

# Effects of Barred Owl (*Strix varia*) Removal on Population Demography of Northern Spotted Owls (*Strix occidentalis caurina*) in Washington and Oregon, 2015–18

Open-File Report 2019-1074

U.S. Department of the Interior  
U.S. Geological Survey

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By J. David Wiens, Katie M. Dugger, Damon B. Lesmeister, Krista E. Dilione, and David C. Simon

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# Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
Length		
meter (m)	3.281	foot (ft)
Area		
hectare (ha)	2.471	acre
square kilometer (km <sup>2</sup> )	0.3861	square mile (mi <sup>2</sup> )

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# Effects of Barred Owl (*Strix varia*) Removal on Population Demography of Northern Spotted Owls (*Strix occidentalis caurina*) in Washington and Oregon, 2015–18

By J. David Wiens<sup>1</sup>, Katie M. Dugger<sup>2</sup>, Damon B. Lesmeister<sup>3</sup>, Krista E. Dilione<sup>1</sup>, and David C. Simon<sup>1</sup>

## Abstract

Populations of Northern Spotted Owls (*Strix occidentalis caurina*; hereinafter referred to as Spotted Owl) have declined throughout the subspecies' geographic range. Evidence indicates that competition with invading Barred Owls (*S. varia*) has contributed significantly to those declines. A pilot study in California showed that removal of Barred Owls coupled with conservation of suitable habitat conditions can slow or even reverse population declines of Spotted Owls. It is unknown, however, whether similar results can be obtained in areas with different forest conditions, greater densities of Barred Owls, and fewer remaining Spotted Owls. We initiated a before-after-control-impact (BACI) experiment at three study areas in Oregon and Washington to determine if removal of Barred Owls can improve population trends of Spotted Owls. This report describes research accomplishments and initial results from the first 3.5 years of the study (March 2015–August 2018).

## Background and Study Objectives

Over the past century, Barred Owls (*Strix varia*) have expanded their geographic range west from eastern North America, and their newly expanded range now completely overlaps that of the federally threatened Northern Spotted Owl (*S. occidentalis caurina*). Evidence indicates that competition with invading Barred Owls has contributed significantly to declines in populations of Spotted Owls (Wiens and others, 2014; Dugger and others, 2016; Yackulic and others, 2019). A pilot study in coastal California demonstrated that removal of Barred Owls in combination with conservation of suitable forest conditions can slow or even reverse the rate of population decline in Spotted Owls (Diller and others, 2014, 2016). It remains unknown, however, whether similar results can be obtained in areas with different forest types, greater densities of Barred Owls, and fewer remaining Spotted Owls.

In 2015 we initiated a comprehensive before-after-control-impact (BACI) experiment to determine the demographic response of Spotted Owls to localized removals of Barred Owls (Wiens and others, 2018). The removal study was based in three long-term demographic study areas for Spotted Owls in Washington and Oregon. The overall goal of this study is to provide a definitive test of whether competitive interactions with Barred Owls cause population declines of Spotted Owls, and if so,

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whether removal of Barred Owls is an effective tool to consider in long-term management of Spotted Owls (Johnson and others, 2008; U.S. Fish and Wildlife Service, 2013). Specific objectives are to:

1. Determine the effect of removal of Barred Owls on site-occupancy dynamics, reproduction, survival, recruitment, and annual rate of population change ( $\lambda_t$ ) of Spotted Owls;
2. Estimate BACI changes in the occurrence and distribution of Barred Owls to assess the effectiveness of removals in reducing populations of Barred Owls; and
3. Characterize the amount of effort and cost required to maintain low numbers of Barred Owls and achieve positive effects on vital rates of Spotted Owls.

In this report, we provide a summary of preliminary results from the first 3.5 years (March 2015–August 2018) of implementing removal experiments in Oregon and Washington. We focus here on the initial effects of Barred Owl removal on territory occupancy and reproduction of Spotted Owls (Objective #1) and occurrence and distribution of Barred Owls (Objective #2). This information is preliminary, pending final analyses and completion of the study. A demographic analysis of the effects of removals on survival, recruitment, and rate of population change of Spotted Owls is scheduled for January 2020.

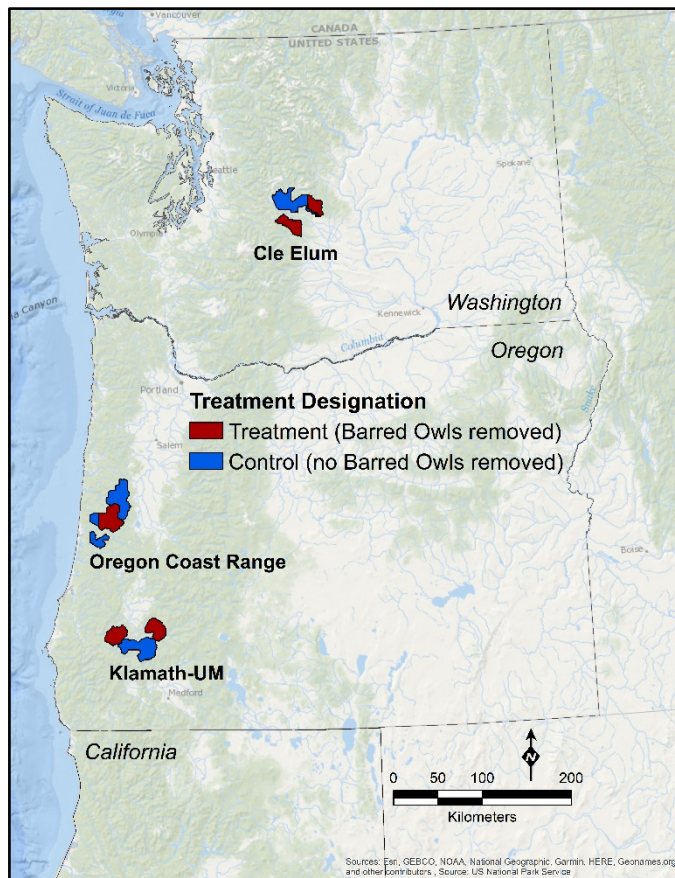
## Study Areas

We conducted the experiment in three study areas where long-term (1990–2018) investigations of Spotted Owl demography have been conducted in Washington and Oregon: Cle Elum, Oregon Coast Range, and Klamath-Union/Myrtle (referred to as Klamath-UM; table 1; fig. 1). Each study area was divided into two or more similar areas where Barred Owls were either removed (treatment areas) or not removed (control areas). The study areas are composed of mostly federal lands, but fieldwork also occurred on adjacent state and private lands with the written permission of the landowner.

**Table 1.** Study areas, treatment levels, and numbers of sites surveyed for Northern Spotted and Barred Owls in Washington and Oregon, 2015–18.

[**Number of Spotted Owl territories:** Historically occupied territories surveyed for Northern Spotted Owls annually during 1990–2018. **Number of Barred Owl sites:** Hexagonal plots used to survey Barred Owls annually in control and treatment areas. km<sup>2</sup>, square kilometer]

Study area and treatment level	Total Area (km <sup>2</sup> )	Number of Spotted Owl territories	Number of Barred Owl sites (5 km <sup>2</sup> hexagons)
Cle Elum			
Control	670	31	109
Treatment	604	45	112
Coast Range			
Control	1,015	58	178
Treatment	582	45	103
Klamath-UM			
Control	698	78	120
Treatment	783	84	144



**Figure 1.** Control (Barred Owls not removed) and treatment (Barred Owls removed) portions of three study areas in Washington and Oregon used to determine the effects of experimental removal of Barred Owls on population demography of Northern Spotted Owls, 2015–18.

## Methods

### Population Monitoring

We used species-specific surveys to track post-treatment changes in populations of Spotted Owls and Barred Owls on control and treatment portions of each study area (Wiens and others, 2018). We conducted annual surveys and mark-recapture studies of Spotted Owls at historically occupied territories as part of a long-term demographic monitoring program (Franklin and others, 1996, Lint and others, 1999; Dugger and others, 2016). Recent summaries of Spotted Owl population trends, breeding and mate status of detected owls, number of owls banded, inter-territory movements and general age distribution are reported elsewhere (Lesmeister and others, 2018a–c).

We used a standard site-occupancy design described by Wiens and others (2011) to survey Barred Owls. Mean home range size for Barred Owls in the Pacific Northwest ranges from 4–7 square kilometers ( $\text{km}^2$ ) (Wiens and others, 2014). Using home range size as a guide we overlaid a grid of 5- $\text{km}^2$  hexagons on each study area. We considered each hexagon grid cell a “site” and surveyed each site repeatedly over three sampling periods: March 1–May 7; May 8–July 9; and July 10–September 10. Sampling periods reflected approximate transition dates between incubation, nestling, and fledgling-dependency breeding stages of Barred Owls (Wiens and others, 2011; 2014). During each survey, observers used an amplified megaphone (FoxPro, Lewiston, Pennsylvania; Wildlife Technologies,

Manchester, New Hampshire) to broadcast digitally recorded calls of Barred Owls at call points established in each site. Observers recorded the number and sex of Barred Owls detected during each survey. A site was considered used by at least one territorial pair of Barred Owls if (1) both sexes were observed within 400 meters (m) of each other on a single visit or (2) at least one adult was observed with young.

## **Barred Owl Removals**

We used well-established field protocols for the removal and scientific collection of Barred Owls (Diller and others, 2014, 2016; U.S. Fish and Wildlife Service, 2013). Barred Owls detected in treatment areas during surveys were subsequently removed using 12-gauge shotguns loaded with non-toxic shot. We observed frequent recolonization by Barred Owls (Wiens et al. 2018), so we did regular follow-up visits to detect colonizing Barred Owls and conduct additional removals as needed. We identified sex of Barred Owls based on vocalizations and morphometric measurements (Wiens and others, 2014). We classified Barred Owls as either adults ( $\geq 3$  years old) or subadults (owls in their first or second year) based on molt and plumage characteristics observed under ultraviolet light (Weidensaul and others, 2011), and by identifying juvenile flight feathers. Once collected, Barred Owls were stored locally until distributed as scientific specimens to permitted museums and universities for future research (appendix 1).

Our protocol for removals prohibited collection of nesting Barred Owls with dependent young. As specified by U.S. Fish and Wildlife Service (2013), however, removal of non-nesting Barred Owls may be permitted during the nesting season (between April 15 and August 15 in our study areas) in cases where observers have high confidence in determining nesting status. In 2017, we continued removals during the nesting period at locations where we documented rapid (within 2–3 weeks) recolonization by Barred Owls after removal visits conducted prior to nesting. We reasoned that Barred Owl colonists arriving at sites after the estimated mean hatching date (~15 April; Wiens et al. 2014) would not have the opportunity to nest between our successive visits. Year-round removal efforts were primarily focused in areas where Spotted Owls were detected in the previous or current year. We did not conduct removals in Cle Elum during the nesting season during 2016–18 because snow limited our ability to access many areas until after April 15. Removal of Barred Owls were conducted by personnel certified to use firearms by the U.S. Geological Survey under Federal and State Scientific Collection permits. All field protocols used for surveys and lethal removals were reviewed and approved by the Institutional Animal Care and Use Committee (IACUC) at Oregon State University.

## **Assessing the Initial Effects of Removals**

### **Spotted Owl Occupancy and Reproduction**

We used long-term monitoring data on Spotted Owls to summarize BACI estimates of numbers of territorial pairs detected, territory occupancy (proportion of historical territories monitored with detections of resident pairs of Spotted Owls), and reproduction (proportion of territorial pairs that successfully fledged at least one young, and total number of young produced). We summarized long-term (2004–2018) monitoring data separately for control and treatment portions of each study area (Franklin and others, 1996, Lint and others, 1999). Because detection probabilities of Spotted Owls are below 1, empirical data presented here may underestimate numbers of territorial pairs, territory occupancy, and reproduction.

## Analysis of Barred Owl Site-Usage

We used dynamic occupancy models (MacKenzie and others, 2002, 2006) to assess evidence for an effect of removals on Barred Owls. For this analysis, we focused inferences on detections/non-detections of at least 1 pair of Barred Owls. We did this because pairs have the potential to reproduce and may defend their territories more aggressively than single birds, and thus may have greater effects on the local population of Spotted Owls. Actual territory boundaries of Barred Owls may overlap more than one survey site in our study, so we interpreted occupancy as the probability of at least 1 territorial pair of Barred Owls using a 5-km<sup>2</sup> survey site (that is, site “usage”; Kendall and others, 2013; Davis and others, 2018). Specifically, we used site-specific detection histories to estimate: the probability of site-usage by at least 1 pair of Barred Owls in the year prior to removals ( $\psi_1$ ); the probability that used sites become unused (local extinction,  $\epsilon$ ); the probability that unused sites become used (local colonization,  $\gamma$ ); and the probability of detecting at least 1 pair Barred Owls given the site was used ( $p$ ). At survey sites with year-round removal of non-nesting Barred Owls ( $n = 39$ ), we considered only surveys within a breeding season that occurred prior to removal of the last Barred Owl to minimize bias of parameter estimates (Diller and others, 2016).

We used program MARK (White and Burnham, 1999) for parameter estimation and to examine evidence for treatment (removal) and time effects on site-usage by Barred Owls. We first examined the effects of year and seasonal visits within years relative to detection probability. We then retained the best time structure for detection as we moved on to model initial occupancy, colonization, and then extinction. We used information theoretic methods to rank and select the best models at each stage of the analysis (Burnham and Anderson, 2002). At each stage, the model with the lowest AICc was cross-checked against competitive models (that is, those with  $\Delta AICc > 2.0$ ) from the previous stage to ensure that we apportioned variation correctly among model parameters. We evaluated the degree to which 95 percent confidence intervals of regression coefficients ( $\beta$ ) overlapped zero to determine the direction and magnitude of treatment effects. We calculated model-averaged estimates where appropriate.

## Preliminary Results, 2015–2018

### Barred Owl Surveys and Removals

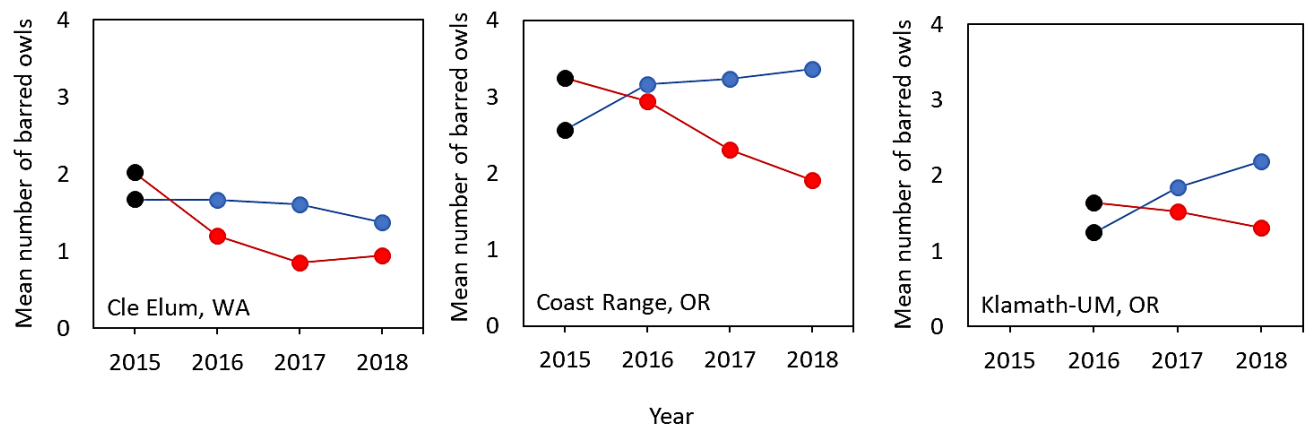
We completed 6,472 surveys of Barred Owls at 765 sites (5-km<sup>2</sup> hexagons; table 2). By August 2018, the proportion of treatment sites with detections of territorial pairs of Barred Owls had decreased by 12–38 percent from pre-treatment estimates (table 2). In contrast, the proportion of control sites with detections of pairs increased by 17 percent in both Oregon study areas. In 2018 in Cle Elum, we observed a decline in the numbers of control sites with pairs detected relative to the previous 2 years. We observed similar differences between control and treatment areas in the mean number of individual barred owls detected per survey (pair and single detections combined; fig. 2). Generally, we detected 2–4 times as many Barred Owls in the Oregon Coast Range than in the other two study areas.

**Table 2.** Barred Owl survey effort and detections of territorial pairs on control (Barred Owls not removed) and treatment (Barred Owls removed) portions of three study areas in Washington and Oregon, 2015–18. [Shading indicates years in which Barred Owls were removed from treatment areas.  $\geq$ , greater than or equal to]

Study area	Treatment level	Hexagons surveyed	Hexagons with $\geq 1$ pair of Barred Owls detected (proportion of hexagons surveyed with $\geq 1$ pair)			
			2015	2016	2017	2018
Cle Elum	Control	109	61 (0.56)	49 (0.45)	51 (0.47)	43 (0.39)
	Treatment	112	66 (0.59)	31 (0.28)	21 (0.19)	23 (0.21)
Oregon Coast Range	Control	178	120 (0.67)	135 (0.76)	147 (0.83)	149 (0.84)
	Treatment	103	80 (0.78)	69 (0.67)	58 (0.56)	53 (0.51)
Klamath–UM	Control	120		48 (0.40)	66 (0.55)	68 (0.57)
	Treatment	143		67 (0.47)	63 (0.44)	50 (0.35)

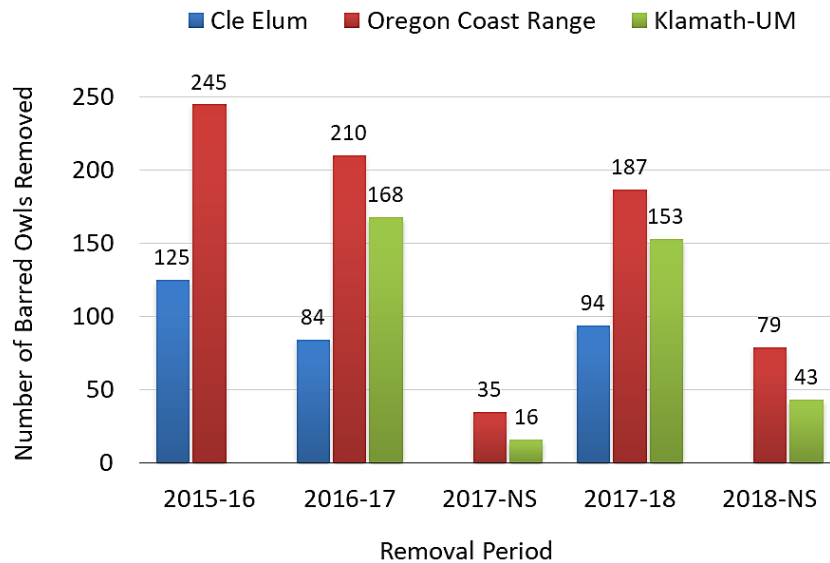
—●— Control (no removal)

—●— Treatment (barred owls removed)



**Figure 2.** Annual changes in the mean number of individual barred owls detected per 5-km<sup>2</sup> survey hexagon during annual surveys of control (Barred Owls not removed) and treatment (Barred Owls removed) portions of three study areas in Washington and Oregon, 2015–18. Annual means were calculated as the sum of maximum counts per site, divided by the total number of sites surveyed. Black dots are pre-treatment estimates.

Field crews completed 2,423 site-visits to remove a total of 1,439 Barred Owls (Cle Elum = 303; Oregon Coast Range = 756; Klamath-UM = 380; fig. 3). The sample included 622 females, 736 males, and 81 owls of unknown sex. We removed a minimum of 286 territorial pairs of Barred Owls (that is, cases where a male and female were removed on the same occasion within 250-m apart). Thirty-seven (2.6 percent) Barred Owls required euthanasia using an IACUC-approved penetrating bolt device (Bunny Rancher, Frankfort, Maine) to ensure rapid death following a single non-lethal shot. We had no known cases where a non-target species was injured or mistakenly killed. We successfully recovered 1,422 carcasses of Barred Owls but were not able to recover 17 carcasses that either got stuck high in a tree or fell onto areas unsafe for nighttime access. The overall mean number of Barred Owls removed per 5-km<sup>2</sup> survey hexagon during the study was 2.0 (SD = 2.2) in Cle Elum (range = 0–9 owls), 4.8 (SD = 4.2) in the Oregon Coast Range (range = 0–25 owls), and 1.3 (SD = 1.9) in Klamath-UM (range = 0–11 owls). To date, carcasses of Barred Owls have been provided as scientific specimens to 14 different institutions for future educational and research purposes (appendix 1).



**Figure 3.** Number of Barred Owls removed from treatment portions of three study areas in Washington and Oregon, 2015–2018. Removal periods were from August 15 to April 15 of each year but were also completed during the nesting season (NS) in 2017 and 2018 (Coast Range and Klamath-UM study areas only).

## Initial Effects of Removals

### Spotted Owl Occupancy and Reproduction

Long-term data prior to removals show sharp declines in the annual number of resident, color-marked Spotted Owls detected in control and treatment portions of each study area (fig. 4A). In the year prior to removals (2015 in Cle Elum and Coast Range, 2016 in Klamath-UM), the total number of territorial pairs of Spotted Owls detected across all control and treatment areas was 30 and 17, respectively (table 3)<sup>4</sup>. By August 2018 (after 2–3 years of removal effort), the total number of territorial pairs detected in control and treatment areas was 11 and 21, respectively. Thus, during the study period we observed an overall 63 percent decline in numbers of territorial pairs of Spotted Owls in control areas with a concurrent 19 percent increase in treatment (removal) areas. This pattern of change was most prominent in the Oregon Coast Range, where we observed an approximate 50 percent increase in the number of pairs of Spotted Owls in the treatment area with a 91 percent decrease in control areas (table 3; also see fig. 4A for total number of individual Spotted Owls detected annually).

Long-term empirical data show that the number of fledgling Spotted Owls produced and detected in control versus treatment areas was highly variable among years and study areas (fig. 4B). In 2018, only 2 (6 percent) of 32 territorial pairs monitored across all control and treatment areas successfully produced a total of 2 young (table 3). No pairs of Spotted Owls attempted to nest in the Coast Range study area, and nesting attempts made by 2 pairs in Cle Elum were unsuccessful.

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<sup>4</sup>Data on Spotted Owls are specific to control and treatment portions of each study area, so may vary from estimates reported in these areas by Regional Ecosystem Office (2013; [www.fs.fed.us/r6/reo/monitoring/reports/](http://www.fs.fed.us/r6/reo/monitoring/reports/)).



**Table 3.** Territory occupancy and reproduction by color-marked pairs of Northern Spotted owls in control (Barred Owls not removed) and treatment (Barred Owls removed) portions of three study areas in Washington and Oregon, 2015–18.

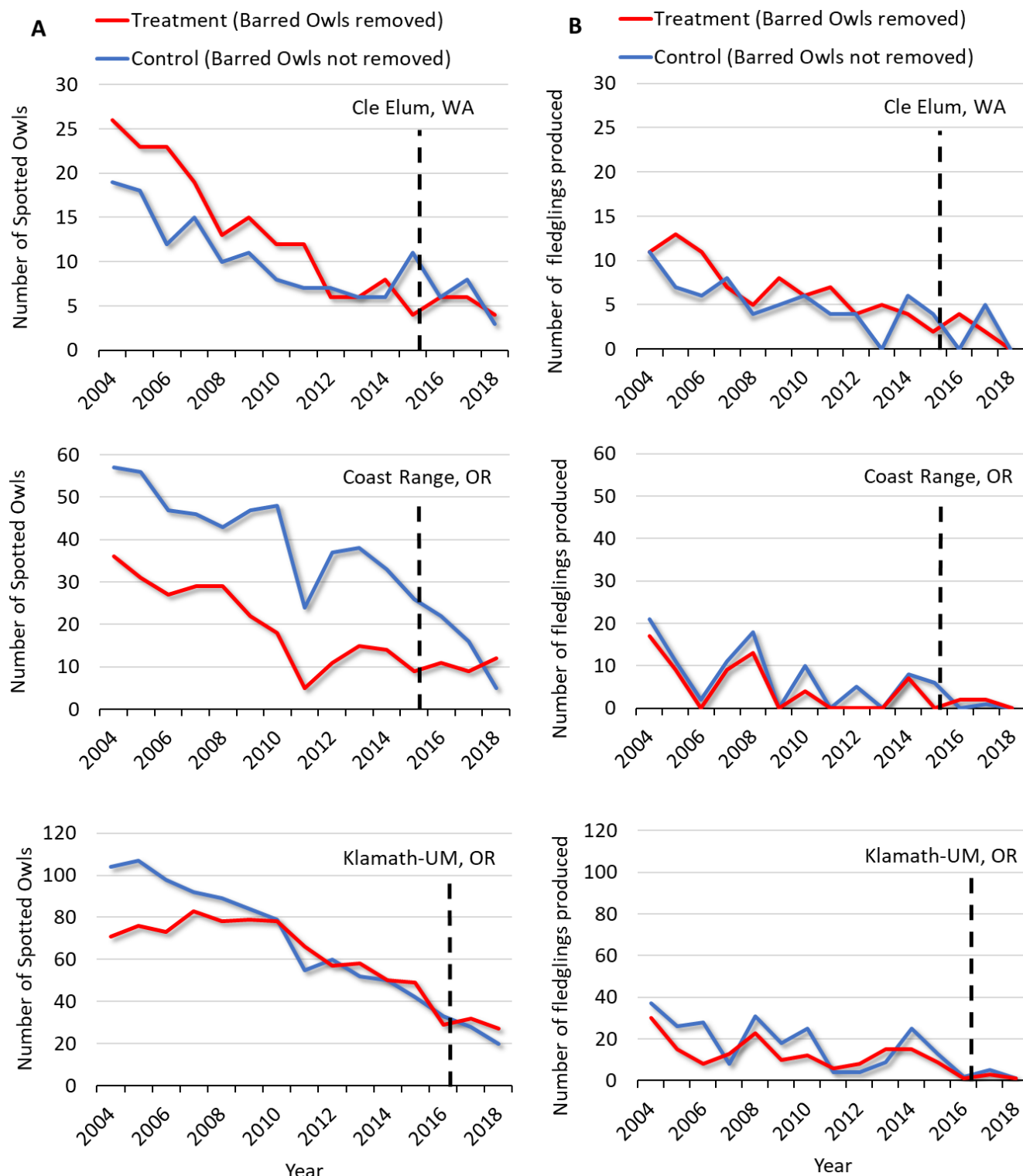
Shading indicates years in which Barred Owls were removed from treatment areas.

### Spotted Owl Territory Occupancy

Study area	Treatment level	Historical territories surveyed	Territories with pairs of Spotted Owls detected (proportion of historical territories surveyed with pairs)			
			2015	2016	2017	2018
Cle Elum	Control	31	5 (0.16)	2 (0.06)	2 (0.06)	3 (0.04)
	Treatment	45	2 (0.04)	2 (0.04)	2 (0.04)	3 (0.07)
Oregon Coast Range	Control	58	11 (0.19)	9 (0.16)	6 (0.10)	1 (0.02)
	Treatment	45	3 (0.07)	5 (0.11)	4 (0.09)	6 (0.13)
Klamath–UM	Control	78	18 (0.23)	14 (0.18)	12 (0.15)	7 (0.09)
	Treatment	84	23 (0.27)	12 (0.14)	13 (0.15)	12 (0.14)

### Spotted Owl Reproduction

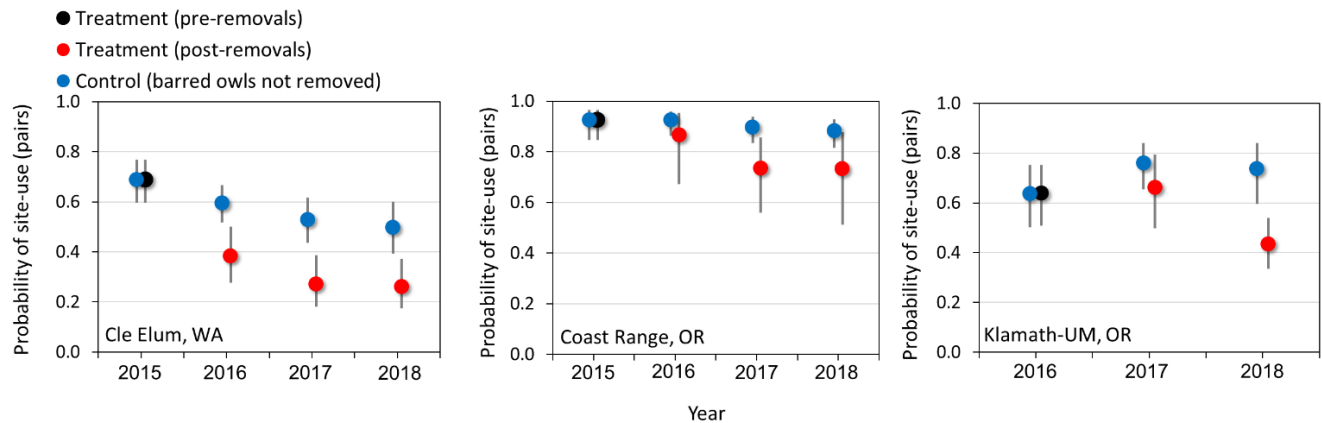
Study area	Treatment level	Historical territories surveyed	Pairs with ≥ 1 young fledged (proportion of pairs that produced young)			
			2015	2016	2017	2018
Cle Elum	Control	31	2 (0.06)	0	2 (0.06)	0
	Treatment	45	1 (0.02)	2 (0.04)	1 (0.02)	0
Oregon Coast Range	Control	58	3 (0.05)	0	1 (0.02)	0
	Treatment	45	0	1 (0.02)	2 (0.04)	0
Klamath–UM	Control	78	8 (0.10)	1 (0.01)	4 (0.05)	1 (0.01)
	Treatment	84	6 (0.07)	1 (0.01)	2 (0.02)	1 (0.01)



**Figure 4.** Long-term (2004–2018) trends in (A) annual number of individual resident (color-banded) Northern Spotted Owls detected, and (B) annual number of Northern Spotted Owl fledglings produced in control (Barred Owls not removed) and treatment (Barred Owls removed) portions of three study areas in Washington and Oregon. Dashed vertical bar indicates when removals were initiated in treatment areas.

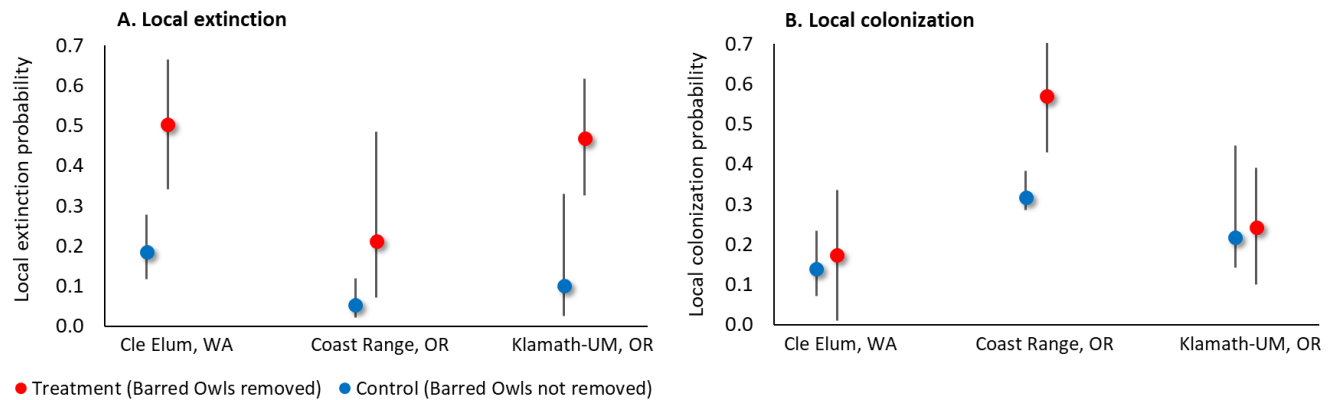
## Barred Owl Site-Usage

Before removals, we found no evidence of a difference between control and treatment areas in the probability of site-usage by territorial pairs of Barred Owls (fig. 5; appendix 2). After removals, site-usage in treatment areas significantly decreased relative to controls (fig. 5). Model-averaged estimates of site-usage by pairs of Barred Owls in treated areas declined by 19 (Coast Range) to 43 (Cle Elum) percent between 2015 and 2018 and were 19 (Coast Range) to 30 (Klamath-UM) percent lower relative to control sites by 2018 (fig. 5). Before-after and control-treatment differences in numbers of Barred Owls detected (fig. 2) and estimates of site-usage (fig. 5) increased as removal efforts progressed—a pattern similar to that observed in pilot studies in California (Diller and others 2016).



**Figure 5.** Model-averaged estimates of site-usage by at least one territorial pair of Barred Owls ( $\hat{\psi}$ ) in control (Barred Owls not removed) and treatment (Barred Owls removed) portions of three study areas in Washington and Oregon, 2015–18. Error bars are unconditional 95 percent confidence intervals.

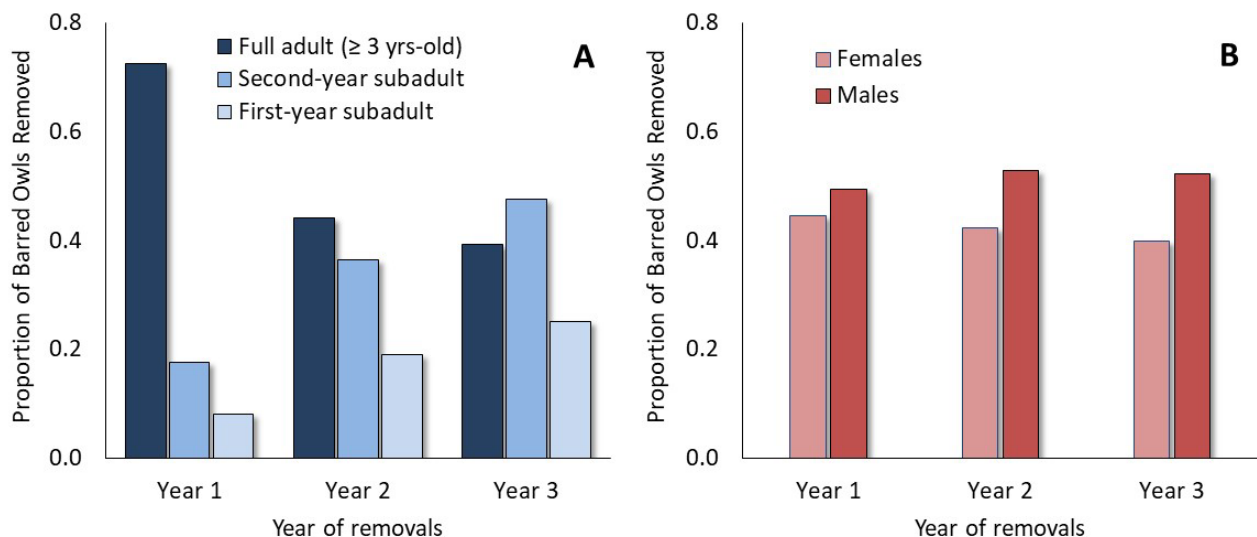
We examined the effects of removals on local extinction and colonization rates of Barred Owls by adding treatment effect as a covariate (trt) to models, which allowed parameter estimates to vary between control and treatment areas. Models that included treatment effects on extinction probability consistently outperformed models without these effects, and 95 percent confidence intervals of beta coefficients for treatment effects did not overlap zero for all three study areas (appendix 2). Extinction rates were 2.7–4.6 times greater in treatment areas relative to control areas in years following removals (fig. 6A). In contrast, there was relatively weak support for treatment (removal) effects on the site-specific probability of colonization (appendix 2). Post-removal recolonization rates of Barred Owls in treated areas were substantially higher in the Coast Range study area ( $\hat{\gamma} = 0.57$ ,  $SE = 0.20$ ) relative to Cle Elum ( $\hat{\gamma} = 0.17$ ,  $SE = 0.06$ ) and Klamath-UM ( $\hat{\gamma} = 0.24$ ,  $SE = 0.11$ ; fig. 6B). Lower extinction rates and higher colonization rates in the Oregon Coast Range study area resulted in less-pronounced differences between treated and untreated areas in site-usage by Barred Owls relative to the other two study areas (fig. 5).



**Figure 6.** Comparison of: (A) site-level extinction and (B) colonization probabilities of territorial pairs of Barred Owls in control (Barred Owls not removed) and treatment (Barred Owls removed) portions of three study areas in Oregon and Washington, 2015–2018. Model-averaged estimates were based on the final time-interval (for example, 2017–2018) for study areas with evidence of annual variation in parameter estimates (Coast Range and Klamath-UM). Error bars are unconditional 95 percent confidence intervals.

### Barred Owl Age Distribution and Sex Ratio

We classified 348 (39 percent) Barred Owls collected during removals as subadults (owls 1–2 years old). There was a marked increase over time in the proportion of subadult Barred Owls collected, with a concurrent decrease in numbers of adults (fig. 7A). This pattern would be expected if younger, first- and second-year “floater” owls were readily available from surrounding landscapes to fill territory vacancies created after removing older, more established territorial birds from treatment areas. We removed more male than female Barred Owls overall and observed a gradual increase in the ratio of males:females as removal efforts progressed (fig. 7B).



**Figure 7.** Change in the proportion of Barred Owls removed during the first three years of the study that were (A) adults (greater than or equal to 3 years-old) versus subadults (1–2 years old), and (B) females versus males, with sex ratio (M:F) shown above bars, 2015–18. Proportions were calculated as mean values across all three study areas in Washington and Oregon.

## Discussion

### Initial Effects of Removals on Spotted Owls and Barred Owls

Long-term data prior to removals illustrate sharp declines in annual numbers of resident Spotted Owls detected in control and treatment portions of all three study areas in Oregon and Washington. In control areas without removal of Barred Owls, total numbers of territorial pairs of Spotted Owls detected during the study declined from 30 to 11 pairs (a 63 percent decline from pre-treatment conditions). In contrast, numbers of pairs of Spotted Owls detected in areas with removals increased from 17 to 21 pairs (a 19 percent increase from pre-treatment conditions). Post-treatment changes in numbers of Spotted Owls appeared to be the greatest in the Oregon Coast Range, where in 2018 (3 years post-treatment) the proportion of historical territories with pairs of Spotted Owls was greater in the treatment area (0.13) than in the control (0.02) for the first time since the early 1990s (fig. 4A; also see Wiens and others, 2018).

Historical, pre-treatment data on reproduction of Spotted Owls in our study areas show a high level of variation among years in the number of young produced. In 2018, reproduction of Spotted Owls was the lowest recorded in our study areas and only two young were produced across all areas combined. A high degree of annual variation in productivity of Spotted Owls, both before and after removal efforts, can obscure the ability to quantify effects of removals on reproduction (Diller and others, 2016). Low reproduction in our study areas in years prior to and during our study further suggests that there may be few young, non-territorial Spotted Owls available to recolonize territory vacancies created by removals. We emphasize that data presented here do not account for imperfect detection of Spotted Owls during demographic surveys, so may underestimate actual numbers of pairs or individuals, or reproductive output. Nonetheless, these data provide the basis of more detailed mark-recapture analyses of population status and trends, so provide an informative proxy of the initial effects of removals on Spotted Owls.

Our preliminary assessment of site-usage by pairs of Barred Owls indicated that removals were effective in reducing the study population by 19–43 percent with 2–3 years of removal effort. We found no evidence that site-usage by Barred Owls varied between control and treatment areas in the year prior to removals. This finding provided confidence that control and treatment areas had similar use by Barred Owls prior to treatments, and that post-treatment changes could be reliably attributed to removals. In the Oregon study areas, site-use by Barred Owls remained constant or increased slightly in control areas over time, as would be expected if populations were continuing to expand (or nearing carrying capacity). In contrast, we observed a reduction in Barred Owl site-usage in the control area of Cle Elum. We hypothesize that a large wildfire in 2017 may have contributed to a reduction in use of affected sites by Barred Owls. Our future analyses will incorporate site-level habitat and disturbance characteristics to more fully understand how these factors interact with removals to affect dynamics in site-usage and colonization of Barred Owls.

### Summary and Next Steps

During 2015–2018 we completed annual demographic surveys of Barred Owls and Spotted Owls at 765 and 341 sites, respectively, and removed a total of 1,439 Barred Owls from treatment areas. Our preliminary results indicate that removals have significantly increased the site-level extinction probability of Barred Owls and decreased the probability of site-use across all treatment areas. In 2018 we detected consistent or increasing numbers of resident Spotted Owls in treatment areas relative to previous years, with correspondingly sharp declines in control areas without removals. Collectively, these initial results provide an indicator that removal efforts may be beginning to positively influence

territory occupancy, apparent survival, and population trend of Spotted Owls in our study areas. We emphasize, however, that numbers of Spotted Owls remaining in our study areas have reached exceptionally low levels and that annual reproduction during our study period was the lowest recorded over a 28-year period. Moreover, long-term pre-treatment monitoring data show large inter-annual fluctuations in detections of pairs and individual Spotted Owls in our study areas (for example, fig. 4). These observations, coupled with a high and regionally variable rate of recolonization by Barred Owls following removals, suggests that demonstrating a positive effect of removals on population demography of Spotted Owls will require additional removal effort. This is a similar finding to what was reported previously for pilot studies in northern California, which required 7 years of removals to demonstrate a positive effect of removals on Spotted Owls (Diller and others, 2016). Continued removal effort in all study areas (that is, experimental replicates) is needed to confirm positive results we observed in 2018 and reduce current uncertainties associated with the effectiveness of removals in benefitting Spotted Owls.

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## Appendix 1. Barred Owl Specimen Disposition

**Table 1.1.** Final disposition of 774 Barred Owl specimens collected during removal experiments in Washington and Oregon, 2015–18.

Destination	Purpose	Total Barred Owls
The Field Museum (Chicago, Illinois)	Museum specimen	425
UC Riverside (Riverside, California)	Museum specimen/research	79
UC Berkeley (Berkeley, California)	Museum specimen	67
Oregon State University (Corvallis, Oregon)	Classroom education/research	64
Burke Museum (Seattle, Washington)	Museum specimen	30
California Academy of Sciences (San Francisco, California)	Museum specimen/taxidermy	24
Fingerlakes Community College (Canandaigua, New York)	Classroom education/research	19
Natural History Museum of Los Angeles County (LA, California)	Museum specimen	19
The Smithsonian Institution (Washington D.C.)	Museum specimen	17
University of Wyoming Museum of Vertebrates (Wyoming)	Museum specimen	15
Liberty Wildlife Non-Eagle Feather Repository (Arizona)	Native American repository	10
USGS – FRESC Snake River FS (Boise, Idaho)	Scientific research	3
Oregon Department of Forestry (Tillamook, Oregon)	Taxidermy display	1
High Desert Museum (Bend, Oregon)	Live capture – educational bird	1
<b>Total Barred Owls provided</b>		<b>774</b>

## Appendix 2. Ranking of Multi-Season Occupancy Models Used to Characterize the Initial Effects of Removals on Site-Use, Extinction, Colonization, and Detection of Territorial Pairs of Barred Owls in Washington and Oregon, 2015–17.

**Table 2.1.** Ranking of Multi-Season Occupancy Models Used to Characterize the Initial Effects of Experimental Removals on Site-Use, Extinction, Colonization, and Detection of Territorial Pairs of Barred Owls in Washington and Oregon, 2015–17.

[We show model parameter structure and the estimated direction of treatment effects for competitive models ( $\Delta\text{AICc} \leq 2$ ) for each study area. Bold denotes beta coefficients with 95 percent Confidence Intervals that did not overlap 0. Model parameters defined as:  $\hat{\psi}_1$  = probability of site-use in the first year of study (initial occupancy),  $\hat{\epsilon}$  = the probability that a previously used site was not used in the subsequent year (extinction),  $\hat{\gamma}$  = the probability that a previously unused site was used in the subsequent year (colonization) and  $\hat{p}$  = the probability of detection. Models with treatment (trt) effects allow parameter estimates to vary between treated (removal) and untreated areas. Time effects were modeled as constant (.) or varying with survey period (survey), year, or between treatment and control areas in years following removals (trtBA).  $\text{AICc}$  = Akaike's Information Criterion for small sample size,  $\Delta\text{AICc}$  = difference between the  $\text{AICc}$  value of each model and the lowest  $\text{AICc}$  model,  $K$  = the number of model parameters, and Deviance was the difference in  $-2[\log(\text{Likelihood})]$  of the current model and  $-2[\log(\text{Likelihood})]$  of the fully saturated model.]

Study area	Model	$\hat{\psi}_1$	$\hat{\epsilon}$	$\hat{\gamma}$	$\hat{p}$	$\Delta\text{AICc}$	$w_i$	$K$	Deviance
Cle Elum	1	.	<b>trt (+)</b>	.	yr, survey, trtBA (–)	0.00	0.36	11	1807.7
	2	.	<b>trt (+)</b>	trt (+)	yr, survey, trtBA (–)	0.61	0.26	12	1806.2
	3	.	<b>trt (+)</b>	yr	yr, survey, trtBA (–)	1.12	0.21	13	1804.7
	4	.	<b>trt (+)</b>	trt (+), yr	yr, survey, trtBA (–)	1.82	0.14	14	1803.3
Coast Range	1	.	<b>trt (+), yr</b>	trt (+)	yr $\times$ survey $\times$ trt (–)	0.00	0.25	31	3082.4
	2	.	<b>trt (+), yr</b>	.	yr $\times$ survey $\times$ trt (–)	0.04	0.24	30	3084.6
	3	.	<b>trt (+), yr</b>	trt (–), yr	yr $\times$ survey $\times$ trt (–)	0.76	0.17	32	3081.1
	4	.	<b>trt (+), yr</b>	trt (–) $\times$ yr	yr $\times$ survey $\times$ trt (–)	1.51	0.12	33	3079.7
	5	.	trt (–) $\times$ yr	trt (–) $\times$ yr	yr $\times$ survey $\times$ trt (–)	1.74	0.11	34	3077.7
Klamath-UM	1	.	<b>trt (+), yr</b>	.	yr $\times$ survey	0.00	0.25	31	3082.4
	2	.	<b>trt (+), yr</b>	yr	yr $\times$ survey	0.04	0.24	30	3084.6
	3	.	<b>trt (+), yr</b>	trt (–)	yr $\times$ survey	0.76	0.17	32	3081.1

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