in any year, so estimates were excluded for those periods.



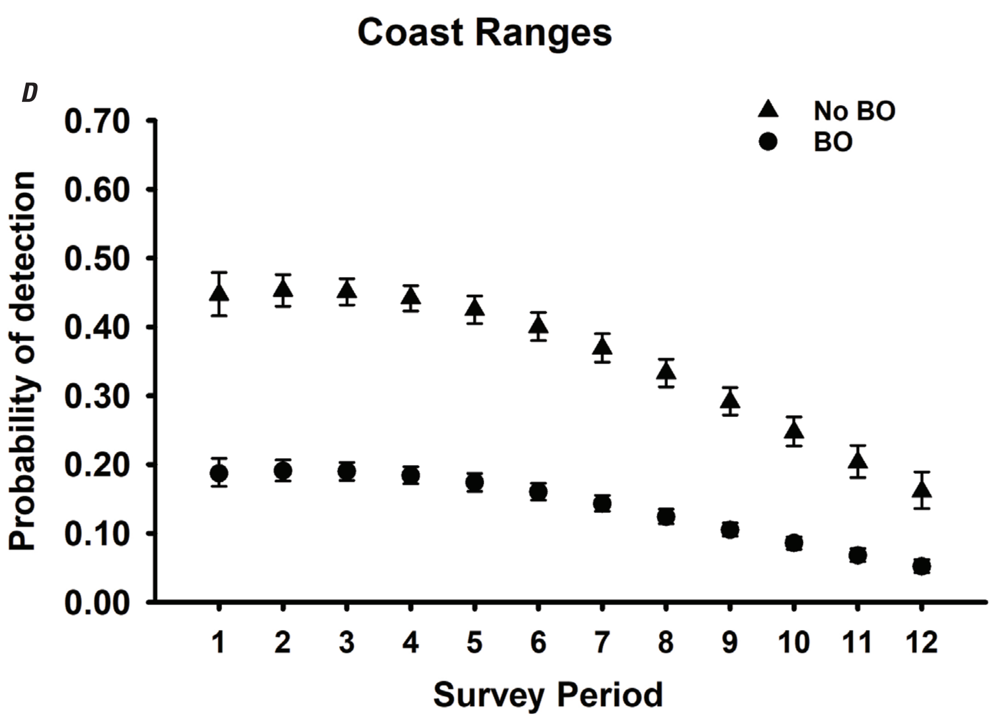


Figure 2.—Continued

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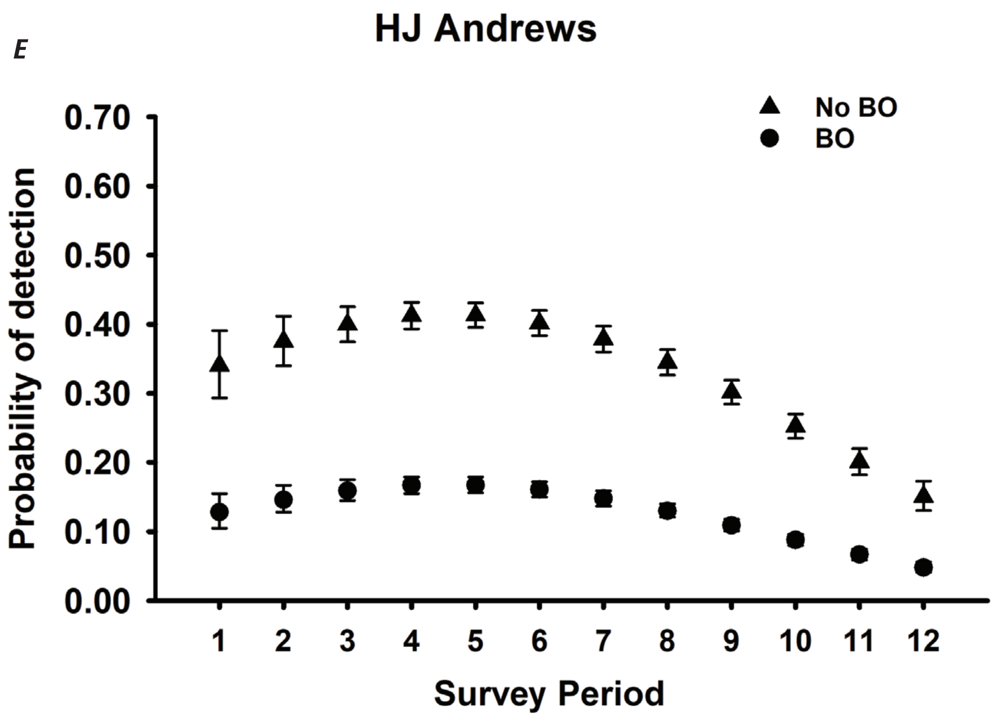

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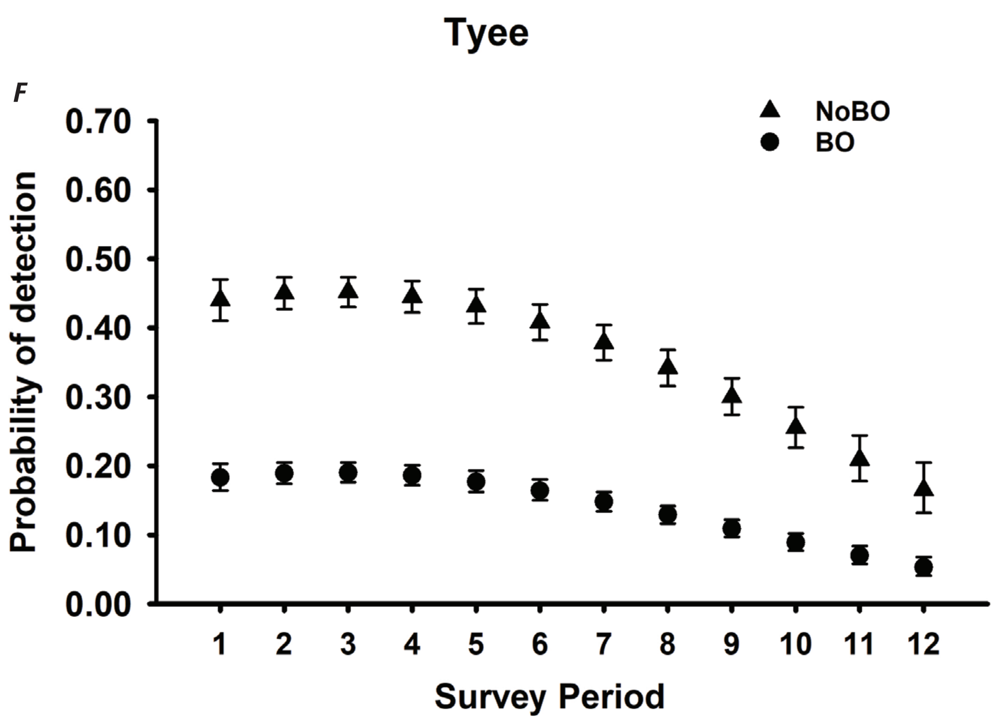

Figure 2.—Continued

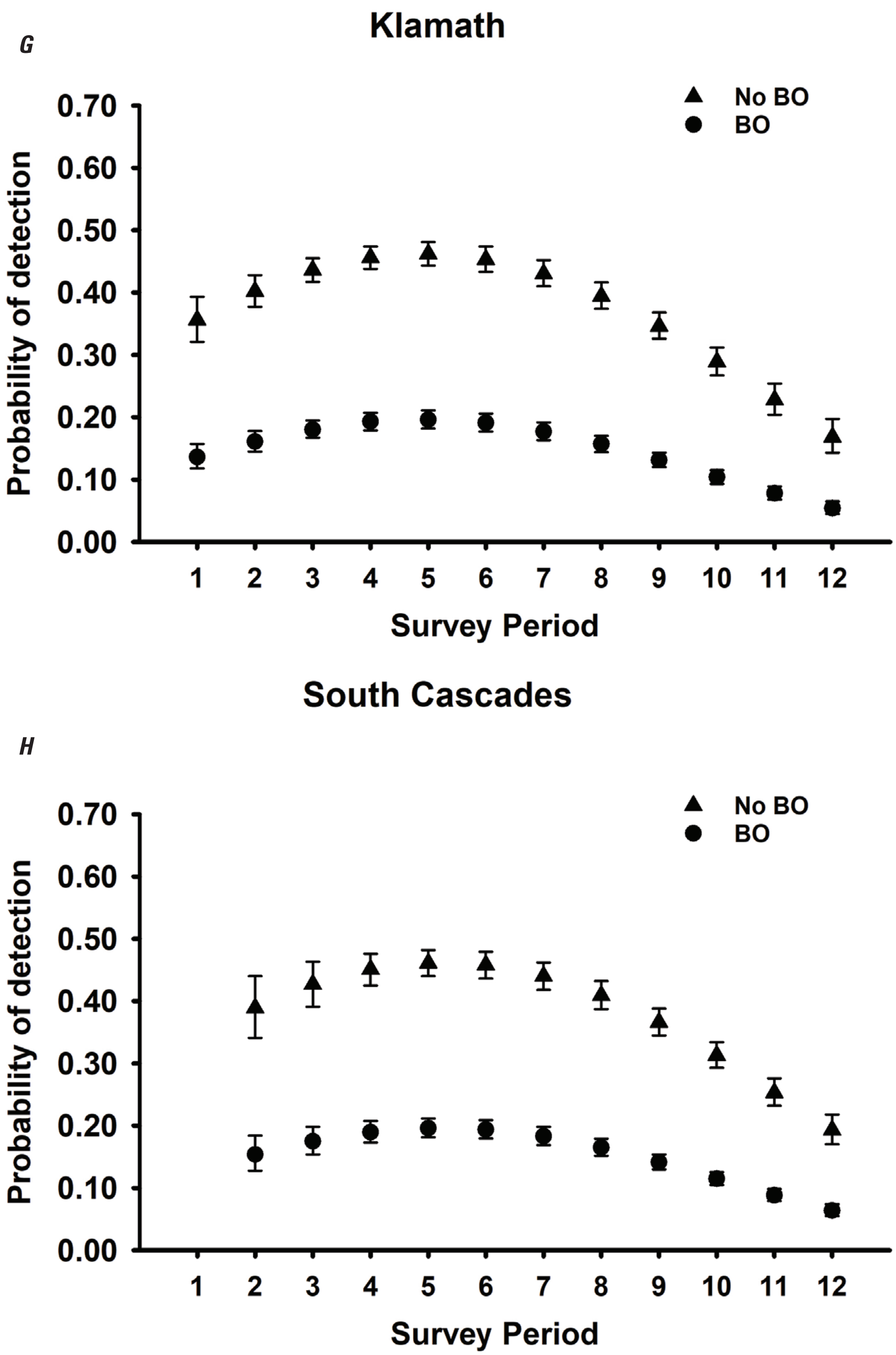

Figure 2.—Continued

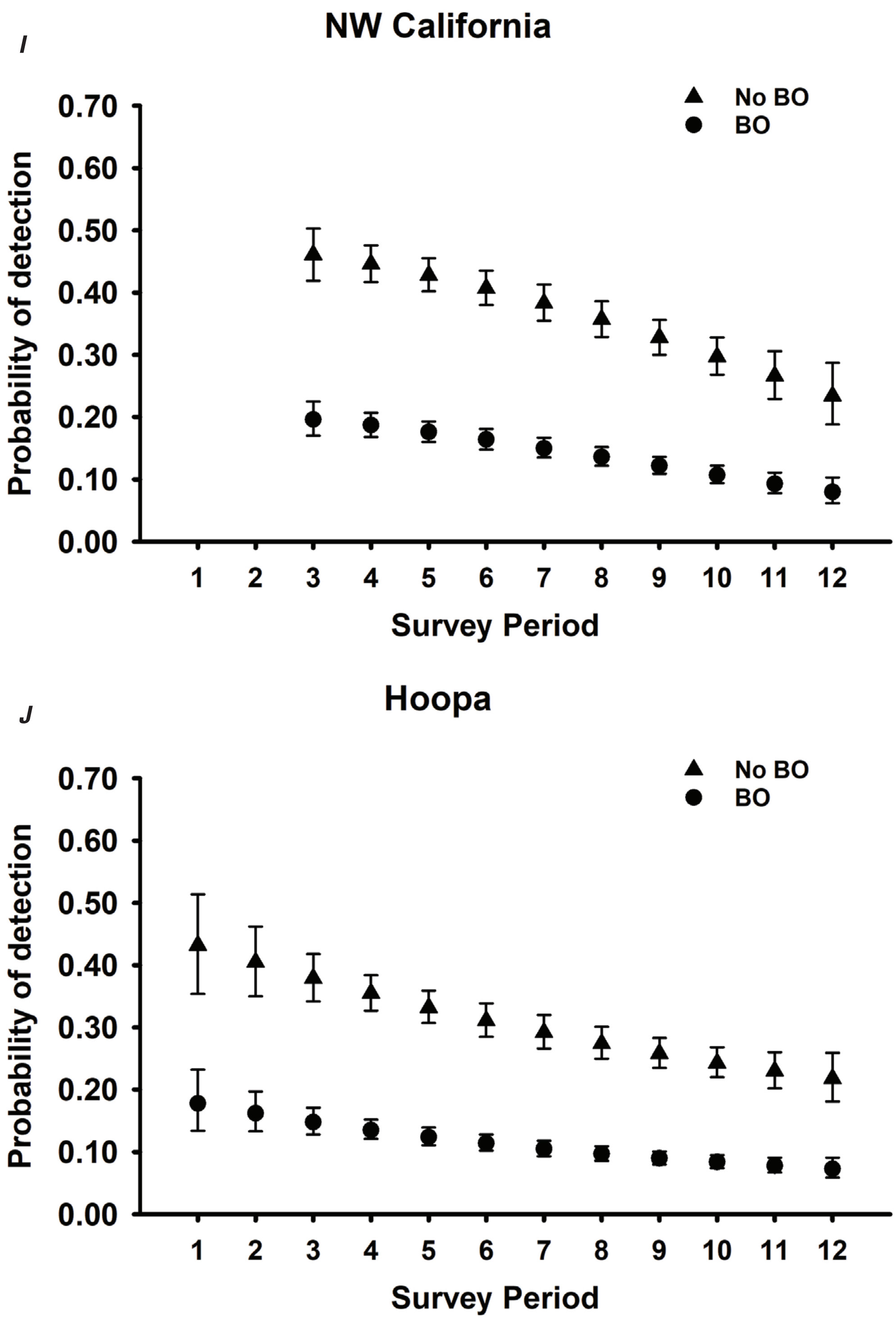

Figure 2.—Continued

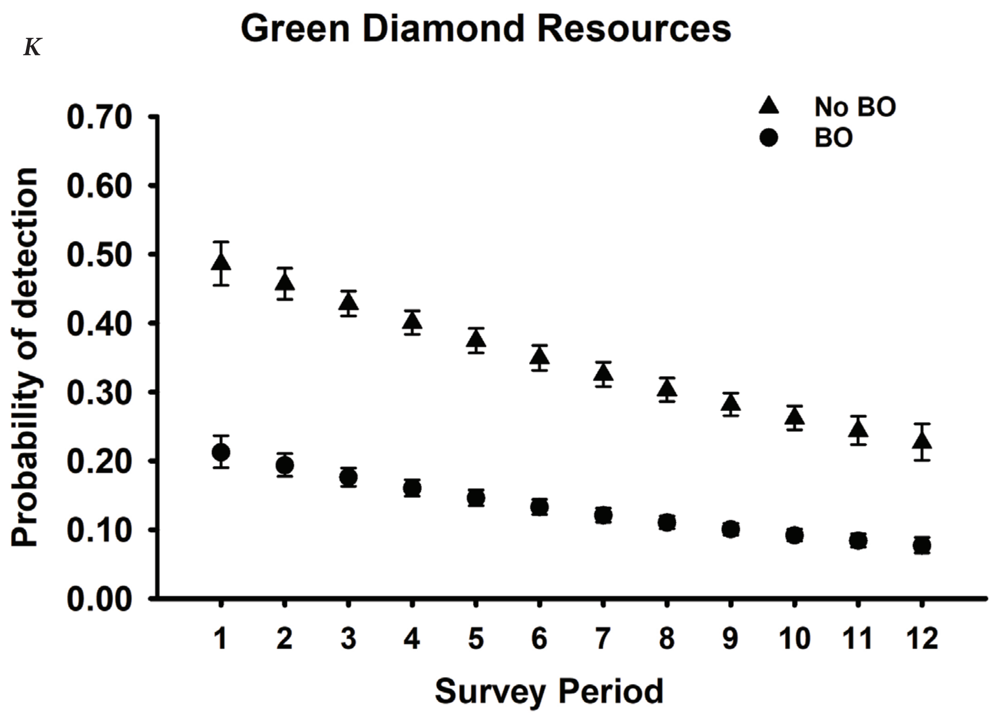

Figure 2.—Continued

Table 4. Cumulative seasonal detection (p^*) or the probability of detecting a northern spotted owl (*Strix occidentalis caurina*) pair one or more times when six surveys are conducted each year on each study area (see table 1) when one or more barred owls (*Strix varia*) are also present.

[Estimates of p^* were based on the (1) single highest, (2) single lowest, (3) six highest, and (4) $\hat{p}_{\cdot j}$ estimates from survey periods 2, 4, 6, 8, 10, and 12 obtained from the best model, which does not include variation between years, but only variation between surveys within years.]

Study area	p^*			
	Highest	Lowest	6 highest	2,4,6,8,10,[1]12
Washington				
Cle Elum	0.925	0.409	0.911	0.834
Rainier	0.795	0.409	0.712	0.630
Olympic	0.532	0.212	0.512	0.432
Oregon				
Coast Ranges	0.719	0.273	0.698	0.579
HJ Andrews	0.666	0.256	0.644	0.549
Tyee	0.718	0.279	0.699	0.585
Klamath	0.730	0.283	0.703	0.608
South Cascades	0.730	0.327	0.704	0.617
California				
Northwest California	0.730	0.394	0.608	0.612
Hoopa	0.692	0.365	0.607	0.508
Green Diamond Resources	0.761	0.382	0.674	0.562

[1]Surveys 3,4,6,8,10,12 used for Northwest California because surveys are not conducted during periods 1 and 2.

Table 5. Cumulative seasonal detection (p^*) or the probability of detecting a northern spotted owl (*Strix occidentalis caurina*) pair one or more times when six surveys are conducted each year for each study area (see table 1) when no barred owls (*Strix varia*) are present. for each study area (see table 1).

[Estimates of p^* were based on the (1) single highest, (2) single lowest, (3) 6 highest, and (4) $\hat{p}_{.j}$ estimates from survey periods 2, 4, 6, 8, 10, and 12 obtained from the best model, which does not include variation between years, but only variation between surveys, within years.]

Study area	p^*			
	Highest	Lowest	6 highest	2,4,6,8,10,[1]12
Washington				
Cle Elum	0.998	0.810	0.998	0.991
Rainier	0.987	0.812	0.971	0.945
Olympic	0.902	0.545	0.890	0.830
Oregon				
Coast Ranges	0.973	0.651	0.968	0.923
HJ Andrews	0.959	0.623	0.952	0.909
Tyee	0.973	0.661	0.968	0.926
Klamath	0.976	0.668	0.969	0.936
South Cascades	0.975	0.724	0.970	0.940
California				
Northwest California	0.975	0.798	0.960	0.940
Hoopa	0.966	0.771	0.938	0.886
Green Diamond Resources	0.982	0.785	0.961	0.916

[1]Surveys 3,4,6,8,10,12 used for Northwest California because surveys are not conducted during periods 1 and 2.

Table 6. Estimates of the probability that a northern spotted owl pair (*Strix occidentalis*; NSO) is present, but not detected during a season when six surveys are conducted (in other words, closed conditional occupancy; $\hat{\Psi}_{condl}$), based on Bayes' Theorem following MacKenzie and others (2018) on 11 study areas in Washington, Oregon, and California.

[Closed conditional occupancy was calculated using estimates of the probability of occupancy for NSO pairs during 2018 ($\hat{\psi}_{2018}$) and cumulative seasonal estimates of the probability of detection (p^*) based on the a) single highest and b) and survey-specific detection rates ($\hat{p}_{\cdot j}$) for surveys 2, 4, 6, 8, 10, 12 on each study area when barred owls (*Strix varia*; BO) were present (see table 1) and when BOs were not present (table 2) from 2-species. occupancy models detailed in Franklin and others (2021).]

Study area	$\hat{\Psi}_{condl}$ BO present			$\hat{\Psi}_{condl}$ BO not present		
	$\hat{\Psi}_{2018}$	p^*		$\hat{\Psi}_{2018}$	p^*	
		Highest	2,4,6,8,10,[1]12		Highest	2,4,6,8,10,[1]12
Washington						
Cle Elum	0.036	0.003	0.006	0.095	0.000	0.001
Rainier	0.091	0.020	0.036	0.205	0.003	0.014
Olympic	0.110	0.055	0.066	0.167	0.019	0.033
Oregon						
Coast Ranges	0.145	0.045	0.067	0.283	0.010	0.030
HJ Andrews	0.241	0.096	0.125	0.362	0.023	0.049
Tyee	0.167	0.054	0.077	0.243	0.009	0.023
Klamath	0.175	0.054	0.077	0.275	0.009	0.024
South Cascades	0.167	0.051	0.071	0.326	0.012	0.028
California						
Northwest California	0.348	0.126	0.171	0.422	0.018	0.043
Hoopa	0.537	0.264	0.363	0.652	0.059	0.175
Green Diamond Resources	0.323	0.103	0.173	0.391	0.012	0.051

[1]Surveys 3,4,6,8,10,12 used for Northwest California because surveys were not conducted during periods 1 and 2.

Discussion

For various ecological and analytical reasons, recent occupancy analyses for NSOs have focused on detections of NSO pairs (Dugger and others, 2011, 2016; Yackulic and others, 2012; 2014; Franklin and others, 2021) rather than detection of any owl, single or pair. From the perspective of understanding population status and trends, territorial occupancy of NSO pairs is the relevant ecological metric. We observed variation in the survey-specific probability of detecting a pair over the course of the breeding season with five study areas having the highest per-survey detection rates in May, consistent with earlier findings by Yackulic and others (2014) on TYE. However, we observed the highest per-survey detection rates earlier in the season (March or April) for all California study areas, and on RAI in Washington, and COA and TYE in Oregon, suggesting that the timing of the most efficient survey effort might be different depending on the study area.

Our estimates of the probability of detection of NSO pairs based on 2-week time periods during the season (per-survey estimates) were 29–59 percent lower than previous estimates for any owl (single or pair) on the same study areas (OLY, CLE, COA, HJA, TYE, CAS; Dugger and others, 2009; table 7). However, our findings were similar to mean per-visit detection rates of owl pairs in Oregon and California across territories with and without BOs (Olson and others, 2005, Kroll and others, 2010). Estimates of the probability of detection of NSO pairs from these earlier studies varied by season but were often less than (<) 0.40 (0.22–0.67; fig. 3 in Olson and others, 2005; 0.27–0.67; fig. 3 in Kroll and others, 2010). On the CAS study area, previous estimates of per-visit detection rates for NSO pairs when BOs were present were often <0.20, as compared to rates >0.50 when BOs were absent (Dugger and others, 2011), consistent with current findings for CAS at least when BOs were present in territories (table 3). Thus, detection rates of pairs in response to BO presence may not have changed substantially in the last 10 years, at least in some areas.

Estimates of detection rates for NSO pairs across 2-week survey periods are not necessarily equivalent to per-visit detection rates reported in previous studies as per-visit detections reflected a single complete territory survey (for example, Olson and others, 2005; Dugger and others, 2011), whereas the 2-week time periods used in our analysis could include the results of less than one complete territory survey. Additionally, detection rates for pairs can be substantially lower than estimates for any owl (both singles and pairs; Olson and others, 2005; Kroll and others, 2010). As a result, cumulative seasonal detection rates for NSO pairs (p^*) from this study when BOs were present were less than 0.95 on all

Table 7. Estimates, standard errors, and 95-percent confidence limits of the highest survey-specific probability of detection for northern spotted owl (*Strix occidentalis caurina*) pairs when barred owls (*Strix varia*) are present for each study area (mean across all years 1993–2018; table 1) in comparison to mean, within season visit-specific estimates for singles and pairs from previous analyses (see table 1; Dugger and others, 2009).

[**Abbreviations:** $\hat{p}_{.j}$, estimates (first number on left side of column), standard errors (first number inside parentheses), and 95-percent confidence limits (number range within parentheses) of the highest survey-specific probability of detection for northern spotted owl pairs; N/A, study areas not included in Dugger and others (2009).]

Study Area	This study	Dugger and others (2009)
	$\hat{p}_{.j}$	$\hat{p}_{.j}$
Washington		
Cle Elum	0.35 (0.09; 0.31–0.39)	0.49 (0.04; 0.42–0.57)
Rainier	0.23 (0.08; 0.19–0.28)	N/A
Olympic	0.12 (0.02; 0.11–0.13)	0.36 (0.02; 0.33–0.40)
Oregon		
Coast Ranges	0.19 (0.02; 0.18–0.21)	0.46 (0.02; 0.42–0.50)
HJ Andrews	0.17 (0.02; 0.16–0.18)	0.40 (0.04; 0.33–0.48)
Tyee	0.19 (0.02; 0.18–0.21)	0.37 (0.04; 0.30–0.45)
Klamath	0.20 (0.05; 0.18–0.21)	N/A
South Cascades	0.20 (0.02; 0.18–0.21)	0.29 (0.02; 0.42–0.50)
California		
Northwest California	0.20 (0.04; 0.17–0.23)	N/A
Hoopa	0.18 (0.07; 0.13–0.23)	N/A
Green Diamond Resources	0.21 (0.04; 0.19–0.24)	N/A

study areas except CLE under a six-survey protocol (table 8). Increasing the number of surveys within a season could increase the probability of detecting an NSO pair at least once during the season, but the number of surveys required to meet a target of p^*>0.95 or even >0.90 would range from 8 to >12 depending on the study area (table 8). Additionally, the extra calling by field crews could also create more negative consequences for breeding NSO because of the increased territory that defense callbacks elicit, or the potential for increased interactions with resident BO that might occur when NSO respond to callbacks. Alternatively, conducting most surveys earlier in the season, when the probability of detecting pairs is highest (through May on most areas) could improve seasonal detection rates. When BO are not present on a territory, a six-survey protocol had a high probability of detecting an NSO pair at least once during the season on all study areas, except for the very lowest $p_{.j}$ estimates (table 8).

In contrast to detection rates, occupancy dynamics have changed substantially since the mid-to late-2000s. Colonization rates have declined and local extinction rates have increased for NSO populations in all study areas coincident with the increasing presence of BO in the landscape (Franklin and others, 2021). These changes in occupancy dynamics have resulted in strong declines in territory occupancy (fig. 9 in Franklin and others, 2021) and increased rates of movement between territories (in other words, breeding dispersal) by NSOs (Jenkins and others, 2021). This result is consistent with overall declines in rates of population change, suggesting that NSO populations continue to decline range-wide (Franklin and others, 2021). Smaller NSO populations and declines in the probability of pair territory occupancy can impact the cumulative seasonal probability of detecting NSO pairs during surveys. Although a six-survey protocol has a high probability of detecting an NSO pair at least once during the season if BO are not present on the territory, by 2018, BO occupancy on NSO territories ranged from 0.49 to 0.97 (fig. 9 in Franklin and others, 2021). Thus, very few NSO territories included in this analysis were not impacted by BO. Consequently, NSO pair occupancy rates observed in 2018 by Franklin and others (2021) were low in many study areas (<0.25 on seven areas). For these study areas, the probability of never detecting NSO pairs within a season, given that they were present (in other words, closed conditional occupancy) when six surveys were conducted, was generally <0.10 for the highest per-survey detection rates observed when BOs were present. Thus, when occupancy rates are very low, the probability of missing an NSO pair if it was present using a six-survey protocol was low, even though per-survey detection rates were also very low. When BOs were not present, $p_{.j}$ estimates on all study areas were generally high enough that there was a low probability of incorrectly assigning pair occupancy status to a territory under a six-survey protocol (in other words, closed conditional occupancy was <0.10 on most study areas; table 6).

Alternative methods of population monitoring—such as the use of passive acoustic monitoring where as little as 3 weeks of recording can document the presence/absence of NSO (singles or pairs) with 95-percent certainty (Wood and others, 2019; Duchac and others, 2020)—may be needed to continue monitoring NSO for research and management (Lesmeister and others, 2021). However, these estimates of the probability of detection are not directly comparable to our estimates of the probability of detecting NSO pairs. These studies have used random grid sampling that estimated the probability of use rather than occupancy of historical territories and estimated detection of any NSO (singles and pairs; Wood and others, 2019; Duchac and others, 2020). Advances in processing and interpretation of acoustic data are ongoing and distinguishing between the sexes (Dale and others, 2022), territory residence, and breeding status (in other words, transients, resident singles, and pairs) may be possible using calling frequency and timing. However, the delineation of NSO activity centers would likely require additional survey effort (walk-ins in addition to the use of passive acoustic monitoring) to provide the information currently used to protect NSO in forest stands proposed for harvest (Duchac and others, 2020). Alternatively, the trigger for stand protection could shift from identifying an occupied NSO activity center to identifying any stand with some specified level of "use" by NSO (Lesmeister and others, 2021).

Changes in NSO pair occupancy rates across the species range (for example, Franklin and others, 2021), and BO effects on NSO behavior including decreased detection rates, and longer, and more likely movement of breeding birds (Jenkins and others, 2019, 2021) has increased the difficulties of monitoring NSO. However, it is critical to NSO conservation and management to understand where on the landscape productive NSO pairs exist, particularly when proposed management activities may negatively impact those pairs. BO control strategies can be successful at halting or reversing declines in NSO populations (Diller and others, 2016; Wiens and others, 2021); however, these activities can only be successful if suitable habitat is available for NSO to recolonize after BO are controlled.

Table 8. Probability of detecting a northern spotted owl (*Strix occidentalis caurina*) pair on a territory at least one time during the season given it is present (p^*), relative to the total number of surveys conducted each season (range 3–12), when one or more barred owl (*Strix varia*) was present, and when barred owls were not present for Cle Elum, Rainier, Olympic, Coast Ranges, HJ Andrews, Tyee, Klamath, South Cascades, Northwest California, Hoopa, and Green Diamond Resources study areas, Washington, Oregon, and California.

[The single highest survey-specific detection rate ($p_{\cdot j}$) observed across all years for each study area (see table 3) was used to calculate p^*. **Abbreviation:** BO, barred owl.]

Total number of surveys	BO present	BO not present
Cle Elum		
3	0.725	0.959
4	0.821	0.986
5	0.884	0.995
6	0.925	0.998
7	0.951	0.999
8	0.968	1
9	0.979	1
10	0.987	1
11	0.991	1
12	0.994	1
Rainier		
3	0.547	0.886
4	0.652	0.945
5	0.733	0.973
6	0.795	0.987
7	0.842	0.994
8	0.879	0.997
9	0.907	0.999
10	0.929	0.999
11	0.945	1
12	0.958	1
Olympic		
3	0.316	0.687
4	0.398	0.787
5	0.469	0.856
6	0.532	0.902
7	0.588	0.933
8	0.637	0.955
9	0.68	0.969
10	0.718	0.979
11	0.752	0.986
12	0.781	0.99

Total number of surveys	BO present	BO not present
Coast Range		
3	0.471	0.836
4	0.572	0.91
5	0.653	0.951
6	0.72	0.973
7	0.773	0.985
8	0.817	0.992
9	0.852	0.996
10	0.88	0.998
11	0.903	0.999
12	0.921	0.999
HJ Andrews		
3	0.422	0.798
4	0.519	0.881
5	0.599	0.93
6	0.666	0.959
7	0.722	0.976
8	0.768	0.986
9	0.807	0.992
10	0.839	0.995
11	0.866	0.997
12	0.888	0.998
Tyee		
3	0.469	0.835
4	0.57	0.91
5	0.651	0.951
6	0.718	0.973
7	0.771	0.985
8	0.815	0.992
9	0.85	0.996
10	0.878	0.998
11	0.902	0.999
12	0.92	0.999

Table 8. Probability of detecting a northern spotted owl (*Strix occidentalis caurina*) pair on a territory at least one time during the season given it is present (p^*), relative to the total number of surveys conducted each season (range 3–12), when one or more barred owl (*Strix varia*) was present, and when barred owls were not present for Cle Elum, Rainier, Olympic, Coast Ranges, HJ Andrews, Tyee, Klamath, South Cascades, Northwest California, Hoopa, and Green Diamond Resources study areas, Washington, Oregon, and California.—Continued

[The single highest survey-specific detection rate ($p_{.j}$) observed across all years for each study area (see table 3) was used to calculate p^*. **Abbreviation:** BO, barred owl.]

Total number of surveys	BO present	BO not present
	Klamath	
3	0.48	0.844
4	0.582	0.916
5	0.664	0.955
6	0.73	0.976
7	0.783	0.987
8	0.825	0.993
9	0.86	0.996
10	0.887	0.998
11	0.909	0.999
12	0.927	0.999
	South Cascades	
3	0.48	0.843
4	0.582	0.916
5	0.664	0.955
6	0.73	0.975
7	0.783	0.987
8	0.825	0.993
9	0.86	0.996
10	0.887	0.998
11	0.909	0.999
12	0.927	0.999
	Northwest California	
3	0.48	0.843
4	0.582	0.916
5	0.664	0.955
6	0.73	0.975
7	0.783	0.987
8	0.825	0.993
9	0.86	0.996
10	0.887	0.998
11	0.909	0.999
12	0.927	0.999

Total number of surveys	BO present	BO not present
	Hoopa	
3	0.445	0.817
4	0.543	0.896
5	0.625	0.941
6	0.692	0.966
7	0.746	0.981
8	0.792	0.989
9	0.829	0.994
10	0.859	0.997
11	0.884	0.998
12	0.905	0.999
	Green Diamond Resources	
3	0.511	0.864
4	0.614	0.93
5	0.696	0.964
6	0.761	0.982
7	0.811	0.991
8	0.851	0.995
9	0.883	0.997
10	0.908	0.999
11	0.927	0.999
12	0.943	1

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