Black-backed Woodpecker MIS Surveys on Sierra Nevada National Forests: 2018 Annual Report

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Rodney B. Siegel, Morgan W. Tingley, and Robert L. Wilkerson
The Institute for Bird Populations
P.O. Box 1346
Point Reyes Station, CA 94956

www.birdpop.org

Black-backed Woodpecker
Photo by Jean Hall

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Summary

The Black-backed Woodpecker (*Picoides arcticus*) was selected by the Pacific Southwest Region of the USDA Forest Service as a Management Indicator Species (MIS) for snags in burned forests across the ten Sierra Nevada National Forest units in the Pacific Southwest Region: Eldorado, Inyo, Lassen, Modoc, Plumas, Sequoia, Sierra, Stanislaus, Tahoe, and the Lake Tahoe Basin Management Unit. In 2008 The Institute for Bird Populations collaborated with Region 5 personnel to develop and field-test survey methods and collect preliminary information on Black-backed Woodpecker distribution across Sierra Nevada National Forests. We used the findings from our 2008 pilot study to design a long-term MIS monitoring program for Black-backed Woodpecker across ten National Forest units of the Sierra Nevada, which we have now implemented annually since 2009. The primary goal of the program is to monitor trends in the amount of recently burned forest on the study area's ten National Forests that is occupied by Black-backed Woodpeckers, so that Forest Service personnel can evaluate the likely effects of forest plan implementation on Black-backed Woodpecker populations. Additional goals are to better understand Black-backed Woodpecker abundance, distribution, and habitat associations across the Sierra Nevada, to develop information that can inform effective conservation of Black-backed Woodpecker in the Sierra Nevada, and to collect and interpret information on other bird species utilizing burned forests.

During the 2018 field season, we used passive and broadcast surveys to assess Black-backed Woodpecker occupancy at 929 survey points arrayed across 49 recent fires (1-10 years post-fire) throughout our study area. Combined with data collected during 2009 – 2017, we now have broadcast surveys and habitat assessment data at 2,365 unique survey points within 125 fires (102 of which have been surveyed in more than one year). We also collected on-the-ground habitat data at each survey point, and collated additional habitat data from remote-sensed GIS sources. In addition, we conducted passive point counts for other bird species at approximately half of the Black-backed Woodpecker survey points.

In 2018 we detected Black-backed Woodpeckers at 166 survey points distributed across 24 of the 49 fires we surveyed, including fires on six of the nine National Forest units in our study area

(we did not survey any fires on the Lake Tahoe Basin Management Unit, and there were no detections within surveyed fires in Eldorado, Lassen, or Stanislaus National Forests). Given that detection probably was <1 and only a subset of areas within each fire was sampled, it is possible that fires with no detections were occupied. We detected Black-backed Woodpeckers on both the west and east sides of the Sierra Nevada crest, and across nearly the full latitudinal range of our study area.

Results were produced by two separate analyses, beginning with an exploration of annual changes in Black-backed Woodpecker occurrence within our sampling frame. To assess these changes, we used a hierarchical modeling approach that incorporated separate but linked models for the observation (detection) and state (occupancy) processes. Additionally, the state process was split into two hierarchical levels, to separately model whether a fire (or at least the portion of it we sampled) was occupied (fire-level occupancy) and whether survey points within a fire were occupied (point-level occupancy). For each occupancy probability model, we defined a logit-linear model that included covariates that we deemed important based on previous years' analyses. Fire age was the only fire-level covariate, while point-level covariates included latitude, snag density (all size classes pooled), burn severity, pre-fire canopy cover, and elevation. Detectability was modeled as a function of survey interval duration (2- vs. 3-minute), count type (passive vs. broadcast survey), and seasonality (day of year). Each survey year was modeled separately, providing independent but comparable models of true occurrence within each year's sampling frame.

Mean occupancy probability for points surveyed in 2018 was 0.21 (95% credible interval: 0.19 – 0.22), which is similar to values obtained for 2017 and within the range of previously observed year-to-year variation in occupancy. Mean fire occupancy (i.e., the proportion of occupied fires, or, more precisely, the proportion of fires with occupancy within the portion of each fire that we surveyed) was 0.49 (95% CI: 0.43 – 0.56), which also was within the range of previously observed year-to-year variation. There is no linear trend in point-level occupancy (mean ± se: -0.003 ± 0.003; P = 0.43) or fire-level occupancy (mean ± se: -0.006 ± 0.008; P = 0.45) from 2009 to 2018.

Our second analysis used data from all nine survey years (2009-2018) to explore occurrence dynamics over time, specifically the probabilities of colonization and extinction of Black-backed Woodpeckers at survey points and fires. Average colonization probability (defined here as the probability of a single survey point becoming occupied by woodpeckers given that it was previously unoccupied subsequent to the fire) was quite low (4.8%), while average extinction probability was much higher (69%). Despite being low, the probability of a site being colonized was strongly and positively associated with snag density and strongly negatively associated with fire age. Thus, early post-fire sites with high snag densities have a relatively higher probability of being colonized, even after initially being vacant, than other sites. For extinction, there was evidence for a moderate but significant negative association with burn severity (i.e., more severe fires make extinction in a given year less likely).

During the 2018 field season we also completed the second year of Black-backed Woodpecker surveys in unburned forest stands with high tree mortality due to drought and bark-beetle activity. We used Aerial Detection Survey (ADS) data to identify appropriate forest stands throughout the same ten National Forests as the burned study areas, and then used the same data collection methodology we used for the burned areas to conduct Black-backed Woodpecker surveys at 849 survey points in 68 beetle-kill forest stands distributed across 8 National Forest units (Modoc, Lassen, Plumas, Lake Tahoe Basin, Stanislaus, Eldorado, Sierra, and Sequoia). We also conducted passive point counts for other bird species at 413 of the Black-backed Woodpecker survey points in beetle-kill stands. Combining data across years, Black-backed Woodpeckers were detected at 7.3% of survey points at 20% of visited stands, suggesting lower occupancy in these habitats than in similar-aged post-fire forests. Additionally, we found a strong gradient in Black-backed Woodpecker occurrence, with birds more likely to be detected in beetle-kill stands in the northern half of the survey region – where drought-based tree mortality is relatively less severe – than in the southern half.

Introduction

The Black-backed Woodpecker (*Picoides arcticus*) is designated by the Pacific Southwest Region of the USDA Forest Service as a Management Indicator Species (MIS) for snags in burned forests across the ten Sierra Nevada National Forest units in the Pacific Southwest Region: Eldorado, Inyo, Lassen, Modoc, Plumas, Sequoia, Sierra, Stanislaus, Tahoe, and the Lake Tahoe Basin Management Unit (USDA Forest Service 2007a, 2007b). The MIS approach identifies species whose population changes are believed to indicate the effects of management activities (USDA Forest Service 2007a). The habitat needs of MIS are to be considered in the establishment of forest plan objectives for important wildlife and fish habitat, and as forest plans are implemented through individual projects, Forest Service managers are to assess their effects on MIS habitat (USDA Forest Service 2007a). Additionally, MIS population distribution monitoring is used to assess the outcomes of forest plan implementation, since it is impossible to monitor the status or population trend of all species (USDA Forest Service 2007a). Population monitoring is thus an integral component of the MIS approach.

Black-backed Woodpeckers are most abundant in stands of recently fire-killed snags (Hutto 1995, Kotliar et al. 2002, Smucker et al. 2005), although the species can be found in unburned forest stands throughout its range. Black-backed Woodpeckers foraging in burned forests feed primarily on wood-boring beetle larvae (Villard and Beninger 1993, Murphy and Lehnhausen 1998, Powell 2000), although some studies have also reported or inferred foraging on bark beetle larvae (Lester 1980, Goggans et al. 1988). Bark beetles and wood-boring beetles share important life-history characteristics (both spend a prolonged portion of their life-cycle as larvae inside dead or dying trees) but also exhibit differences that may be important in their ecological interactions with Black-backed Woodpeckers. Bark beetles are small (generally <6 mm in length), numerous, often able to attack live trees, and generally remain as larvae in bark less than a year before emerging as adults (Powell 2000). In contrast, wood-boring beetles have much larger larvae (up to 50 mm long), are less numerous, and can remain as larvae in dead wood for up to three years (Powell 2000). Additionally, most wood-boring beetles are unable to attack living trees, and concentrate heavily in fire-killed wood, which some genera have been shown to find by sensing smoke or heat (reviewed in Powell 2000).

Although the Black-backed Woodpecker shows a strong association with burned stands of conifer forest, the species is not closely tied to any particular tree species or forest type. Studies from different parts of its range report preferential foraging on Lodgepole Pine (*Pinus contorta*; Bull et al. 1986, Goggans et al. 1989), spruce (*Picea* sp.; Villard 1994, Murphy and Lehnhausen 1998), White Pine (*Pinus strobus*; Villard and Beninger 1993), and in California, Red Fir (*Abies magnifica*; Raphael and White 1984). Research in burned forests of California indicates that the overall abundance of fire-killed trees, rather than the presence of any particular tree species, is among the more important predictors of Black-backed Woodpecker occupancy (Saracco et al. 2011, Tingley et al. 2018) and home-range size (Tingley et al. 2014).

In 2008 The Institute for Bird Populations collaborated with Region 5 personnel to develop and field-test survey methods and collect preliminary information on Black-backed Woodpecker distribution across Sierra Nevada National Forests (Siegel et al. 2008). We used the findings from the 2008 pilot study to design a long-term MIS monitoring program for Black-backed Woodpecker across ten National Forest units of the Sierra Nevada. The primary goal of the program is to monitor trends in the amount of recently burned forest on the study area's ten National Forests that is occupied by Black-backed Woodpecker, so that Forest Service personnel can evaluate the likely effects of forest plan implementation on Black-backed Woodpecker populations. Additional goals are to better understand Black-backed Woodpecker abundance, distribution, and habitat associations across the Sierra Nevada, to develop information that can inform effective conservation of Black-backed Woodpecker in the Sierra Nevada, and to collect information on other bird species utilizing burned forests.

Results from Black-backed Woodpecker MIS monitoring have formed the basis of numerous published papers (e.g., Saracco et al. 2011, Casas et al. 2016, Tingley et al. 2016a, Tingley et al. 2016b, and Tingley et al. 2018) and the development of a model for making spatially explicit predictions about Black-backed Woodpecker density after fire under competing post-fire management scenarios (Tingley et al. 2015). The predictive model has been used widely by Forest Service personnel developing options for postfire forest management. Findings from the publications cited above, and other works, also informed the development and subsequent updating of a conservation strategy for Black-backed Woodpecker in California (Siegel et al. 2018).

In 2018 we continued Sierra-wide MIS monitoring for Black-backed Woodpeckers. Here we detail the results of this tenth year of MIS monitoring in recently burned forest stands, and also report summary results from a two-year survey in beetle-kill stands throughout the same study region.

Methods

Sample Design

We used the Rapid Assessment of Vegetation Condition after Wildfire (RAVG) Query Tool (available at https://www.fs.fed.us/postfirevegcondition/index.shtml) to identify new fires that burned during 2017. To cross check for completeness we used the GIS data layer VegBurnSeverity18_1.mdb (available from https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd596278.zip), which indicates boundaries and severity of fires throughout California, to extract data for all fires that occurred between 2008 and 2017 and that included at least 50 ha of conifer forest that burned at mid-severity and/or high-severity on one or more of the ten National Forest units in our study area.

We assigned fires that met our selection criteria, including fires that were sampled in previous years and fires that were new to the survey, to a random priority order. Our intention was to survey the first 50 fires on the list, but if that proved impossible, we would discard fires according to the priority order, to avoid biasing the sample.

Data Collection

All data collection procedures remained consistent with the protocol we utilized during the previous several field seasons (e.g., Siegel et al. 2014b, 2015, 2016, 2017, and 2018).

Establishing survey points. In 2018, the fires we selected varied in size from 140 ha (2009 Silver Fire on Plumas NF) to 59,414 ha (2015 Rough Fire on Sierra and Sequoia NFs). At the smaller fires, a 2-person team could easily saturate the fires with survey effort in a single morning; however saturating the larger fires with survey effort could require weeks of work. We limited survey effort to what could be achieved by a 2-person team in one day, generally surveys at about 20 survey points.

For fires that we had not previously surveyed, we determined where within the fire to place our survey points by using GIS to randomly select a ‘survey target point’ somewhere within the perimeter of each fire, and indicating that point on field maps given to field crews. Crews were instructed to establish their survey points as close to the survey target point as possible, using the following rules:

1 – If trails or roads passed through the fire, survey points were placed along them, such that the point along the road and trail network that was closest to the survey target point and lay within low- mid- or high-severity burned conifer forest was included within a contiguous array of survey points, spaced 250 m apart. Survey points that were placed along a road were offset 50 m from the actual road in a randomly selected direction, unless only one side of the road was accessible (due to cliffs, for example) or only one side of a road was burned.

2 – If no trails or roads bisected the fire, crews established an array of evenly spaced (250 m between points), off-trail survey points, as close to the target survey point as reasonably possible, without compromising safety or requiring additional days of hiking to access.

At the larger fires we thus sampled only a fraction of the total land area, but that fraction was randomly selected, within reasonable accommodations for accessibility and safety.

For fires that had been surveyed previously, we simply used the same survey points that were established previously by our field crews, using the placement rules described above. On rare occasions where survey points established previously were inaccessible due to washed out roads, later-lingering snowpack, etc., substitute points were established as close as possible to the previous points following the previously described rules.

Broadcast surveys. At each survey point we conducted a 6-min broadcast survey to elicit responses from Black-backed Woodpeckers. We used FoxPro digital game callers to broadcast electronic recordings of Black-backed Woodpecker vocalizations and drumming. The electronic recording we broadcast was obtained from The Macaulay Library of Natural Sounds, Cornell Laboratory of Ornithology (G.A. Keller, recordist), and included the *scream-rattle-snarl* vocalization, *pik* calls, and territorial drumming.

We began the 6-min broadcast survey (Fig. 1) at each survey point by broadcasting the recording of Black-backed Woodpecker vocalizations and drumming for approximately 30 seconds at a standardized volume, and then quietly listening and watching for Black-backed Woodpeckers until two minutes had elapsed (including the 30-second broadcast period). At two minutes into the survey we again broadcasted the 30-second recording, and then quietly listened and watched until a total of four minutes had elapsed since the beginning of the survey, at which point we repeated the sequence of broadcasting and listening one more time, yielding three 2-min survey intervals. When Black-backed Woodpeckers were detected, we recorded their initial distance and bearing from the observer, whether species identification was confirmed visually, age (adult or juvenile) and sex (male, female, or unknown) of each bird, and whether the individual performed territorial drumming or vocalized. Black-backed Woodpecker surveys generally began within 10 min of official local sunrise, and were always completed by 3.5 h after sunrise.

Passive surveys and multi-species point counts. At alternating points along each transect, we *preceded* the broadcast survey with a 7-min passive point count to count all birds of any species (including Black-backed Woodpecker). The 7-min point count consisted of a 3-min interval immediately followed by two 2-min intervals (Fig. 1). Division of the count into discrete detection intervals yields information for assessing detection probability of Black-backed Woodpeckers. Observers estimated the horizontal distance, to the nearest meter, to each bird detected. Estimating distance to each bird provides additional information for estimating detection probability in a distance sampling framework (Buckland et al. 2001). The observers also recorded whether each bird ever produced its territorial song during the point count. Additional details of the point count methods are provided in Siegel et al. (2010).

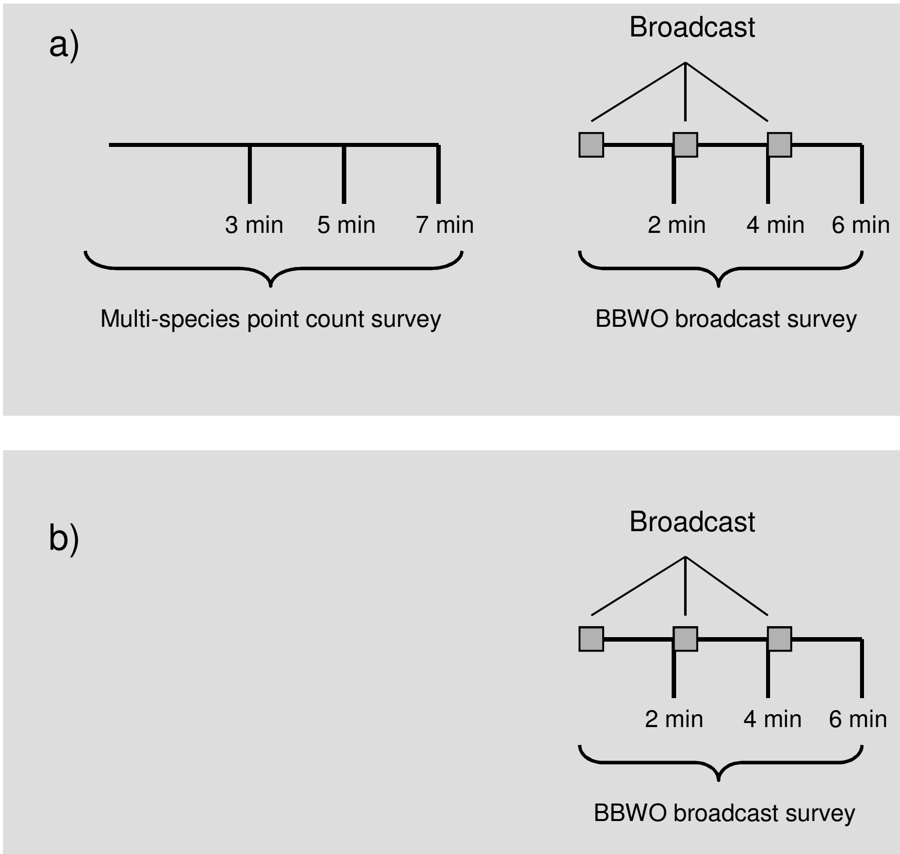

Figure 1. Schematic diagram of our survey methodology for detecting Black-backed Woodpeckers. Dark gray squares indicate period of actively broadcasting Black-backed Woodpecker drumming and vocalizations; black line segments indicate periods of passive observation. Observers alternated between both passive and broadcast (a) and broadcast-only (b) methods at successive survey points.

Habitat and other ancillary data. After completing point counts and broadcast surveys each day, observers returned to the survey points to collect cursory habitat data. In addition to recording UTM coordinates, they classified the habitat within a 50-m radius plot centered on the survey point, according to the California Wildlife Habitat Relationships (CWHR) habitat classification system (California Department of Fish and Game 2005). They also characterized the abundance and size of snags within the plot, estimated basal area of snags and live trees using a 10 BAF slope-compensating angle guage, recorded the dominant pre-fire habitat type, and used CWHR-defined categories to classify the dominant tree size (including snags) and amount of remaining live canopy cover. Additional details of the methods for collecting habitat data are provided in Siegel et al. (2010).

Data Analysis

Goals and analysis structure. Based on previous analyses of the MIS data (Siegel et al. 2018), our analytical goals for the 2018 data centered on formalizing analyses begun in 2011 to capitalize on the extended time-series of monitoring data. Specifically, our analysis focuses on answering two questions:

(1) What is the overall proportion of fires and points in the sampling frame occupied in 2018 and how does this compare to previous years?

(2) What are the probabilities of colonization and extinction at sites, and how have they changed over time and with site-specific environmental factors?

Question 1 builds extensively on previous work, provides a model for future annual assessments, and is the central question that this monitoring program was implemented to answer. Question 2 allows a greater understanding of the dynamics underlying changes in Black-backed Woodpecker occurrence. Descriptions of the methods used in addressing each of these questions follow this section.

Based on previous modeling work with the 2009-2017 MIS monitoring data and recent publications (Tingley et al. 2018), we examined the relationship between occupancy (and occupancy dynamics) and the following environmental and site characteristics:

- Latitude (in decimal degrees) recorded from USGS topographic maps.
- Elevation, collected in the field from GPS and USGS topographic maps but formalized from intersecting GPS points with a 10-m resolution California DEM (Gesch 2007, Gesch et al. 2002). In models we used the residuals of a regression of elevation on latitude, thereby controlling for the downslope bias in elevational ranges as latitude increases (Saracco et al. 2011, Siegel et al. 2011).
- Density of snags (standing dead trees) recorded at the survey point. Snag counts were conducted immediately after completing woodpecker surveys at burned sites and consisted of counting all snags of different size classes (10-30, 30-60, and >60 cm dbh) within 50 m of

each survey point. Size-specific snag counts were aggregated in the field into different categories (≤5, 6-15, 16-30, 31-50, 51-100, >100), which were converted to numerical quantities (1, 6, 16, 31, 51, 101, respectively) for analysis. Counts across all three size classes were summed and snag density (snags/ha) was calculated.

- Density of live trees recorded at the survey point. Live tree density was calculated from vegetation survey data using the same methods as snag density.
- Pre-fire % tree cover calculated from 100-m resolution California Multi-source Land Cover Data (http://frap.fire.ca.gov/data/frapgisdata-subset). We calculated this variable by averaging midpoints of the % tree cover variable (WHRDENSITY) at 100 m buffers around survey points.
- Number of years since fire (range = 1 to 10 years).
- Change in percent canopy cover (a measure of burn severity) based on satellite derived relativized difference normalized burn ratio score RdNBR (Miller et al. 2009). Values of canopy change (*cc*) were summarized at 90-m^2 resolution by averaging 30-m^2 values from GIS layers provided by the US Forest Service (J. D. Miller) using the 'raster' package in R (Hijmans and Etten 2012).

Modeling annual occupancy. Occupancy models allow the estimation of the true presence (or occupancy) of a species at a location, unbiased by false absences. As survey data inherently contain an unknown quantity of false absences (i.e., non-detections when the species was truly present), it is critical that survey data be interpreted only after accounting for false absences. The framework presented here builds on the framework developed in the 2011 MIS report (Siegel et al. 2012) and published by Saracco et al. (2011) and Tingley et al. (2016b). As presented in prior reports (Siegel et al. 2012, 2014a, b, 2015–2018), given 3 (or more) years of sampling, combining all data into one model is not advantageous due to pseudoreplication of treating yearly surveys at the same sites as independent occurrence samples. A dynamic occupancy modeling framework (MacKenzie et al. 2003) allows the annual modeling of occupancy within one model, and avoids pseudoreplication, but that framework prioritizes the modeling of colonization and extinction probabilities, leaving annual occupancy solely as a derived parameter (as in Tingley et al. 2018). When occupancy is a derived parameter, one cannot explicitly model relationships between it and other factors, such as environmental covariates. Thus, we prefer not to use dynamic occupancy models for direct inference on annual changes in occupancy. While we present a dynamic occupancy analysis here (see *Modeling dynamic occupancy*), for consistency in occurrence estimates across yearly reports, we also present results of single-year occupancy models for each year of monitoring that has been completed. The drawback of using multiple single-year occupancy models is that covariate relationships will be modeled independently for each year, yielding different occupancy estimates than if all years were pooled into a single model. However, combined with modeling of occupancy dynamics, we believe this to be a strong framework for the analysis of trends over time.

Our annual model of occupancy was based from data on $i = 1,\ldots,N$ survey points, $j = 1,\ldots,M$ fires, and $k = 1,\ldots,K$ survey intervals, with values for N, M, and K, unique to survey year. For the eight years of monitoring, these values were: 899, 860, 895, 953, 1008, 976, 969, 954, 881, and 929 for N points in 2009–2018 respectively; 51, 49, 50, 52, 53, 51, 50, 50, 47, and 49 for M fires; and 5, 9, 6, 6, 6, 6, 6, 6, 6, and 6 for K survey intervals (combined passive surveys with 3 broadcast surveys).

The observational data for our model consisted of encounter histories for each survey point. In 2009, our field protocol consisted of what might be called a 'double' removal design (Farnsworth et al. 2002), such that only the first interval of encounter was recorded for the passive count intervals, and the count was discontinued following a detection on the broadcast count intervals. In 2010 - 2018, a full detection history recording all detections or non-detections was recorded for all passive survey intervals, while the removal design (i.e., discontinuing counts following the initial broadcast-based detection) was used for broadcast intervals. This sampling framework resulted in 32 possible detection histories for 2018, the results of which are summarized in Table 1. Tables of encounter histories for previous years can be found in previous annual reports (Siegel et al. 2010, 2011, 2012, 2014a, 2014b, 2015, 2016, 2017, and 2018).

Table 1. Encounter history frequencies (numbers of survey points) in the 2018 Black-backed Woodpecker survey data from burned areas. For passive surveys, the total number of survey intervals that one or more Black-backed Woodpeckers were detected in is listed (passive surveys were only conducted at approximately half of points). For broadcast survey capture histories, 1 indicates detections, 0 indicates non-detection, and NA indicates missing data (by design, see text for detail).

Number of passive detections	**Broadcast History**			**Frequency**
	Interval 1	*Interval 2*	*Interval 3*	
-	0	0	0	395
-	0	0	1	16
-	0	1	NA	13
-	1	NA	NA	52
0	0	0	0	368
0	0	0	1	15
0	0	1	NA	17
0	1	NA	NA	17
1	0	0	0	7
1	0	0	1	1
1	0	1	NA	1
1	1	NA	NA	7
2	0	0	0	0
2	0	0	1	2
2	0	1	NA	1
2	1	NA	NA	4
3	0	0	0	2
3	0	0	1	0
3	0	1	NA	0
3	1	NA	NA	11

To model annual occupancy, we used a hierarchical modeling framework (Royle and Dorazio 2008) to build separate but linked models for the observation (detection) and state (occupancy) processes. Our occupancy model structure identically followed that described in the 2011 analysis (Siegel et al. 2012). This structure subdivides the state (i.e., true occurrence) observation into two hierarchical levels separating the processes that determine whether a fire is occupied (more accurately, the portion of a fire surveyed by all points), and the processes that determine whether a point is occupied. This separation of fire-level and point-level occupancy processes better describe the heterogeneity of the system and the observed dynamics of woodpecker occupancy (Tingley et al. 2018).

For each year of data, the same set of covariates was used for modeling occupancy (both fire-level and point-level) and detectability. Detectability was modeled as a function of survey interval duration (3-minute or 2-minute), survey type (passive or broadcast), and day of year. Fire-level occupancy was modeled as a function of fire age but was also allowed a random fire-level effect (Saracco et al. 2011). Point-level occupancy was modeled as a function of latitude, elevation, snag density, pre-fire canopy cover, and burn severity (see *Goals and analysis structure*, above). All combinations of these covariates had pairwise correlations < |0.4|, except for elevation and latitude (rho ~ 0.65), which we addressed by using the residuals of a regression of elevation on latitude rather than unadjusted elevation values.

We implemented a Bayesian analysis of the model using Markov chain Monte Carlo (MCMC) methods (Gilks et al. 1996) in the software package JAGS (Plummer 2003). We used vague prior distributions for all model parameters. For all covariate effects in the model we used Normal(mean = 0, precision = 0.1) priors. We assigned a prior of Normal(0, $1/\sigma_f^2$) for the random point effect ($fire_j$) in the model for ω_j, and a prior of Uniform(0,10) for the variance parameter σ_f. For the intercepts of the p and ψ models, we defined priors for inverse-logit transformed parameters using Uniform(0, 1). We conducted the JAGS analysis from R (R Development Core Team 2012) using the R2jags package (Su and Yajima 2014). Further details of model structure and parameterization, are provided in our previous analyses (Siegel et al. 2011, 2012, 2014a, b, 2015–2018).

Modeling point-level dynamic occupancy. Detectability, initial occupancy, colonization and extinction of Black-backed Woodpeckers at survey points over time were modeled using a dynamic occupancy framework (MacKenzie et al. 2003). In this framework, initial occupancy (ψ_0) is modeled for all survey points in the first year of sampling, and then the occurrence status is allowed to change between years according to an estimated probability of colonization (γ) or extinction (ε). Thus, the probability of occupancy at time t is dependent on both the initial occupancy probability as well as the probability (combined γ and ε) that the point has transitioned states from time 0 to time t.

In this dynamic framework, ψ has a slightly different interpretation from the previous analysis (*Modeling annual occupancy*). First, as the focus was on colonization and extinction dynamics, occupancy was modeled only at the point level (i.e., no fire-level occupancy) and occurrence at neighboring points within the same fire were assumed to be independent (i.e., no random effect of fire). Second, in a dynamic framework, average occupancy for year *t* is based upon the total number of points that are surveyed across all years, not the total number of points that were actually surveyed in year *t*. In other words, the dynamic framework estimates occupancy in any year across all 2365 survey points, not the ~850-1000 that were visited in any given survey season. As occupancy estimates are always proportions, the occupancy estimates derived from the two analyses will always be different due to different denominators within the occupancy proportions. Thus, care needs be taken when comparing occupancy estimates derived from the two analyses.

Dynamic occupancy modeling was conducted in a likelihood-based framework, whereby different competing models were built and their relative strength was measured using the Akaike Information Criterion (AIC; Burnham and Anderson 2002). In this model selection framework, competing models are built using all possible combinations of *a priori* selected variables. Since four variables can be parameterized (p, ψ_0, γ, and ε), this can lead to an untenable number of competing models. Thus, we used a two-step process, through which the best parameterization for p and ψ_0 was determined by AIC, and then that single parameterization was used for all competing models of γ and ε. Similar to the previous analysis, for detectability we investigated the effect of interval duration, survey type and day of year. For initial occupancy, we only investigated the effect of elevation (including quadratic effects) and latitude. Combined, these factors resulted in 48 competing models which were combined with null (i.e., random) model parameterizations for colonization and extinction. All 48 models were run and the best supported model was selected as the one with the lowest AIC.

Following selection of the best supported parameterization for detectability and initial occupancy, this parameterization was used to compare differently parameterized models of colonization and extinction. We tested the effects of snag density (snags per ha [all sizes pooled], as estimated from counts of all size within a 50-m radius of survey points), fire age, burn severity (as measured by the % change in canopy cover following fire, Miller at al. 2009), and pre-fire canopy cover (%) as potential covariates for both colonization and extinction. Including all additive combinations of these covariates, this resulted in 256 uniquely parameterized competing models, each with the same initial occupancy and detectability covariates, but with different colonization and extinction covariates. Support within the data for each model was determined through comparisons of AIC (Arnold 2010) and the calculation of summed model weights (Burnham and Anderson 2002). Model averaging over all models in the candidate set (Burnham and Anderson 2002), following the guidelines of Arnold (2010), was used to provide predictive inference on relationships between model parameters and covariates. All models were run in R version 3.4.4 (R Core Team 2018) using the 'colext()' function from the package 'unmarked' (Fiske and Chandler 2011).

Black-backed Woodpecker Surveys in Beetle-kill Forest Stands

We used Forest Service Region 5 Aerial Detection Survey (ADS) data (https://www.fs.usda.gov/detail/r5/forest-grasslandhealth/?cid=fseprd506712) to identify forest stands with elevated tree mortality, presumably due to a combination of the recent drought and colonization by bark beetles (hereafter 'beetle-kill' stands). We limited consideration to sites within property boundaries of the ten Sierra/Cascades ecoregion National Forest units. Portions of ADS polygons that overlapped with recent fires (less than ten years old) were identified using Forest Service Region 5 Vegetation Burn Severity GIS layer for the 2017 fire year, available from https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd596278.zip, and removed from consideration using GIS. In order to ensure the remaining high-mortality polygons were large enough to accommodate a survey transect with enough survey points to ensure reasonably high survey efficiency, we discarded polygons with area < 250 ha. We drew a random sample of the polygons that met our criteria, and then assessed road length and vegetation coverage in each selected polygon to ensure that it contained enough road length within coniferous forest to accommodate a survey transect. Smaller polygons that could not fit a complete survey transect in conifer forest were paired with a second polygon by selecting the closest neighboring polygon that met all of the above criteria. Selected polygons were visited in a largely random priority order (with minor deviations for logistical reasons), and surveyed according to the same methods described above for fires.

Results

Scope of Survey Work Completed

In 2018 we completed surveys fully to protocol at 49 fires distributed across 9 of the 10 focal National Forests (our random draw yielded no fires to visit on Tahoe Basin Management Unit; Table 2), including broadcast surveys and habitat assessments at 929 survey points and passive, multi-species point counts at 453 of those points. All surveys were conducted between 17 May and 12 July, 2018 and surveyed fires encompassed nearly the full latitudinal range of the surveyed National Forests. Combined with data collected during 2009-2017 we now have broadcast surveys and habitat assessment data at 2,365 unique survey points within 125 fires. We provide summary information about fires surveyed once or more between 2009 and 2018 in Table 2.

Additionally, in 2018, we completed surveys for Black-backed Woodpeckers in 68 beetle-kill forest stands across 8 National Forests (Modoc, Lassen, Plumas, Lake Tahoe Basin, Eldorado, Stanislaus, Sierra, Sequoia). These surveys included broadcast and habitat assessments at 849 survey points, and passive, multi-species point counts at 413 of those points. Combined with similar data collected in 2017, we have now conducted Black-backed Woodpecker surveys at a total of 1601 survey points across 132 beetle-kill forest stands. Results for Black-backed Woodpecker occurrence in beetle-kill stands are provided in the section “Results from Beetle-kill Forest Stands,” below.

Black-backed Woodpecker Detections

In 2018 we detected Black-backed Woodpeckers at 166 survey points distributed across 24 of the 49 fires we surveyed (Figs. 2-4). We detected Black-backed Woodpeckers at one or more fires at 6 of 9 National Forest units surveyed in our study area in 2018. Woodpeckers were not detected in Eldorado, Lassen, or Stanislaus National Forests, where we surveyed at a cumulative total of 9 fires (Table 2). All of these National Forest units have contained one or more Black-backed Woodpecker detections in previous years. As was the case in previous years, we detected Black-backed Woodpeckers on both the west and east sides of the Sierra crest, and across nearly the full latitudinal range of our study area, including the most northerly fire we surveyed (the Barry

Point fire on the Modoc NF; Fig. 2), and the second-most southerly fire we surveyed (the Cedar fire on the Sequoia NF; Fig. 5).

Table 2. Summary information for each fire surveyed once or more during the 2009 – 2018 field seasons of Black-backed Woodpecker MIS monitoring on Sierra Nevada National Forests.

Primary National Forest	Fire name	Year of fire	Dominant pre-fire habitat[1]	Number of points surveyed									
				2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Eldorado	Freds	2004	SMC	20	0	19	20	20	20	0	0	0	0
Eldorado	King	2014	SMC	0	0	0	0	0	0	0	20	0	0
Eldorado	Plum	2002	SMC	12	12	12	13	0	0	0	0	0	0
Eldorado	Power	2004	SMC	20	20	20	20	20	20	0	0	0	0
Eldorado	Star	2001	SMC	0	20	20	0	0	0	0	0	0	0
Eldorado	Trailhead	2016	MHC	0	0	0	0	0	0	0	0	0	13
Inyo	Azusa	2000	PJN	8	0	0	0	0	0	0	0	0	0
Inyo	Birch	2002	PJN	19	0	0	0	0	0	0	0	0	0
Inyo	Clark	2016	JPN	0	0	0	0	0	0	0	0	20	20
Inyo	Crater	2001	JPN	20	20	20	0	0	0	0	0	0	0
Inyo	Dexter	2003	JPN	16	16	0	16	16	0	0	0	0	0
Inyo	Inyo Complex	2007	PPN	16	0	0	0	0	0	0	0	0	0
Inyo	Mclaughlin	2001	JPN	0	13	13	0	0	0	0	0	0	0
Inyo	Owens River	2016	JPN	0	0	0	0	0	0	0	0	20	20
Inyo	Sawmill 00	2000	PPN	5	0	0	0	0	0	0	0	0	0
Inyo	Sawmill 06	2006	PJN	0	0	19	0	20	0	20	0	0	0
Inyo	Sherwin	2008	SMC	0	0	0	0	13	13	0	0	13	13
Inyo	Summit	2003	JPN	0	0	16	0	16	0	0	0	0	0
Inyo	Walker	2015	JPN	0	0	0	0	0	0	0	17	16	16
Lassen	Bald	2014	SMC	0	0	0	0	0	0	20	20	20	20
Lassen	Brown	2009	SMC	0	20	20	20	19	20	20	20	19	20
Lassen	Cone	2002	JPN	21	0	21	0	0	0	0	0	0	0
Lassen	Corral	2008	EPN	0	0	0	20	20	20	20	20	20	20
Lassen	Cub	2008	SMC	0	20	20	15	20	20	21	20	0	20
Lassen	Eiler	2014	SMC	0	0	0	0	0	0	20	20	18	0
Lassen	Onion 2	2008	SMC	0	20	20	20	20	20	20	20	20	20

Primary National Forest	Fire name	Year of fire	Dominant pre-fire habitat[1]	Number of points surveyed									
				2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Lassen	Peterson Complex	2008	EPN	20	20	20	20	20	20	20	0	20	0
Lassen	Reading	2012	SMC	0	0	0	0	20	20	20	20	20	0
Lassen	Straylor	2004	EPN	0	0	0	20	20	20	0	0	0	0
Lassen	Sugar Loaf	2009	SMC	0	21	21	21	21	21	20	21	21	20
Modoc	Barry Point	2012	EPN	0	0	0	0	20	20	20	0	0	20
Modoc	Bell	2001	JUN	20	20	20	0	0	0	0	0	0	0
Modoc	Bell West	1999	EPN	21	0	0	0	0	0	0	0	0	0
Modoc	Blue	2001	EPN	20	20	20	0	0	0	0	0	0	0
Modoc	Cougar	2011	PPN	0	0	0	20	0	20	20	0	0	20
Modoc	Cove	2017	SMC	0	0	0	0	0	0	0	0	0	20
Modoc	Fletcher	2007	EPN	19	17	19	20	20	20	0	20	0	0
Modoc	Frog	2015	SMC	0	0	0	0	0	0	0	20	20	20
Modoc	High	2006	EPN	0	19	19	19	0	19	0	19	0	0
Modoc	Soup 2	2016	SMC	0	0	0	0	0	0	0	0	18	18
Modoc	Steele	2017	PPN	0	0	0	0	0	0	0	0	0	20
Plumas	Antelope Cplx	2007	SMC	21	21	21	21	21	21	20	21	21	0
Plumas	Bar	2010	SMC	0	0	0	0	0	0	0	19	19	19
Plumas	Belden	2008	SMC	0	13	13	13	13	13	13	13	0	0
Plumas	Boulder Cplx	2006	EPN	20	20	0	0	20	20	0	0	0	0
Plumas	Bucks	1999	SMC	20	0	0	0	0	0	0	0	0	0
Plumas	Chips	2012	SMC	0	0	0	0	20	20	20	20	0	0
Plumas	Cold	2008	SMC	0	0	0	19	19	19	0	19	19	19
Plumas	Devils Gap	1999	SMC	20	0	0	0	0	0	0	0	0	0
Plumas	Fox	2008	MHC	0	0	18	0	20	18	20	20	20	20
Plumas	Frey	2008	SMC	0	20	18	0	20	20	0	18	20	19
Plumas	Grease	2006	EPN	0	0	0	17	17	17	0	17	0	0
Plumas	Horton 2	1999	SMC	20	0	0	0	0	0	0	0	0	0
Plumas	Lookout	1999	SMC	21	0	0	0	0	0	0	0	0	0

Primary National Forest	Fire name	Year of fire	Dominant pre-fire habitat[1]	Number of points surveyed									
				2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Plumas	Minerva 5	2017	SMC	0	0	0	0	0	0	0	0	0	20
Plumas	Moonlight	2007	SMC	20	20	20	20	0	20	20	20	20	0
Plumas	Peak	2012	SMC	0	0	0	0	0	0	20	20	20	20
Plumas	Pidgen	1999	SMC	18	0	0	0	0	0	0	0	0	0
Plumas	Pit	2008	MHC	0	0	0	20	20	0	20	0	20	20
Plumas	Rich	2008	SMC	21	21	0	21	0	20	21	20	20	0
Plumas	Scotch	2008	SMC	21	21	0	21	20	21	21	0	0	21
Plumas	Silver	2009	SMC	0	0	11	11	11	11	11	11	11	11
Plumas	Storrie	2000	RFR	15	0	0	0	0	0	0	0	0	0
Plumas	Stream	2001	EPN	20	20	15	0	0	0	0	0	0	0
Sequoia	Albanita	2003	JPN	21	21	21	21	21	0	0	0	0	0
Sequoia	Broder Beck	2006	JPN	0	20	20	20	20	20	20	20	0	0
Sequoia	Cabin	2015	JPN	0	0	0	0	0	0	0	18	9	18
Sequoia	Cedar	2016	SMC	0	0	0	0	0	0	0	0	20	20
Sequoia	Clover	2008	JPN	0	20	20	20	0	0	0	0	15	20
Sequoia	Comb	2005	SMC	0	0	0	20	20	21	0	0	0	0
Sequoia	Cooney	2003	SMC	0	0	0	20	20	0	0	0	0	0
Sequoia	Crag 04	2004	JPN	19	0	18	19	19	0	0	0	0	0
Sequoia	Crag 05	2005	JPN	21	20	21	21	21	21	20	0	0	0
Sequoia	Deep	2004	SMC	11	11	11	11	11	11	0	0	0	0
Sequoia	Fish	2013	SMC	0	0	0	0	0	20	19	20	0	19
Sequoia	George	2012	JPN	0	0	0	0	20	20	20	20	20	20
Sequoia	Granite	2009	SMC	0	20	20	0	20	20	20	20	19	20
Sequoia	Highway	2001	MHC	0	0	20	0	0	0	0	0	0	0
Sequoia	Hooker	2003	JPN	20	16	20	20	0	0	0	0	0	0
Sequoia	Jacoboson	2016	SMC	0	0	0	0	0	0	0	0	19	18
Sequoia	Lion 17	2017	SMC	0	0	0	0	0	0	0	0	0	20
Sequoia	Lion	2009	LPN	0	20	20	20	20	0	20	20	20	20

Primary National Forest	Fire name	Year of fire	Dominant pre-fire habitat[1]	Number of points surveyed									
				2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Sequoia	Lion 11	2011	SMC	0	0	0	20	0	20	20	20	0	0
Sequoia	Manter	2000	PJN	21	20	0	0	0	0	0	0	0	0
Sequoia	McNally	2002	SMC	19	17	16	17	0	0	0	0	0	0
Sequoia	Meadow	2016	SMC	0	0	0	0	0	0	0	0	12	0
Sequoia	Pier	2017	MHC	0	0	0	0	0	0	0	0	0	20
Sequoia	Piute 08	2008	SMC	20	19	0	0	20	20	20	20	20	20
Sequoia	Sheep	2010	SMC	0	0	0	20	20	21	0	0	0	0
Sequoia	Shotgun	2009	SMC	0	0	0	16	0	0	15	15	0	13
Sequoia	Soda	2014	JPN	0	0	0	0	0	0	20	20	20	20
Sequoia	Tamarack	2006	SMC	0	0	0	20	20	19	20	20	0	0
Sequoia	Vista	2007	JPN	19	19	19	19	0	19	19	19	0	0
Sierra	Aspen	2013	SMC	0	0	0	0	0	20	20	20	20	20
Sierra	Bear	2012	JPN	0	0	0	0	20	20	20	20	0	20
Sierra	French	2014	SMC	0	0	0	0	0	0	20	20	20	0
Sierra	Motor	2011	BOP	0	0	0	24	0	0	0	0	0	0
Sierra	North Fork	2001	SMC	20	13	8	0	0	0	0	0	0	0
Sierra	Oliver	2008	SMC	0	0	17	0	15	0	20	19	19	0
Sierra	Railroad	2017	SMC	0	0	0	0	0	0	0	0	0	20
Sierra	Rough	2015	SMC	0	0	0	0	0	0	0	0	20	20
Sierra	Tehipite	2008	SMC	0	0	0	21	21	0	20	21	21	21
Stanislaus	Dome Rock	2008	SMC	0	0	0	0	0	19	19	19	0	19
Stanislaus	El Portal	2014	SMC	0	0	0	0	0	0	0	16	16	0
Stanislaus	Hiram	1999	JPN	10	0	0	0	0	0	0	0	0	0
Stanislaus	Kibbie	2003	SMC	21	0	21	21	21	0	0	0	0	0
Stanislaus	Knight	2009	SMC	0	19	19	19	19	19	19	19	19	0
Stanislaus	Mountain	2003	RFR	0	12	12	9	0	0	0	0	0	0
Stanislaus	Mud	2003	RFR	21	20	21	21	21	0	0	0	0	0
Stanislaus	Power 13	2013	MHC	0	0	0	0	0	0	20	0	0	18

Primary National Forest	Fire name	Year of fire	Dominant pre-fire habitat[1]	Number of points surveyed									
				2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Stanislaus	Ramsey	2012	SMC	0	0	0	0	20	20	20	20	20	0
Stanislaus	Rim	2013	SMC	0	0	0	0	0	20	20	20	20	0
Stanislaus	Whit	2003	SMC	20	0	20	19	19	0	0	0	0	0
Stanislaus	White	2001	SMC	8	8	8	0	0	0	0	0	0	0
Tahoe	American	2013	SMC	0	0	0	0	0	20	0	0	20	0
Tahoe	Bassetts	2006	SMC	18	18	0	19	17	17	17	18	0	0
Tahoe	Fall	2008	SMC	10	10	10	10	19	18	19	0	19	19
Tahoe	Gap	2001	SMC	0	20	19	0	0	0	0	0	0	0
Tahoe	Government	2008	SMC	19	19	19	0	19	19	19	0	19	19
Tahoe	Harding	2005	EPN	21	21	21	20	20	21	21	0	0	0
Tahoe	Peavine	2008	SMC	16	0	0	0	0	0	16	16	0	16
Tahoe	Treasure	2001	EPN	10	10	0	0	0	0	0	0	0	0
Tahoe Basin	Angora	2007	SMC	19	12	19	19	19	18	19	19	19	0
Tahoe Basin	Gondola	2002	RFR	12	12	0	12	0	0	0	0	0	0
Tahoe Basin	Showers	2002	SMC	9	9	0	8	0	0	0	0	0	0

[1]Habitat classifications follow California Habitat Relationships (CWHR; California Department of Fish and Game 2005), and indicate the primary pre-fire habitat at the greatest number of survey points in a particular fire, based on our own on-the-ground assessments. Class codes are: BOP = Blue Oak-Foothill Pine; EPN = Eastside Pine; JPN = Jeffrey Pine; JUN = Juniper; LPN = Lodgepole Pine; MHC = Mixed Hardwood-Conifer; PJN = Pinyon-Juniper; PPN = Ponderosa Pine; RFR = Red Fir; and SMC = Sierra Mixed Conifer.

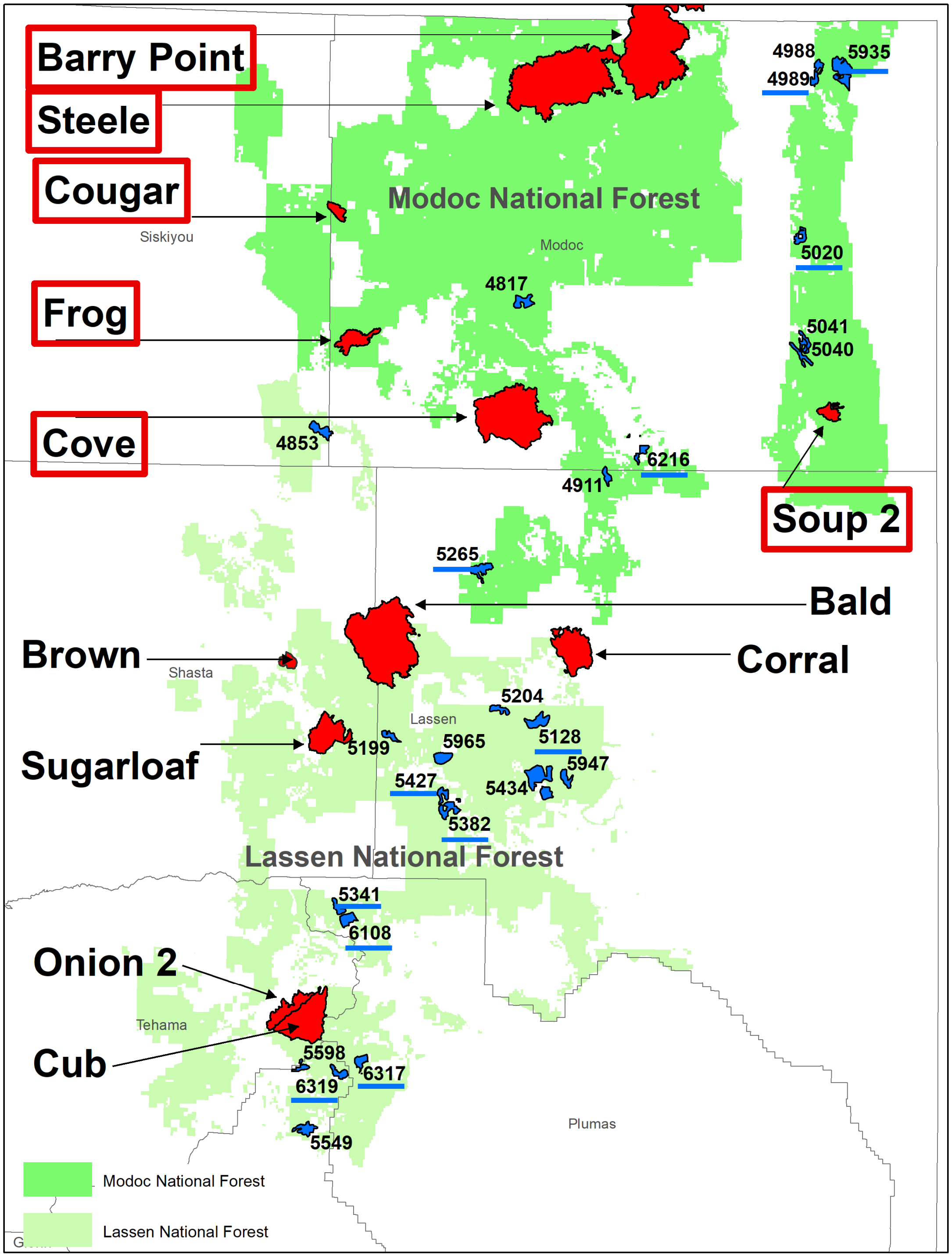

Figure 2. Fires (red shading) on the Modoc and Lassen National Forests surveyed for Black-backed Woodpeckers during the 2018 MIS monitoring field season. Names of fires where Black-backed Woodpeckers were detected are enclosed in red boxes. Lack of detection does not necessarily mean Black-backed Woodpeckers were absent (see text for discussion of detection probability during this survey). Drought-killed forest patches surveyed in 2018 for Black-backed Woodpeckers are colored in blue and labeled with a polygon number designated by IBP. Polygon numbers underlined in blue indicate one or more Black-backed Woodpecker detections.

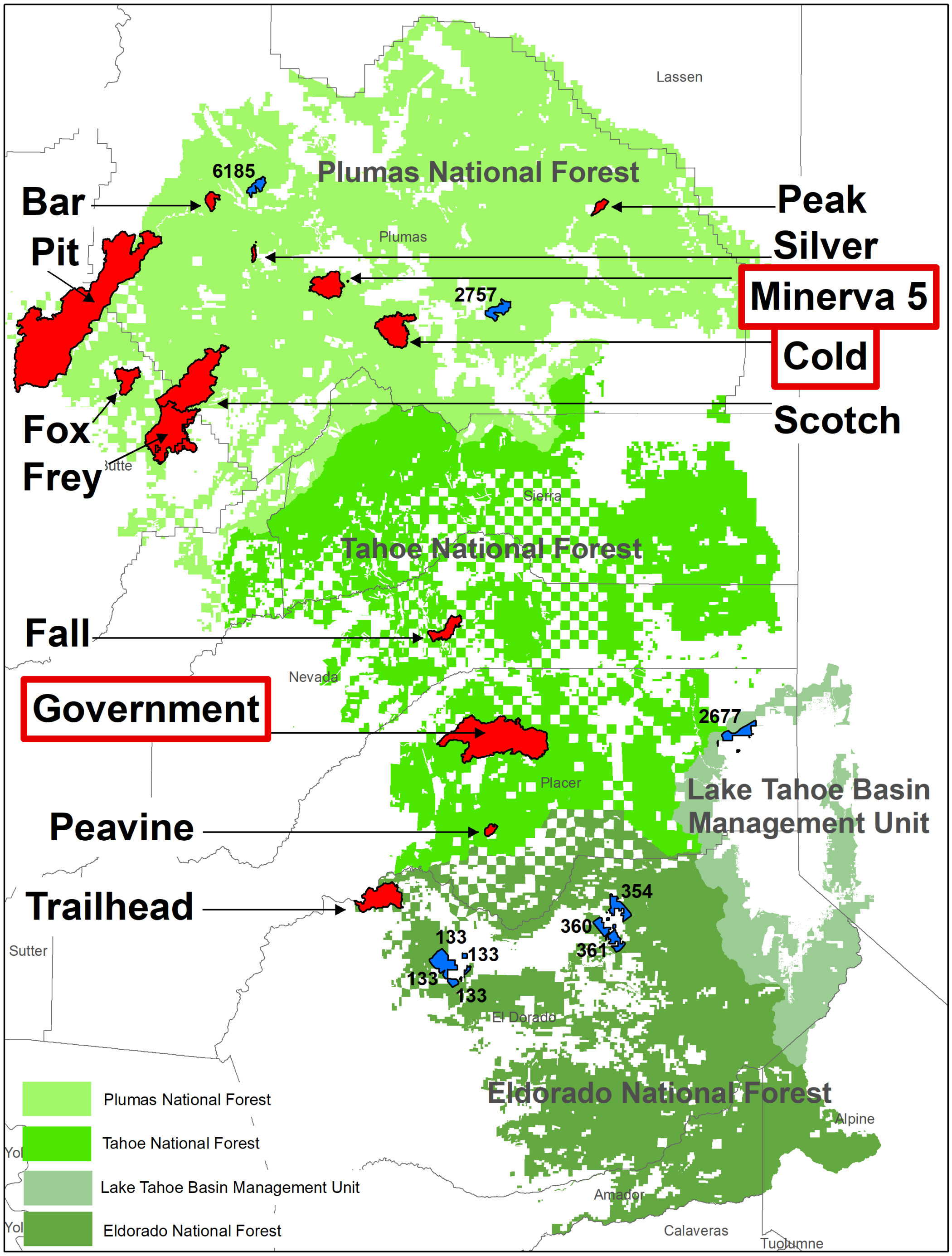

Figure 3. Fires (red shading) on the Plumas, Tahoe, and Eldorado National Forests and the Lake Tahoe Basin Management Unit surveyed for Black-backed Woodpeckers during the 2018 MIS monitoring field season. Names of fires where Black-backed Woodpeckers were detected are enclosed in red boxes. Lack of detection does not necessarily mean Black-backed Woodpeckers were absent (see text for discussion of detection probability during this survey). Drought-killed forest patches surveyed in 2018 for Black-backed Woodpeckers are colored in blue and labeled with a polygon number designated by IBP. Polygon numbers underlined in blue indicate one or more Black-backed Woodpecker detections.

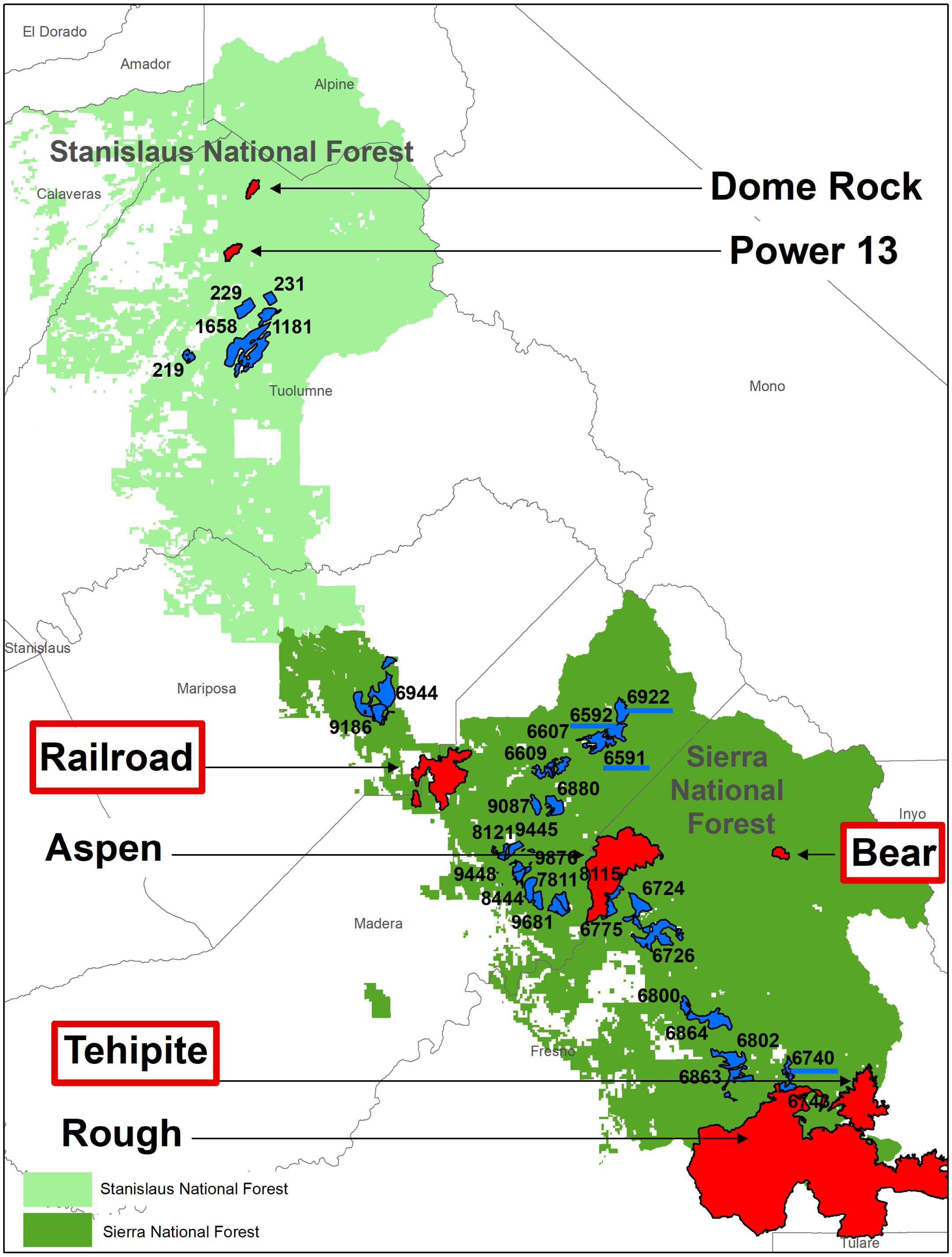

Figure 4. Fires (red shading) on the Stanislaus and Sierra National Forests surveyed for Black-backed Woodpeckers during the 2018 MIS monitoring field season. Names of fires where Black-backed Woodpeckers were detected are enclosed in red boxes. Lack of detection does not necessarily mean Black-backed Woodpeckers were absent (see text for discussion of detection probability during this survey). Drought-killed forest patches surveyed in 2018 for Black-backed Woodpeckers are colored in blue and labeled with a polygon number designated by IBP. Polygon numbers underlined in blue indicate one or more Black-backed Woodpecker detections.

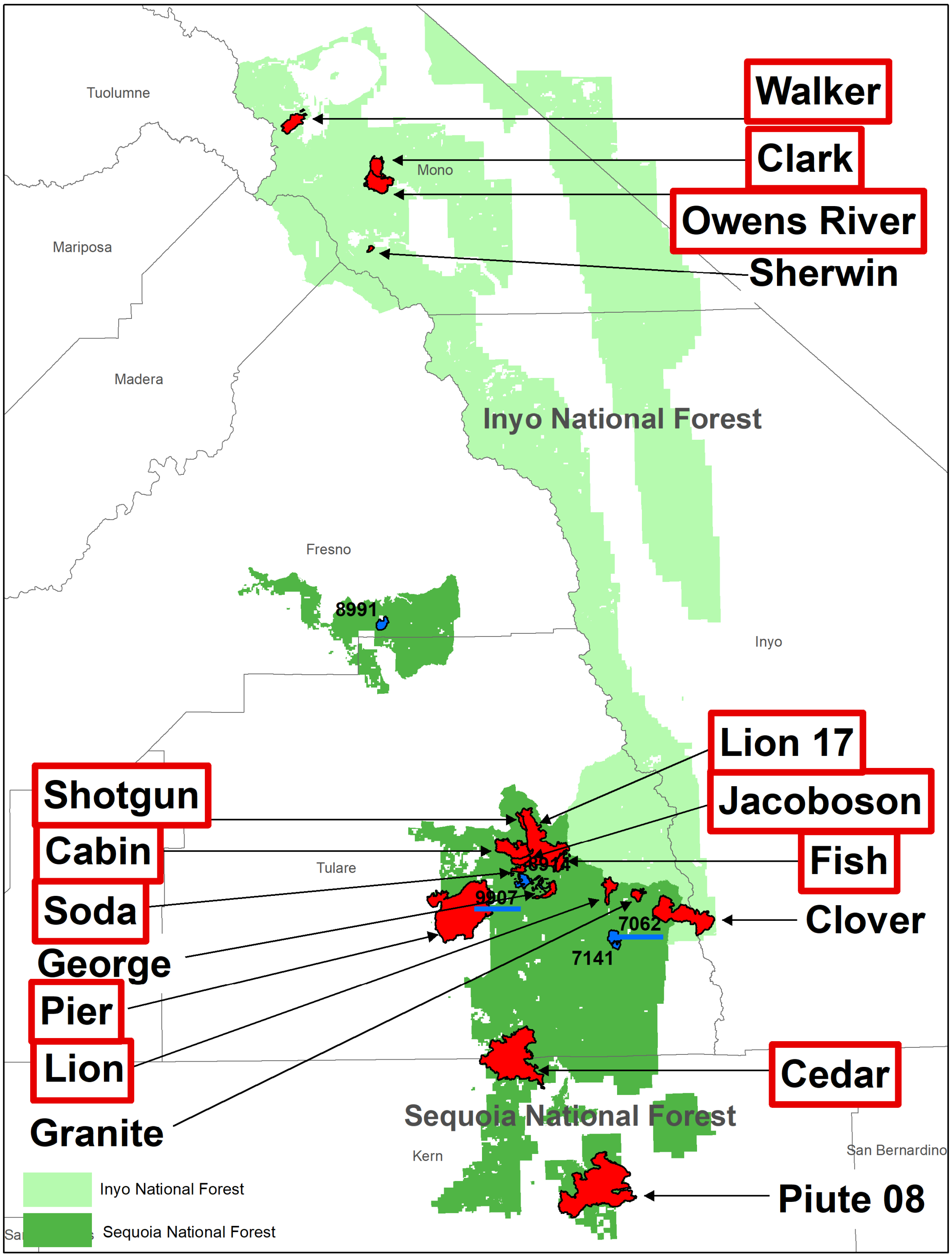

Figure 5. Fires (red shading) on the Inyo and Sequoia National Forests surveyed for Black-backed Woodpeckers during the 2018 MIS monitoring field season. Names of fires where Black-backed Woodpeckers were detected are enclosed in red boxes. Lack of detection does not necessarily mean Black-backed Woodpeckers were absent (see text for discussion of detection probability during this survey). Drought-killed forest patches surveyed in 2018 for Black-backed Woodpeckers are colored in blue and labeled with a polygon number designated by IBP. Polygon numbers underlined in blue indicate one or more Black-backed Woodpecker detections.

Analysis of Annual Occupancy

Mean occupancy probability for points in fires surveyed in 2018 was 0.21 (95% credible interval: 0.19 – 0.22; Fig. 6b). Point-level occupancy probability has varied substantially over the 10 years of the study, and the estimate obtained for 2018 is within the range of variation observed between 2010 – 2017 (Fig. 6b). Table 3 summarizes detections and Table 4 summarizes predicted occupancy probabilities for each fire surveyed in 2009 through 2018.

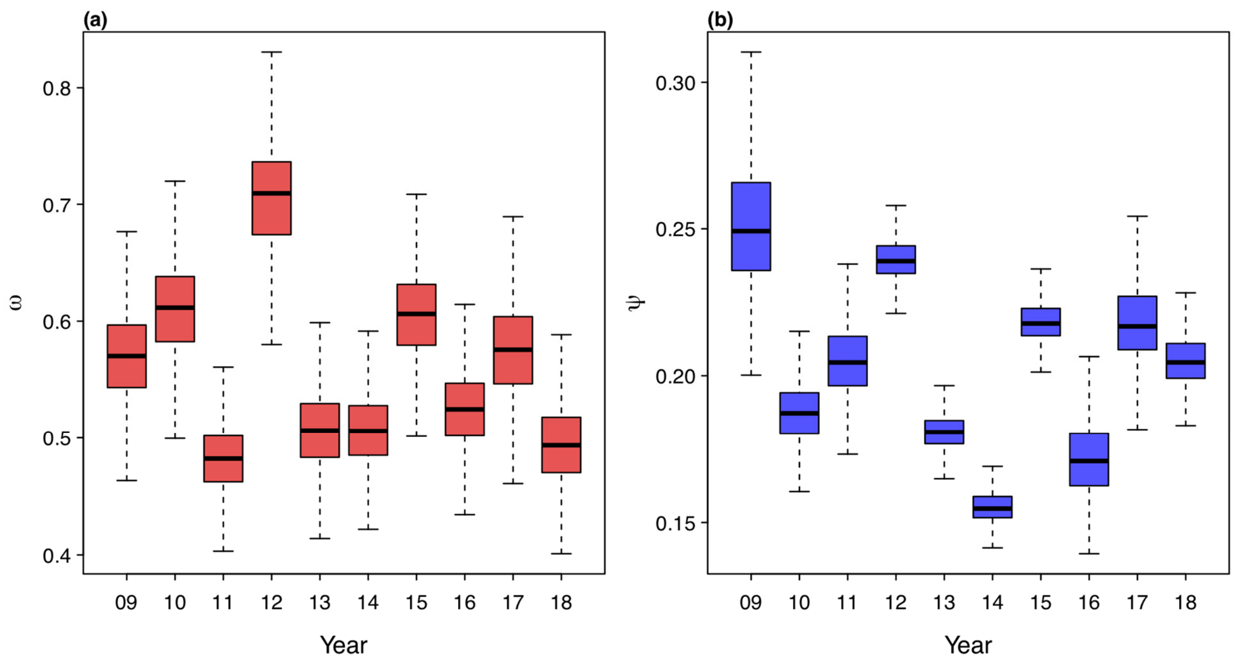

Figure 6. Mean probability of fire-level (ω, panel 'a') and point-level (ψ, panel 'b') occupancy for Black-backed Woodpeckers as modeled from individual year-based hierarchical models. Plots show median (bold line), 50% (box) and 95% (whiskers) Bayesian credible intervals of posterior distribution of modeled parameters.

Table 3. Summary of Black-backed Woodpecker positive detections at surveyed points for each fire visited during 2009 - 2018.

	Number of detections (Number of points surveyed)									
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Albanita	1 (21)	0 (21)	0 (21)	6 (21)	0 (21)	-	-	-	-	-
American	-	-	-	-	-	0 (20)	-	-	6 (20)	-
Antelope Complex	9 (21)	2 (21)	6 (21)	8 (21)	4 (21)	2 (21)	6 (20)	1 (21)	7 (21)	-
Angora	13 (19)	7 (12)	13 (19)	13 (19)	13 (19)	9 (18)	3 (19)	0 (19)	0 (19)	-
Aspen	-	-	-	-	-	6 (20)	0 (20)	1 (20)	0 (20)	0 (20)
Azusa	0 (8)	-	-	-	-	-	-	-	-	-
Bald	-	-	-	-	-	-	6 (20)	2 (20)	0 (20)	0 (20)
Barry Point	-	-	-	-	17 (20)	15 (20)	14 (20)	-	-	5 (20)
Bar	-	-	-	-	-	-	-	0 (19)	1 (19)	0 (19)
Bassetts	7 (18)	7 (18)	-	5 (19)	2 (17)	1 (17)	0 (17)	1 (18)	-	-
Bear	-	-	-	-	15 (20)	11 (20)	3 (20)	1 (20)	-	4 (20)
Belden	-	0 (13)	0 (13)	0 (13)	0 (13)	0 (13)	0 (13)	0 (13)	-	-
Bell	0 (20)	0 (20)	0 (20)	-	-	-	-	-	-	-
Bell West	1 (21)	-	-	-	-	-	-	-	-	-
Birch	0 (19)	-	-	-	-	-	-	-	-	-
Blue	5 (20)	5 (20)	5 (20)	-	-	-	-	-	-	-
Boulder Complex	9 (20)	1 (20)	-	-	1 (20)	0 (20)	-	-	-	-
Broder Beck	-	7 (20)	0 (20)	2 (20)	3 (20)	5 (20)	5 (20)	5 (20)	-	-
Brown	-	7 (20)	14 (20)	10 (20)	2 (19)	0 (20)	1 (20)	0 (20)	0 (19)	0 (20)
Bucks	0 (20)	-	-	-	-	-	-	-	-	-
Cabin	-	-	-	-	-	-	-	4 (18)	4 (9)	12 (18)
Cedar	-	-	-	-	-	-	-	-	0 (20)	7 (20)
Chips	-	-	-	-	1 (20)	5 (20)	4 (20)	8 (20)	-	-
Clark	-	-	-	-	-	-	-	-	12 (20)	17 (20)
Clover	-	7 (20)	0 (20)	1 (20)	-	-	-	-	0 (15)	0 (20)
Cold	-	-	-	11 (19)	11 (19)	7 (19)	-	7 (19)	6 (19)	8 (19)
Comb	-	-	-	0 (20)	0 (20)	0 (21)	-	-	-	-
Cone	5 (21)	-	6 (21)	-	-	-	-	-	-	-
Cooney	-	-	-	1 (20)	0 (20)	-	-	-	-	-
Corral	-	-	-	10 (20)	7 (20)	2 (20)	2 (20)	0 (20)	2 (20)	0 (20)
Cougar	-	-	-	13 (20)	-	9 (20)	8 (20)	-	-	6 (20)
Cove	-	-	-	-	-	-	-	-	-	12 (20)
Crag 04	4 (19)	-	0 (18)	1 (19)	0 (19)	-	-	-	-	-
Crag 05	0 (21)	0 (20)	0 (21)	0 (21)	0 (21)	0 (21)	0 (20)	-	-	-
Crater	8 (20)	3 (20)	7 (20)	-	-	-	-	-	-	-
Cub	-	3 (20)	3 (20)	1 (15)	5 (20)	5 (20)	3 (21)	2 (20)	-	0 (20)
Deep	0 (11)	0 (11)	0 (11)	0 (11)	0 (11)	0 (11)	-	-	-	-

Fire name	Number of detections (Number of points surveyed)									
	2009	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Devils Gap	0 (20)	-	-	-	-	-	-	-	-	-
Dexter	6 (16)	1 (16)	-	7 (16)	0 (16)	-	-	-	-	-
Dome Rock	-	-	-	-	-	6 (19)	2 (19)	4 (19)	-	0 (19)
Eiler	-	-	-	-	-	-	13 (20)	15 (20)	8 (18)	-
El Portal	-	-	-	-	-	-	-	0 (16)	0 (16)	-
Fall	0 (10)	1 (10)	0 (10)	1 (10)	4 (19)	4 (18)	3 (19)	-	2 (19)	0 (19)
Fish	-	-	-	-	-	7 (20)	14 (19)	4 (20)	-	6 (19)
Fletcher	15 (19)	5 (17)	8 (19)	10 (20)	0 (20)	0 (20)	-	3 (20)	-	-
Fox	-	-	0 (18)	-	0 (20)	0 (18)	0 (20)	0 (20)	0 (20)	0 (20)
Freds	0 (20)	-	0 (19)	0 (20)	0 (20)	0 (20)	-	-	-	-
French	-	-	-	-	-	-	0 (20)	0 (20)	1 (20)	-
Frey	-	0 (20)	0 (18)	-	0 (20)	0 (20)	-	0 (18)	0 (20)	0 (19)
Frog	-	-	-	-	-	-	-	14 (20)	15 (20)	7 (20)
Gap	-	0 (20)	0 (19)	-	-	-	-	-	-	-
George	-	-	-	-	2 (20)	1 (20)	6 (20)	6 (20)	0 (20)	0 (20)
Gondola	6 (12)	4 (12)	-	2 (12)	-	-	-	-	-	-
Government	1 (19)	3 (19)	4 (19)	-	6 (19)	3 (19)	0 (19)	-	4 (19)	1 (19)
Granite	-	6 (20)	10 (20)	-	10 (20)	10 (20)	12 (20)	0 (20)	5 (19)	0 (20)
Grease	-	-	-	0 (17)	0 (17)	0 (17)	-	0 (17)	-	-
Harding	7 (21)	2 (21)	0 (21)	0 (20)	0 (20)	0 (21)	0 (21)	-	-	-
High	-	1 (19)	5 (19)	11 (19)	-	1 (19)	-	8 (19)	-	-
Highway	-	-	0 (20)	-	-	-	-	-	-	-
Hiram	0 (10)	-	-	-	-	-	-	-	-	-
Hooker	0 (20)	0 (16)	0 (20)	0 (20)	-	-	-	-	-	-
Horton 2	7 (20)	-	-	-	-	-	-	-	-	-
Inyo Complex	0 (16)	-	-	-	-	-	-	-	-	-
Jacoboson	-	-	-	-	-	-	-	-	9 (19)	7 (18)
Kibbie	6 (21)	-	3 (21)	5 (21)	0 (21)	-	-	-	-	-
King	-	-	-	-	-	-	-	3 (20)	-	-
Knight	-	0 (19)	0 (19)	0 (19)	0 (19)	0 (19)	0 (19)	0 (19)	0 (19)	-
Lion 17	-	-	-	-	-	-	-	-	-	2 (20)
Lion 11	-	-	-	4 (20)	-	0 (20)	1 (20)	0 (20)	-	-
Lion	-	7 (20)	2 (20)	6 (20)	7 (20)	-	10 (20)	5 (20)	10 (20)	5 (20)
Lookout	0 (21)	-	-	-	-	-	-	-	-	-
Manter	0 (21)	0 (20)	-	-	-	-	-	-	-	-
Mclaughlin	-	0 (13)	1 (13)	-	-	-	-	-	-	-
McNally	0 (19)	0 (17)	0 (16)	0 (17)	-	-	-	-	-	-
Meadow	-	-	-	-	-	-	-	-	0 (12)	-
Minerva 5	-	-	-	-	-	-	-	-	-	8 (20)
Moonlight	11 (20)	5 (20)	11 (20)	11 (20)	-	4 (20)	4 (20)	2 (20)	1 (20)	-

	Number of detections (Number of points surveyed)									
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Motor	-	-	-	0 (24)	-	-	-	-	-	-
Mountain	-	1 (12)	3 (12)	4 (9)	-	-	-	-	-	-
Mud	10 (21)	12 (20)	8 (21)	8 (21)	9 (21)	-	-	-	-	-
North Fork	0 (20)	0 (13)	0 (8)	-	-	-	-	-	-	-
Oliver	-	-	6 (17)	-	0 (15)	-	0 (20)	0 (19)	0 (19)	-
Onion 2	-	0 (20)	0 (20)	1 (20)	0 (20)	0 (20)	2 (20)	0 (20)	0 (20)	0 (20)
Owens River	-	-	-	-	-	-	-	-	12 (20)	11 (20)
Peak	-	-	-	-	-	-	17 (20)	12 (20)	6 (20)	0 (20)
Peavine	0 (16)	-	-	-	-	-	1 (16)	0 (16)	-	0 (16)
Peterson Complex	9 (20)	7 (20)	14 (20)	3 (20)	0 (20)	0 (20)	0 (20)	-	1 (20)	-
Piute 08	0 (20)	0 (19)	-	-	0 (20)	0 (20)	0 (20)	0 (20)	0 (20)	0 (20)
Pidgen	0 (18)	-	-	-	-	-	-	-	-	-
Pier	-	-	-	-	-	-	-	-	-	3 (20)
Pit	-	-	-	2 (20)	0 (20)	-	0 (20)	-	0 (20)	0 (20)
Plum	0 (12)	0 (12)	0 (12)	0 (13)	-	-	-	-	-	-
Power 13	-	-	-	-	-	-	0 (20)	-	-	0 (18)
Power	1 (20)	0 (20)	0 (20)	2 (20)	0 (20)	0 (20)	-	-	-	-
Railroad	-	-	-	-	-	-	-	-	-	1 (20)
Ramsey	-	-	-	-	8 (20)	10 (20)	3 (20)	2 (20)	3 (20)	-
Reading	-	-	-	-	12 (20)	8 (20)	15 (20)	8 (20)	11 (20)	-
Rich	1 (21)	1 (21)	-	6 (21)	-	0 (20)	4 (21)	0 (20)	1 (20)	-
Rim	-	-	-	-	-	0 (20)	0 (20)	0 (20)	1 (20)	-
Rough	-	-	-	-	-	-	-	-	3 (20)	0 (20)
Sawmill 06	-	-	0 (19)	-	0 (20)	-	0 (20)	-	-	-
Sawmill 00	0 (5)	-	-	-	-	-	-	-	-	-
Scotch	3 (21)	0 (21)	-	1 (21)	2 (20)	1 (21)	1 (21)	-	-	0 (21)
Sheep	-	-	-	1 (20)	0 (20)	0 (21)	-	-	-	-
Sherwin	-	-	-	-	4 (13)	0 (13)	-	-	0 (13)	0 (13)
Shotgun	-	-	-	3 (16)	-	-	0 (15)	0 (15)	-	2 (13)
Showers	3 (9)	6 (9)	-	4 (8)	-	-	-	-	-	-
Silver	-	-	7 (11)	6 (11)	5 (11)	1 (11)	3 (11)	2 (11)	0 (11)	0 (11)
Soda	-	-	-	-	-	-	4 (20)	0 (20)	0 (20)	2 (20)
Soup 2	-	-	-	-	-	-	-	-	12 (18)	14 (18)
Star	-	6 (20)	1 (20)	-	-	-	-	-	-	-
Steele	-	-	-	-	-	-	-	-	-	15 (20)
Storrie	4 (15)	-	-	-	-	-	-	-	-	-
Straylor	-	-	-	1 (20)	0 (20)	0 (20)	-	-	-	-
Stream	0 (20)	0 (20)	0 (15)	-	-	-	-	-	-	-
Sugar Loaf	-	3 (21)	2 (21)	0 (21)	0 (21)	0 (21)	0 (20)	0 (21)	0 (21)	0 (20)
Summit	-	-	0 (16)	-	0 (16)	-	-	-	-	-

Fire name	Number of detections (Number of points surveyed)									
	2009	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Tamarack	-	-	-	3 (20)	0 (20)	0 (19)	0 (20)	0 (20)	-	-
Tehipite	-	-	-	9 (21)	11 (21)	-	17 (20)	4 (21)	7 (21)	10 (21)
Trailhead	-	-	-	-	-	-	-	-	-	0 (13)
Treasure	2 (10)	4 (10)	-	-	-	-	-	-	-	-
Vista	9 (19)	8 (19)	2 (19)	5 (19)	-	5 (19)	6 (19)	4 (19)	-	-
Walker	-	-	-	-	-	-	-	0 (17)	4 (16)	1 (16)
White	0 (8)	0 (8)	0 (8)	-	-	-	-	-	-	-
Whit	6 (20)	-	7 (20)	9 (19)	4 (19)	-	-	-	-	-
Total	169 (899)	132 (860)	148 (895)	207 (953)	165 (1008)	138 (976)	193 (969)	128 (954)	154 (881)	166 (929)

Table 4. Summary of Black-backed Woodpecker posterior distributions of both fire-level (ω) and average point-level (ψ) predictions of occupancy probability for all fires surveyed during 2009 - 2018.

	Estimated probability of fire-level occupancy (ω)										Estimated probability of average point-level occupancy (ψ)									
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Albanita	0.84	0.12	0.13	0.84	0.04	-	-	-	-	-	0.10	0.00	0.00	0.30	0.00	-	-	-	-	-
American	-	-	-	-	-	0.28	-	-	0.86	-	-	-	-	-	-	0.00	-	-	0.32	-
Antelope Complex	0.90	0.89	0.86	0.86	0.83	0.82	0.83	0.83	0.81	-	0.62	0.23	0.41	0.42	0.26	0.13	0.34	0.20	0.40	-
Angora	0.90	0.89	0.87	0.86	0.83	0.82	0.83	0.13	0.12	-	0.78	0.61	0.73	0.70	0.71	0.54	0.19	0.00	0.00	-
Aspen	-	-	-	-	-	0.93	0.33	0.87	0.23	0.34	-	-	-	-	-	0.32	0.00	0.11	0.00	0.00
Azusa	0.12	-	-	-	-	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-
Bald	-	-	-	-	-	-	0.91	0.88	0.18	0.27	-	-	-	-	-	-	0.34	0.18	0.00	0.00
Barry Point	-	-	-	-	0.96	0.92	0.89	-	-	0.80	-	-	-	-	0.86	0.76	0.74	-	-	0.31
Bar	-	-	-	-	-	-	-	0.14	0.84	0.12	-	-	-	-	-	-	-	0.00	0.17	0.00
Bassetts	0.89	0.88	-	0.85	0.79	0.80	0.10	0.83	-	-	0.48	0.44	-	0.30	0.16	0.09	0.00	0.10	-	-
Bear	-	-	-	-	0.96	0.92	0.89	0.87	-	0.79	-	-	-	-	0.78	0.59	0.19	0.10	-	0.28
Belden	-	0.61	0.18	0.28	0.49	0.34	0.36	0.19	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-
Bell	0.11	0.10	0.11	-	-	-	-	-	-	-	0.00	0.00	0.00	-	-	-	-	-	-	-
Bell West	0.77	-	-	-	-	-	-	-	-	-	0.15	-	-	-	-	-	-	-	-	-
Birch	0.13	-	-	-	-	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-
Blue	0.81	0.78	0.79	-	-	-	-	-	-	-	0.59	0.32	0.34	-	-	-	-	-	-	-
Boulder Complex	0.88	0.88	-	-	0.79	0.10	-	-	-	-	0.54	0.09	-	-	0.09	0.00	-	-	-	-
Broder Beck	-	0.87	0.16	0.85	0.80	0.79	0.82	0.83	-	-	-	0.41	0.00	0.12	0.21	0.28	0.29	0.28	-	-
Brown	-	0.92	0.88	0.86	0.90	0.19	0.86	0.14	0.17	0.11	-	0.37	0.75	0.52	0.12	0.00	0.07	0.00	0.00	0.00
Bucks	0.09	-	-	-	-	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-
Cabin	-	-	-	-	-	-	-	0.88	0.87	0.89	-	-	-	-	-	-	-	0.27	0.48	0.70
Cedar	-	-	-	-	-	-	-	-	0.21	0.92	-	-	-	-	-	-	-	-	0.00	0.38
Chips	-	-	-	-	0.96	0.92	0.89	0.87	-	-	-	-	-	-	0.07	0.27	0.24	0.44	-	-
Clark	-	-	-	-	-	-	-	-	0.88	0.92	-	-	-	-	-	-	-	-	0.70	0.88
Clover	-	0.91	0.19	0.86	-	-	-	-	0.13	0.07	-	0.42	0.00	0.08	-	-	-	-	0.00	0.00
Cold	-	-	-	0.86	0.87	0.84	-	0.84	0.82	0.64	-	-	-	0.62	0.61	0.39	-	0.46	0.43	0.50
Comb	-	-	-	0.21	0.09	0.10	-	-	-	-	-	-	-	0.00	0.00	0.00	-	-	-	-

	Estimated probability of fire-level occupancy (ω)										Estimated probability of average point-level occupancy (ψ)									
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Cone	0.82	-	0.81	-	-	-	-	-	-	-	0.47	-	0.36	-	-	-	-	-	-	-
Cooney	-	-	-	0.84	0.04	-	-	-	-	-	-	-	-	0.07	0.00	-	-	-	-	-
Corral	-	-	-	0.86	0.87	0.84	0.84	0.13	0.82	0.07	-	-	-	0.56	0.42	0.17	0.18	0.00	0.21	0.00
Cougar	-	-	-	0.86	-	0.90	0.88	-	-	0.76	-	-	-	0.68	-	0.46	0.44	-	-	0.34
Cove	-	-	-	-	-	-	-	-	-	0.94	-	-	-	-	-	-	-	-	-	0.67
Crag 04	0.86	-	0.14	0.85	0.06	-	-	-	-	-	0.29	-	0.00	0.07	0.00	-	-	-	-	-
Crag 05	0.19	0.16	0.16	0.15	0.08	0.08	0.10	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-
Crater	0.81	0.77	0.79	-	-	-	-	-	-	-	0.48	0.20	0.39	-	-	-	-	-	-	-
Cub	-	0.91	0.88	0.86	0.86	0.85	0.84	0.84	-	0.08	-	0.17	0.25	0.11	0.27	0.27	0.19	0.20	-	0.00
Deep	0.49	0.30	0.15	0.40	0.14	0.15	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-
Devils Gap	0.09	-	-	-	-	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-
Dexter	0.84	0.82	-	0.85	0.04	-	-	-	-	-	0.53	0.19	-	0.47	0.00	-	-	-	-	-
Dome Rock	-	-	-	-	-	0.85	0.84	0.84	-	0.07	-	-	-	-	-	0.40	0.15	0.27	-	0.00
Eiler	-	-	-	-	-	-	0.91	0.87	0.87	-	-	-	-	-	-	-	0.70	0.79	0.51	-
El Portal	-	-	-	-	-	-	-	0.24	0.27	-	-	-	-	-	-	-	-	0.01	0.01	-
Fall	0.42	0.91	0.19	0.86	0.86	0.84	0.84	-	0.82	0.07	0.02	0.16	0.00	0.14	0.23	0.23	0.21	-	0.16	0.00
Fish	-	-	-	-	-	0.93	0.90	0.87	-	0.83	-	-	-	-	-	0.37	0.75	0.26	-	0.36
Fletcher	0.90	0.90	0.86	0.86	0.14	0.12	-	0.83	-	-	0.90	0.40	0.53	0.56	0.00	0.00	-	0.25	-	-
Fox	-	-	0.18	-	0.45	0.28	0.24	0.16	0.25	0.10	-	-	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00
Freds	0.17	-	0.14	0.14	0.06	0.08	-	-	-	-	0.00	-	0.00	0.00	0.00	0.00	-	-	-	-
French	-	-	-	-	-	-	0.20	0.19	0.87	-	-	-	-	-	-	-	0.00	0.00	0.12	-
Frey	-	0.49	0.18	-	0.38	0.21	-	0.15	0.22	0.10	-	0.00	0.00	-	0.00	0.00	-	0.00	0.00	0.00
Frog	-	-	-	-	-	-	-	0.88	0.87	0.89	-	-	-	-	-	-	-	0.75	0.78	0.39
Gap	-	0.10	0.11	-	-	-	-	-	-	-	-	0.00	0.00	-	-	-	-	-	-	-
George	-	-	-	-	0.96	0.91	0.89	0.86	0.23	0.28	-	-	-	-	0.11	0.06	0.31	0.33	0.00	0.00
Gondola	0.83	0.80	-	0.84	-	-	-	-	-	-	0.74	0.43	-	0.25	-	-	-	-	-	-
Government	0.91	0.91	0.88	-	0.87	0.84	0.13	-	0.82	0.64	0.10	0.20	0.31	-	0.34	0.20	0.00	-	0.26	0.08
Granite	-	0.92	0.88	-	0.90	0.87	0.86	0.16	0.83	0.09	-	0.37	0.53	-	0.54	0.52	0.62	0.00	0.35	0.00
Grease	-	-	-	0.15	0.11	0.10	-	0.12	-	-	-	-	-	0.00	0.00	0.00	-	0.00	-	-
Harding	0.87	0.86	0.14	0.14	0.09	0.09	0.10	-	-	-	0.41	0.14	0.00	0.00	0.00	0.00	0.00	-	-	-

	Estimated probability of fire-level occupancy (ω)										Estimated probability of average point-level occupancy (ψ)									
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
High	-	0.87	0.86	0.85	-	0.80	-	0.83	-	-	-	0.07	0.36	0.60	-	0.08	-	0.48	-	-
Highway	-	-	0.11	-	-	-	-	-	-	-	-	-	0.00	-	-	-	-	-	-	-
Hiram	0.10	-	-	-	-	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-
Hooker	0.14	0.12	0.13	0.14	-	-	-	-	-	-	0.00	0.00	0.00	0.00	-	-	-	-	-	-
Horton 2	0.77	-	-	-	-	-	-	-	-	-	0.51	-	-	-	-	-	-	-	-	-
Inyo Complex	0.26	-	-	-	-	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-
Jacoboson	-	-	-	-	-	-	-	-	0.88	0.92	-	-	-	-	-	-	-	-	0.50	0.43
Kibbie	0.85	-	0.81	0.84	0.05	-	-	-	-	-	0.33	-	0.21	0.27	0.00	-	-	-	-	-
King	-	-	-	-	-	-	-	0.87	-	-	-	-	-	-	-	-	-	0.29	-	-
Knight	-	0.61	0.20	0.24	0.44	0.22	0.27	0.16	0.21	-	-	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Lion 17	-	-	-	-	-	-	-	-	-	0.94	-	-	-	-	-	-	-	-	-	0.14
Lion 11	-	-	-	0.87	-	0.21	0.87	0.20	-	-	-	-	-	0.21	-	0.00	0.06	0.00	-	-
Lion	-	0.92	0.88	0.87	0.90	-	0.85	0.85	0.83	0.68	-	0.41	0.15	0.32	0.39	-	0.53	0.29	0.56	0.34
Lookout	0.10	-	-	-	-	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-
Manter	0.14	0.08	-	-	-	-	-	-	-	-	0.00	0.00	-	-	-	-	-	-	-	-
Mclaughlin	-	0.10	0.79	-	-	-	-	-	-	-	-	0.00	0.13	-	-	-	-	-	-	-
McNally	0.35	0.23	0.12	0.37	-	-	-	-	-	-	0.00	0.00	0.00	0.00	-	-	-	-	-	-
Meadow	-	-	-	-	-	-	-	-	0.37	-	-	-	-	-	-	-	-	-	0.01	-
Minerva 5	-	-	-	-	-	-	-	-	-	0.93	-	-	-	-	-	-	-	-	-	0.47
Moonlight	0.90	0.90	0.86	0.86	-	0.82	0.83	0.84	0.82	-	0.61	0.28	0.61	0.58	-	0.25	0.24	0.23	0.14	-
Motor	-	-	-	0.39	-	-	-	-	-	-	-	-	-	0.00	-	-	-	-	-	-
Mountain	-	0.82	0.82	0.84	-	-	-	-	-	-	-	0.21	0.32	0.46	-	-	-	-	-	-
Mud	0.85	0.81	0.82	0.85	0.68	-	-	-	-	-	0.54	0.65	0.44	0.42	0.47	-	-	-	-	-
North Fork	0.25	0.17	0.12	-	-	-	-	-	-	-	0.00	0.00	0.00	-	-	-	-	-	-	-
Oliver	-	-	0.87	-	0.44	-	0.16	0.17	0.18	-	-	-	0.43	-	0.00	-	0.00	0.00	0.00	-
Onion 2	-	0.30	0.18	0.86	0.23	0.16	0.84	0.14	0.15	0.08	-	0.00	0.00	0.08	0.00	0.00	0.12	0.00	0.00	0.00
Owens River	-	-	-	-	-	-	-	-	0.88	0.92	-	-	-	-	-	-	-	-	0.69	0.63
Peak	-	-	-	-	-	-	0.89	0.87	0.85	0.18	-	-	-	-	-	-	0.86	0.66	0.40	0.00
Peavine	0.54	-	-	-	-	-	0.84	0.16	-	0.09	0.01	-	-	-	-	-	0.07	0.00	-	0.00
Peterson Complex	0.92	0.91	0.87	0.86	0.19	0.15	0.12	-	0.82	-	0.51	0.37	0.74	0.20	0.00	0.00	0.00	-	0.12	-

	Estimated probability of fire-level occupancy (ω)										Estimated probability of average point-level occupancy (ψ)									
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Piute 08	0.37	0.23	-	-	0.18	0.15	0.13	0.20	0.13	0.08	0.00	0.00	-	-	0.00	0.00	0.00	0.00	0.00	0.00
Pidgen	0.09	-	-	-	-	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-
Pier	-	-	-	-	-	-	-	-	-	0.93	-	-	-	-	-	-	-	-	-	0.18
Pit	-	-	-	0.86	0.45	-	0.23	-	0.26	0.10	-	-	-	0.11	0.00	-	0.00	-	0.00	0.00
Plum	0.29	0.22	0.12	0.23	-	-	-	-	-	-	0.00	0.00	0.00	0.00	-	-	-	-	-	-
Power 13	-	-	-	-	-	-	0.30	-	-	0.33	-	-	-	-	-	-	0.00	-	-	0.00
Power	0.86	0.18	0.13	0.85	0.06	0.07	-	-	-	-	0.10	0.00	0.00	0.12	0.00	0.00	-	-	-	-
Railroad	-	-	-	-	-	-	-	-	-	0.94	-	-	-	-	-	-	-	-	-	0.09
Ramsey	-	-	-	-	0.96	0.92	0.89	0.86	0.85	-	-	-	-	-	0.43	0.54	0.18	0.21	0.23	-
Reading	-	-	-	-	0.96	0.91	0.89	0.87	0.85	-	-	-	-	-	0.62	0.42	0.77	0.48	0.61	-
Rich	0.91	0.91	-	0.86	-	0.15	0.84	0.14	0.82	-	0.12	0.08	-	0.31	-	0.00	0.22	0.00	0.10	-
Rim	-	-	-	-	-	0.26	0.19	0.21	0.86	-	-	-	-	-	-	0.00	0.00	0.01	0.11	-
Rough	-	-	-	-	-	-	-	-	0.87	0.31	-	-	-	-	-	-	-	-	0.23	0.00
Sawmill 06	-	-	0.16	-	0.11	-	0.10	-	-	-	-	-	0.00	-	0.00	-	0.00	-	-	-
Sawmill 00	0.17	-	-	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-	-	-	-
Scotch	0.91	0.29	-	0.86	0.86	0.85	0.84	-	-	0.07	0.22	0.01	-	0.09	0.12	0.05	0.08	-	-	0.00
Sheep	-	-	-	0.86	0.41	0.27	-	-	-	-	-	-	-	0.06	0.00	0.00	-	-	-	-
Sherwin	-	-	-	-	0.87	0.15	-	-	0.13	0.07	-	-	-	-	0.45	0.00	-	-	0.00	0.00
Shotgun	-	-	-	0.86	-	-	0.14	0.19	-	0.68	-	-	-	0.20	-	-	0.00	0.00	-	0.21
Showers	0.82	0.79	-	0.84	-	-	-	-	-	-	0.52	0.72	-	0.55	-	-	-	-	-	-
Silver	-	-	0.88	0.87	0.90	0.87	0.85	0.85	0.28	0.14	-	-	0.68	0.56	0.46	0.10	0.28	0.28	0.01	0.00
Soda	-	-	-	-	-	-	0.91	0.23	0.22	0.86	-	-	-	-	-	-	0.21	0.00	0.00	0.13
Soup 2	-	-	-	-	-	-	-	-	0.88	0.92	-	-	-	-	-	-	-	-	0.74	0.84
Star	-	0.77	0.79	-	-	-	-	-	-	-	-	0.35	0.18	-	-	-	-	-	-	-
Steele	-	-	-	-	-	-	-	-	-	0.94	-	-	-	-	-	-	-	-	-	0.78
Storrie	0.80	-	-	-	-	-	-	-	-	-	0.48	-	-	-	-	-	-	-	-	-
Straylor	-	-	-	0.85	0.06	0.07	-	-	-	-	-	-	-	0.13	0.00	0.00	-	-	-	-
Stream	0.11	0.09	0.11	-	-	-	-	-	-	-	0.00	0.00	0.00	-	-	-	-	-	-	-
Sugar Loaf	-	0.92	0.88	0.15	0.23	0.18	0.16	0.14	0.16	0.10	-	0.17	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Summit	-	-	0.14	-	0.04	-	-	-	-	-	-	-	0.00	-	0.00	-	-	-	-	-

	Estimated probability of fire-level occupancy (ω)										Estimated probability of average point-level occupancy (ψ)									
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Tamarack	-	-	-	0.85	0.11	0.10	0.11	0.15	-	-	-	-	-	0.16	0.00	0.00	0.00	0.00	-	-
Tehipite	-	-	-	0.86	0.87	-	0.84	0.84	0.82	0.64	-	-	-	0.44	0.55	-	0.86	0.22	0.39	0.53
Trailhead	-	-	-	-	-	-	-	-	-	0.73	-	-	-	-	-	-	-	-	-	0.00
Treasure	0.80	0.77	-	-	-	-	-	-	-	-	0.29	0.42	-	-	-	-	-	-	-	-
Vista	0.90	0.90	0.86	0.85	-	0.82	0.83	0.84	-	-	0.52	0.50	0.17	0.29	-	0.31	0.36	0.25	-	-
Walker	-	-	-	-	-	-	-	0.18	0.87	0.89	-	-	-	-	-	-	-	0.00	0.41	0.23
White	0.23	0.20	0.12	-	-	-	-	-	-	-	0.00	0.01	0.00	-	-	-	-	-	-	-
Whit	0.84	-	0.82	0.84	0.67	-	-	-	-	-	0.36	-	0.41	0.49	0.28	-	-	-	-	-
Mean (95% CI)	0.57 (0.49, 0.65)	0.61 (0.53, 0.69)	0.48 (0.42, 0.54)	0.70 (0.53, 0.78)	0.51 (0.44, 0.57)	0.51 (0.44, 0.57)	0.60 (0.51, 0.68)	0.52 (0.46, 0.59)	0.57 (0.49, 0.66)	0.49 (0.43, 0.56)	0.25 (0.22, 0.31)	0.19 (0.17, 0.21)	0.21 (0.18, 0.24)	0.24 (0.23, 0.26)	0.18 (0.17, 0.20)	0.16 (0.15, 0.17)	0.22 (0.21, 0.23)	0.17 (0.15, 0.21)	0.22 (0.19, 0.25)	0.21 (0.19, 0.22)

Models of annual occupancy show changes in the total estimated proportion of (sampled) fires occupied by at least one Black-backed Woodpecker in different years (Tables 3, 4; Fig. 6a). These proportions have varied from year to year, from a high (mean estimate) of 70% of sampled fires estimated as occupied in 2012, to a low of 48% in 2011. In 2018, the estimated proportion of occupied fires was 49%, which represents the second-lowest estimate, but still fully within the observed range of variation over the last decade (Figure 6a).

With ten years of data we can assess the presence of linear trends over time through evaluation of the posterior estimates of mean annual point-level and fire-level occupancy. Accounting for uncertainty, there was no linear trend from 2009 to 2018 for either point-level occupancy (mean ± se: -0.0028 ± 0.0034; P = 0.43) or fire-level occupancy (mean ± se: -0.0060 ± 0.0076; P = 0.45).

We compared modeled covariate relationships with occupancy and detectability for each of the nine annual occupancy models (Table 5). Covariate signs showed general consistency across years, with 2018 showing similar parameter magnitudes and posteriors as in previous years. Across years, elevation and snag density remain the two strongest predictors of Black-backed Woodpecker occurrence at the point level, although latitude is consistently showing a positive relationship to occupancy (significant in 4 of 10 years). Burn severity continues to have a weak and non-significant relationship to occurrence, although the relationship is positive when it is significant. The role of pre-fire canopy cover remains similarly uncertain. In 2018, similar to previous years, the parameter mean has been negative (i.e., lower occupancy with higher pre-fire canopy cover), but insignificant. Of the ten years, the parameter has been significantly negative twice, and significantly positive once (Table 5). Pre-fire canopy cover likely also interacts with snag density, which could lead to the switching in directions over years. Consistent with three previous years, the effect of fire age on fire-level occupancy was significant in 2018. Generally, fire age is important in years with low overall occupancy (e.g., 2009, 2010, 2013, 2014). Of the factors affecting detectability, survey type (i.e., passive versus broadcast) remains the only covariate which is significant across all 9 years (broadcast has a higher detection rate than passive).

Table 5. Posterior summaries (means and 95% credible intervals) for intercepts and regression coefficients for single-year occupancy models as applied to 2009-2018 survey data. Parameters with 95% credible intervals that do not cross 0 are indicated in bold type.

Parameter	Year									
Fire level occupancy probability	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
σ_f (variance of random fire effect)	6.5 (0.93, 9.87)	6.34 (1.05, 9.85)	6.2 (0.57, 9.86)	6.4 (0.89, 9.86)	6.2 (0.45, 9.88)	6.3 (0.97, 9.86)	6.6 (0.94, 9.88)	6.3 (1.07,9.85)	6.1 (0.92, 9.84)	4.8 (0.29, 9.53)
γ_1 (fire age)	**-2.76** (-6.58, -0.14)	**-3.23** (-7.42, -0.39)	-1.83 (-5.15, 0.44)	-0.49 (-3.77, 2.49)	**-5.81** (-11.9, -1.35)	**-3.23** (-7.67, -0.38)	-2.04 (-5.76, 0.60)	-0.85 (-3.39, 1.37)	-1.08 (-3.68, 1.00)	**-3.31** (-6.67, -0.98)
Point-level occupancy probability										
β_0	**-1.01** (-1.37, -0.61)	**-1.17** (-1.47, -0.86)	**-0.45** (-0.76, -0.11)	**-0.97** (-1.19, -0.77)	**-1.01** (-1.33, -0.70)	**-0.98** (-1.25, -0.71)	**-0.80** (-1.03, -0.57)	**-0.94** (-1.27, -0.56)	**-0.88** (-1.20, -0.52)	**-0.98** (-1.30, -0.66)
β_1 (latitude)	**0.54** (0.17, 1.01)	-0.26 (-0.53, 0.00)	0.22 (-0.06, 0.52)	**0.53** (0.34, 0.73)	-0.06 (-0.33, 0.21)	-0.01 (-0.24, 0.22)	0.18 (-0.05, 0.41)	**0.49** (0.24, 0.74)	-0.03 (-0.29, 0.25)	**0.28** (0.04, 0.54)
β_2 (elevation)	**1.20** (0.70, 1.91)	**0.81** (0.45, 1.16)	-0.07 (-0.37, 0.24)	**0.53** (0.27, 0.80)	**1.00** (0.60, 1.41)	**0.54** (0.20, 0.90)	**0.77** (0.48, 1.07)	0.14 (-0.19, 0.50)	**0.68** (0.37, 1.02)	**0.77** (0.46, 1.09)
β_3 (snag density)	0.08 (-0.18, 0.32)	**0.29** (0.00, 0.60)	0.10 (-0.15, 0.36)	**0.36** (0.18, 0.54)	**0.45** (0.23, 0.70)	**0.40** (0.12, 0.68)	**0.84** (0.56, 1.13)	**0.29** (0.05, 0.57)	0.13 (-0.14, 0.39)	**0.46** (0.24, 0.68)
β_4 (burn severity)	**0.37** (0.06, 0.72)	0.21 (-0.05, 0.47)	0.20 (-0.09, 0.49)	0.03 (-0.18, 0.22)	**0.25** (0.00, 0.50)	0.12 (-0.12, 0.36)	-0.04 (-0.27, 0.17)	-0.13 (-0.37, 0.10)	0.13 (-0.14, 0.40)	-0.11 (-0.39, 0.17)
β_5 (pre-fire canopy cover)	0.06 (-0.22, 0.33)	**0.35** (0.06, 0.63)	0.22 (-0.03, 0.48)	**-0.21** (-0.41, -0.01)	-0.31 (-0.31, 0.24)	**-0.28** (-0.55, -0.02)	-0.06 (-0.27, 0.18)	-0.22 (-0.49, 0.05)	-0.15 (-0.36, 0.05)	-0.13 (-0.34, 0.09)
Detection probability										
α_0	**-3.45** (-4.41, -2.65)	**-1.57** (-1.89, -1.25)	**-1.2** (-1.58, -0.83)	**-0.94** (-1.24, -0.63)	**-1.33** (-1.71, -0.97)	**-1.12** (-1.59, -0.77)	**-0.96** (-1.33, -0.62)	**-1.98** (-2.61, -1.39)	**-1.83** (-2.40, -1.29)	**-1.09** (-1.48, -0.73)
α_1 (interval duration)	**1.94** (1.11, 2.91)	**0.72** (0.14, 1.31)	0.09 (-0.51, 0.68)	0.25 (-0.25, 0.75)	0.23 (-0.39, 0.84)	0.44 (-0.22, 1.09)	0.21 (-0.39, 0.80)	0.46 (-0.34, 1.26)	-0.44 (-1.25, 0.31)	0.23 (-0.34, 0.79)
α_2 (survey type)	**2.83** (2.03, 3.77)	**1.05** (0.65, 1.47)	**0.67** (0.22, 1.12)	**0.92** (0.53, 1.30)	**1.37** (0.92, 1.83)	**1.30** (0.78, 1.83)	**1.09** (0.65, 1.54)	**1.78** (1.19, 2.42)	**1.25** (0.75, 1.75)	**0.95** (0.52, 1.39)
α_3 (day of year)	-0.24 (-0.54, 0.06)	-0.16 (-0.41, 0.08)	0.01 (-0.21, 0.22)	0.07 (-0.11, 0.26)	0.03 (-0.20, 0.26)	**0.43** (0.15, 0.72)	0.23 (-0.01, 0.47)	0.40 (-0.08, 0.86)	0.15 (-0.25, 0.55)	-0.19 (-0.46, 0.08)

Analysis of Dynamic Occupancy

Of the 2,365 individual points surveyed across 125 fires, 1,912 points (81%) have been surveyed in more than one year, and 100 points (4.2%) have been surveyed in nine out of ten years.

Our analysis of ten years of data exploring 48 model parameterizations of detectability and initial occupancy resulted in strong support for four similar models, which together represented over 87% of the total AIC model weight. These four models fall within 2 AIC units of each other, an index often used to delineate models with "substantial support" (Burnham and Anderson 2002). The top model selected (AIC weight = 0.32; AIC = 4224) retained 2 of 3 covariates for detectability (survey type and survey duration, but not Julian day) and retained elevation (including quadratic term) for initial occupancy.

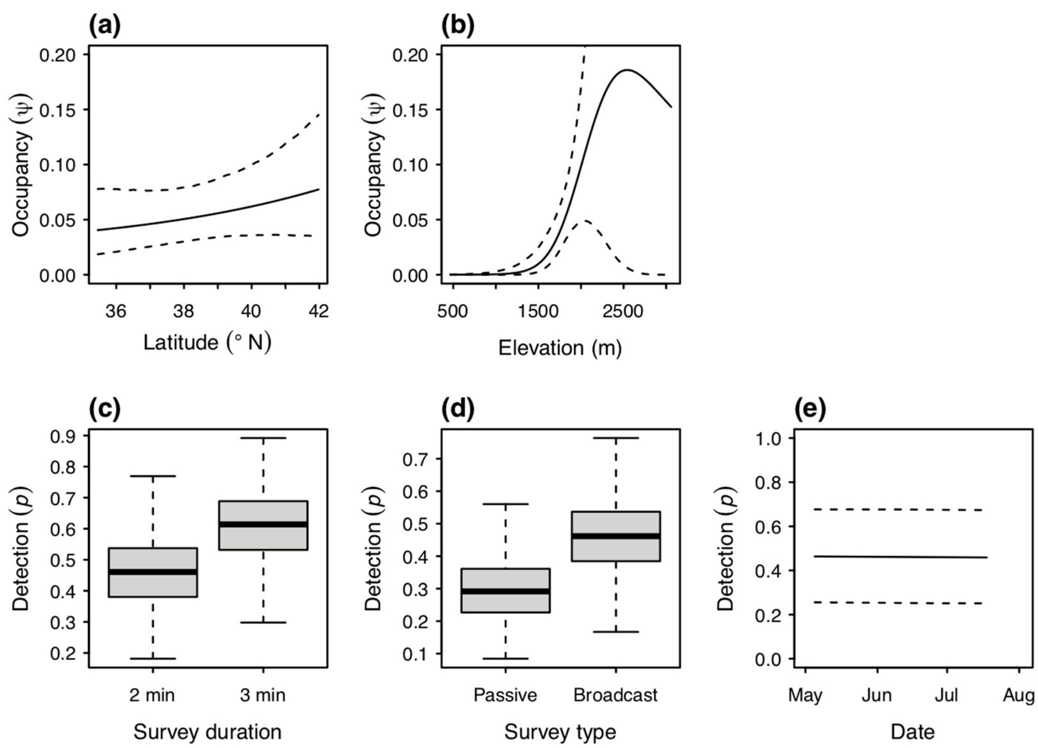

Figure 7. Model-averaged covariate relationships for occupancy (a, b) and detection (c – e) probabilities. Mean covariate relationships are depicted by a solid black line (a, b, e) or a bold horizontal line (c, d). Dotted black lines indicate 95% confidence intervals on relationships, estimated from parametric bootstrapping of model-averaged covariate and intercept means and standard errors. In the case of elevation (b), model-averaging was only conducted on the subset of models containing both linear and quadratic terms.

Model-averaged predictions holding other variables constant showed that detectability per survey interval varied from about 0.2 – 0.7, with detectability higher during 3-minute survey intervals compared to 2-minute intervals, during broadcast surveys when compared to passive surveys, but with no relationship to day of year (Figure 7c-e). Initial occupancy was low (generally < 0.2) but increased weakly with latitude and strongly with elevation, with the latter interpretation based on residuals of elevation after accounting for latitude (Figure 7a-b). The selection of two initial occupancy covariates (i.e., linear and quadratic terms on elevation) and two detectability covariates (survey duration and type) was used for all subsequent models of colonization and extinction.

Table 6. Top models ($\Delta_i < 2$) comparing different combinations of colonization and extinction covariates for point-level changes in occupancy.

Colonization covariates	Extinction covariates	K	AIC	Δ_i	w_i
Snag density + fire age	Burn severity	11	4129.9	0.00	0.11
Snag density + fire age	Burn severity + canopy cover	12	4130.2	0.31	0.09
Snag density + fire age	Burn severity + snag density	12	4131.4	1.59	0.05
Snag density + fire age	Burn severity + snag density + canopy cover	13	4131.5	1.61	0.05
Snag density + fire age + burn severity	Burn severity	12	4131.7	1.89	0.04
Snag density + fire age	Burn severity + fire age	12	4131.8	1.98	0.04
Snag density + fire age + canopy cover	Burn severity	12	4131.8	1.98	0.04

Model support for colonization and extinction models was broadly distributed across many similar candidate models (Table 6). Seven models were within 2 AIC units of each other and together comprised over 40% of the total AIC model weight. Although there was no single "top model" for colonization and extinction models, there was general consistency in support for certain variables. All top models within 2 AIC units included both snag density and fire age as colonization covariates, and all extinction models included burn severity (Table 6). Compared to previous analyses with fewer years of data, the covariates selected were highly consistent with previous results, but for the first time show strong consistent support that survey points with higher burn severity show lower extinction rates (Siegel et al. 2012, 2014a, 2014b, 2015, 2016, 2017, and 2018).

The cumulative AIC weight in support of the tested variables shows strong differences in support for colonization versus extinction covariates (Table 7). Both snag density and fire age have full, universal support as covariates of colonization, while other variables had little support (< 0.5). There was very low support (< 0.01) for models that had colonization as a random process at a fixed probability. In comparison, the cumulative weights for covariates of extinction showed much more widespread, ambiguous support, with only strong support (0.80) appearing for burn severity (Table 7). Six percent of AIC weight supported models where extinction occurred randomly at a fixed probability.

Table 7. Cumulative AIC weights in support of individual covariates in compared models for both colonization and extinction probabilities.

Covariate	Colonization relative importance score	Extinction relative importance score
Snag density	1.00	0.32
Fire age	1.00	0.27
Burn severity	0.31	0.80
Pre-fire canopy cover	0.28	0.47

The sign and magnitude of covariate relationships to probabilities of colonization and extinction link our results to environmental features. Model averaged results show relatively low average probabilities of colonization (< 0.15) and high probabilities of local extinction (0.5 – 0.9) at points from year to year. Colonization probability, however, strongly increased with snag density and decreased with fire age (Figure 8a-b). Extinction probability shows a still uncertain but moderately strong effect that extinction probability decreases with greater burn severity.

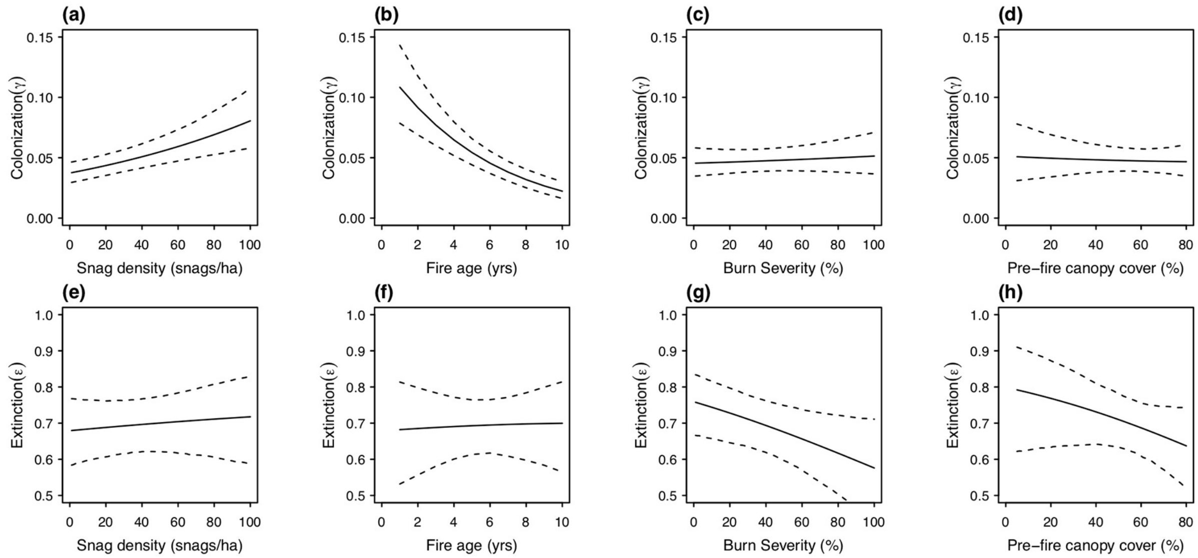

Figure 8. Modeled relationships between *a priori* covariates and probabilities of colonization (a-d) and local extinction (e-h). Plots show model-averaged mean covariate relationships (solid black line) and 95% confidence interval for slopes (dotted black line). Confidence intervals were estimated through parametric bootstrapping of model-averaged covariate and intercept means and standard errors.

<u>Results from Beetle-kill Forest Stands</u>

In 2018, we detected Black-backed Woodpeckers at 69 survey points distributed across 18 of the 68 beetle-kill stands we surveyed (Table 7; Figs. 2-5). Black-backed Woodpeckers were detected relatively more frequently in beetle-kill stands in northern areas than in southern areas, with detections at 5 of 10 stands visited in Modoc NF and 7 of 15 stands visited in Lassen NF, although no detections were made within the 1 stand visited in Tahoe Basin MU or the 2 stands visited in Plumas NF. Farther to the south, detections were relatively rarer: Black-backed Woodpeckers were detected at 0 of 5 stands visited on Stanislaus NF, 4 of 26 stands visited on Sierra NF, and 2 of 5 stands visited on Sequoia NF. Altogether, Black-backed Woodpeckers were detected at 8.1% of survey points at 26% of visited stands.

Along with data from 2017, our study of Black-backed Woodpecker occurrence in beetle-kill forest stands supports a strong latitudinal pattern in occurrence, with more of our focal species present in stands in the northern half of our study region, than in the southern half, where beetle-kill stands are relatively more common on the landscape and mortality effects have generally been more severe. Combining both years of data, Black-backed Woodpeckers were detected at 7.3% of survey points at 20% of visited stands.

Table 8. Summary of survey effort and Black-backed Woodpecker detections at surveyed points in beetle-kill forest stands in 2018.

Polygon ID	National Forest	Survey points	Points with ≥1 detection	Dominant CWHR type[1]	Snag density (snags/ha)[2]
4817	Modoc	20	0	EPN	19.8
4911	Modoc	10	0	SMC	49.4
4988	Modoc	10	0	SMC	37.1
4989	Modoc	10	3	SMC	49.4
5020	Modoc	20	5	SMC	49.4
5040	Modoc	10	0	EPN	49.4
5041	Modoc	10	0	SMC	7.4
5265	Modoc	20	1	SMC	24.7
5935	Modoc	20	1	SMC	12.4
6216	Modoc	10	9	SMC	12.4
4853	Lassen	20	0	SMC	12.4
5128	Lassen	20	8	JPN	12.4
5199	Lassen	9	0	EPN	12.4
5204	Lassen	20	0	SMC	49.4
5341	Lassen	10	4	SMC	17.3
5382	Lassen	10	2	SMC	12.4
5427	Lassen	10	1	SMC	7.4
5434	Lassen	10	0	SMC	7.4
5549	Lassen	19	0	SMC	9.9
5598	Lassen	9	0	SMC	24.7
5947	Lassen	10	0	SMC	7.4
5965	Lassen	10	0	SMC	7.4
6108	Lassen	10	2	SMC	7.4
6317	Lassen	20	3	WFR	24.7
6319	Lassen	10	2	SMC	12.4
2757	Plumas	18	0	SMC	19.8
6185	Plumas	10	0	SMC	7.4
2677	Tahoe Basin	20	0	SMC	17.3
133	Eldorado	18	0	MHC	7.4
354	Eldorado	15	0	SMC	9.9
360	Eldorado	7	0	SMC	12.4
361	Eldorado	8	0	SMC	7.4
219	Stanislaus	15	0	SMC	19.8
229	Stanislaus	10	0	SMC	24.7
231	Stanislaus	10	0	SMC	9.9
1181	Stanislaus	9	0	SMC	37.1

Polygon ID	National Forest	Survey points	Points with ≥1 detection	Dominant CWHR type[1]	Snag density (snags/ha)[2]
1658	Stanislaus	10	0	SMC	49.4
6591	Sierra	19	12	SMC	247.1
6592	Sierra	20	1	SMC	247.1
6607	Sierra	10	0	SMC	123.6
6609	Sierra	10	0	SMC	197.7
6724	Sierra	19	0	SMC	148.3
6726	Sierra	16	0	SMC	123.6
6740	Sierra	10	1	RFR	123.6
6743	Sierra	9	0	SMC	123.6
6775	Sierra	20	0	SMC	247.1
6800	Sierra	10	0	SMC	61.8
6802	Sierra	9	0	SMC	49.4
6863	Sierra	10	0	RFR	49.4
6864	Sierra	10	0	SMC	37.1
6880	Sierra	10	0	SMC	123.6
6922	Sierra	20	4	SMC	49.4
6944	Sierra	12	0	SMC	61.8
7811	Sierra	10	0	SMC	7.4
8115	Sierra	8	0	SMC	74.1
8121	Sierra	10	0	SMC	49.4
8444	Sierra	10	0	SMC	69.2
9087	Sierra	10	0	SMC	24.7
9186	Sierra	14	0	SMC	12.4
9445	Sierra	9	0	SMC	123.6
9448	Sierra	8	0	SMC	123.6
9681	Sierra	10	0	MHC	123.6
9876	Sierra	7	0	SMC	98.8
7062	Sequoia	10	6	SMC	19.8
7141	Sequoia	10	0	SMC	12.4
8914	Sequoia	8	0	SMC	74.1
8991	Sequoia	14	0	SMC	74.1
9907	Sequoia	10	4	SMC	98.8

[1]California Wildlife Habitat Relationships forest types (MHC = Montane Hardwood-Conifer, PPN = Ponderosa Pine, RFR = Red Fir, SMC = Sierran Mixed Conifer).

[2]Preliminary snag density (snags/ha) estimated from Aerial Detection Survey (ADS) data.

Discussion

Black-backed Woodpecker Annual Occupancy

Our tenth year of surveys indicate that Black-backed Woodpeckers continue to be widely distributed across recent fires on the National Forests in our study area. While we did not detect Black-backed Woodpeckers in 2018 in three National Forest units (Eldorado, Lassen, Stanislaus), we have detected woodpeckers within all of those forests previously and do not consider this a trend. Of the three units, only 2 fires (Dome Rock, Power 13) were sampled in Stanislaus, 1 (Trailhead) in Eldorado, and 6 in Lassen. In Lassen, in particular, the surveyed fires are all relatively old, with 5 of the 6 fires having burned in either 2008 or 2009. Occupancy of Black-backed Woodpeckers after fire has been shown to decline precipitously after 5–7 years following fire (Tingley et al. 2018), so widespread occurrence at these 5 older fires would not necessarily be expected.

Overall, the proportion of occupied fires and the proportion of occupied points in 2018 were well within the range of recent annual variation (Figure 6). Point estimates of the percentage of occupied survey points within each year's sampling frame have varied across years: 25% in 2009, 19% in 2010, 21% in 2011, 24% in 2012, 18% in 2013, 16% in 2014, 22% in 2015, 17% in 2016, 22% in 2017, and most recently, 21% in 2018. The estimated percentage of occupied fires within the sampling frame has shown greater variation: 57% in 2009, 61% in 2010, 48% in 2011, 70% in 2012, 51% in both 2013 and 2014, 60% in 2015, 52% in 2016, 57% in 2017, and 49% in 2018. With ten years of data, there is no evidence for a linear temporal trend in either fire-level or point-level occupancy by Black-backed Woodpeckers. Although the distribution of the species appears to vary somewhat from year to year, Black-backed Woodpeckers remain present within recently burned forest across their historic range in California.

Black-backed Woodpecker Dynamic Occupancy

Our results from 10 years of data indicate strong differences between colonization and extinction dynamics of Black-backed Woodpeckers in burned forests. Average colonization probability (defined here as the probability of a single survey point becoming occupied by woodpeckers given that it was previously unoccupied subsequent to the fire) was quite low (4.7%), while average extinction probability was much higher (70%). The probability of a site being colonized was strongly and positively associated with snag density and strongly negatively associated with fire age. Thus, early post-fire sites with high snag densities have a relatively higher probability of being colonized than other sites. By comparison, only burn severity showed a moderately strong negative association with extinction (i.e., more severe fires make extinction less likely). Inferential trends over multiple years of repeating this analysis with increasing amounts of data suggest that the relationship between burn severity and extinction probability is likely important (i.e., real), but that the relationship strength may vary through time or may interact with other environmental variables (e.g., climate, tree composition) or population density. Additional years of data has helped to resolve this complex relationship. Previous analyses of occupancy dynamics (Siegel et al. 2012, 2014a, 2014b) have indicated extinction might be best modeled as purely random, but stronger evidence for a burn severity appeared only after 8 years of data (Siegel et al. 2017).

The differences between the relative frequency of colonization versus extinction as well as the strength of covariate relationships of colonization versus extinction lead to novel insight on the drivers behind changes in Black-backed Woodpecker occurrence. Based on analyses limited to modeling occupancy (e.g., Siegel et al. 2011, Saracco et al. 2011, Tingley et al. 2016, Table 5), we tend to think of occurrence as being limited predominantly by fire age and snag density. This leads to the assumption that an occupied site may go extinct because the site has aged to a certain point, and that the critical age at which a site goes extinct depends on habitat quality characteristics, such as snag density. Our results, however, suggest that the mechanistic pathway is actually the opposite. Extinction appears to be a relatively likely event, but one with relatively weak controls (e.g., burn severity). That does not mean that other factors that were not investigated (e.g., post-fire management actions that change habitat, patch dynamics across the larger landscape) do not have an effect on extinction, but that extinction appears to occur with no strong relationship to the investigated covariates. By contrast, colonization (after fires are greater than 1 year old) is a relatively unlikely event, but one which is strongly associated with both fire age and snag density. Colonization after one year post-fire, consequently, is an important dynamic strongly influencing the observed distribution of Black-backed Woodpeckers on a landscape. If management actions were to be taken aimed at increasing overall occupancy, these results suggest that colonization should be targeted rather than extinction, presumably through retention of early post-fire stands with high snag densities (Tingley et al. 2018).

Black-backed Woodpeckers in Beetle-kill Forest Stands

Results from two years of Black-backed Woodpecker surveys in forest stands with high tree mortality due to drought and bark-beetles confirms that the birds do occur in such areas, but possibly at much lower densities than observed in recent fires. Additionally, while we have found latitude to be weakly predictive of woodpecker occupancy in the burned areas (with higher occupancy probability at more northerly fires), our raw results from beetle-kill stands suggest a much stronger relationship to latitude, with detections across both years at 17 of 33 (52%) stands surveyed in Lake Tahoe Basin or further north, but only 9 of 80 (11%) stands south of Lake Tahoe Basin, although this could simply be a result of the particular elevations at which beetle-killed habitat was available.

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