The INSTITUTE for BIRD POPULATIONS

Black-backed Woodpecker MIS Surveys on Sierra Nevada National Forests: 2019 Annual Report

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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. The Institute for Bird Populations collaborated with Region 5 personnel 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 2019 field season, we used passive and broadcast surveys to assess Black-backed Woodpecker occupancy at 964 survey points arrayed across 50 recent fires (1–10 years post-fire) throughout our study area. Combined with data collected during 2009–2018, we now have broadcast surveys and habitat assessment data at 2,551 unique survey points within 133 fires. 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 2019 we detected Black-backed Woodpeckers at 198 survey points distributed across 34 of the 50 fires we surveyed, including fires on eight of the nine National Forest units in our study area (we did not survey in the Lake Tahoe Basin Management Unit and there were no detections within the single fire we surveyed on Tahoe National Forest). We detected Black-backed

Woodpeckers on both the west and east sides of the Sierra Nevada crest, and across the full latitudinal range of our study area.

Results were produced by two separate analyses, the first 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, 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 2019 was 0.23 (95% credible interval: 0.23 – 0.25), which is well 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 0.65 (95% CI: 0.56 – 0.72), which also was within the range of previously observed year-to-year variation, albeit at the higher end. There was no linear trend in point-level occupancy ($P = 0.79$) or fire-level occupancy ($P = 0.95$) from 2009 to 2019.

Our second analysis used data from all eleven survey years (2009–2019) 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 (<15%), while average extinction probability was much higher (50–90%). 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 higher probability of being colonized, even after initially being vacant, than other sites. For extinction, there was evidence for a moderate negative association with burn severity (i.e., more severe fires make extinction in a given year less likely).

During the 2019 field season we also completed multi-species bird surveys at 478 survey points, adding to our growing dataset of bird community response in the decade following fire. In 2019, we added only one newly detected species (Northern Mockingbird) to the cumulative species list, which now totals 148 species.

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). Black-backed Woodpeckers are far more likely to occur in stands of trees killed by fire than in stands killed by bark beetle infestation (Tingley et al. 2020b).

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, Tingley et al. 2018, Tingley et al. 2020a, Tingley et al. 2020b) 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 2019 we continued Sierra-wide MIS monitoring for Black-backed Woodpeckers. Here we detail the results of this eleventh year of MIS monitoring in recently burned forest stands.

Methods

Sample Design

We used the Rapid Assessment of Vegetation Condition after Wildfire (RAVG) Query Tool (available at https://fsapps.nwcg.gov/ravg/) to identify new fires that burned during 2018. To cross check for completeness we used the GIS data layer VegBurnSeverity18_1.mdb (available from https://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=STELPRDB5327833), which indicates boundaries and severity of fires throughout California, to extract data for all fires that occurred between 2008 and 2018 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 (Siegel et al. 2014b, 2015, 2016, 2017, 2018, 2019).

Establishing survey points. In 2019, the fires we selected varied in size on NF land, from 140 ha (2009 Silver Fire on Plumas NF) to 93,022 ha (2013 Rim Fire on Stanislaus NF). 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).

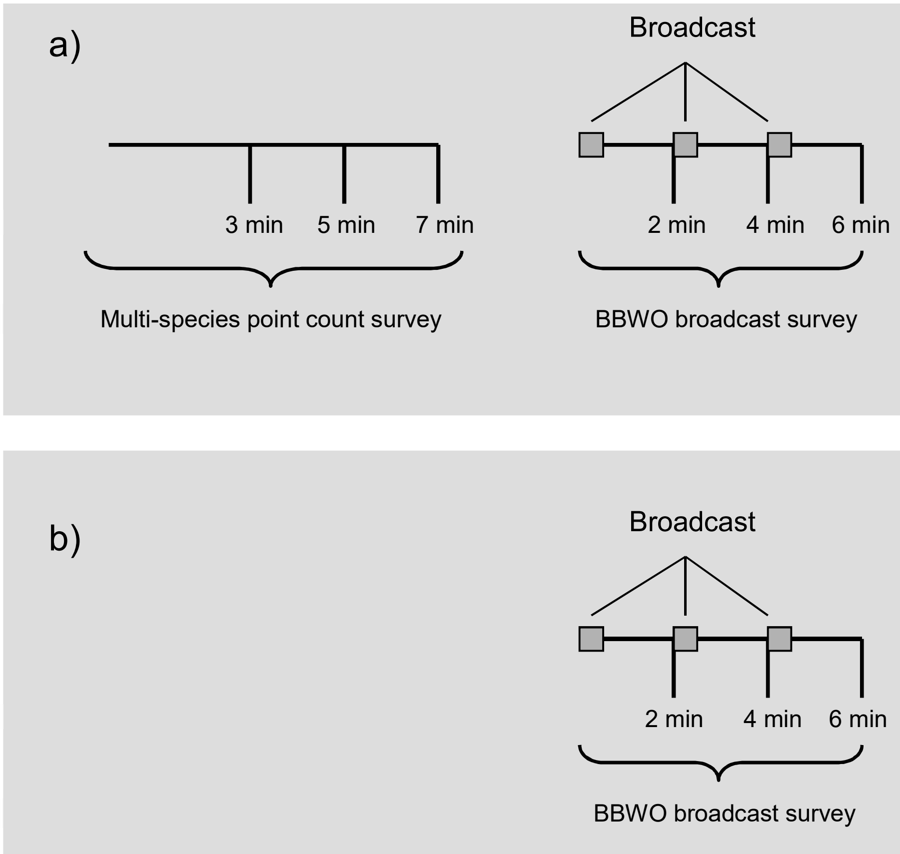

Figure 1. Schematic diagram of our survey methodology for detecting Black-backed Woodpeckers. Dark gray squares indicate period of actively broadcasting Black-backed Woodpecker drumming and vocalizations; black line segments indicate periods of passive observation. Observers alternated between both passive 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 gauge, 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. 2019), our analytical goals for the 2019 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 2019 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 2009-2018 MIS monitoring data and recent publications (Tingley et al. 2018, 2019), 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 downloaded from the USFS RAVG data portal (https://fsapps.nwcg.gov/ravg/data-access) 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, 2015–2019), 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 eleven years of monitoring, these values were: 899, 860, 895, 953, 1008, 976, 969, 954, 881, 929, and 964 for N points in 2009–2019 respectively; 51, 49, 50, 52, 53, 51, 50, 50, 47, 49, and 50 for M fires; and 5, 9, and then 6 annually 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 2010–2019, 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 2019, the results of which are summarized in Table 1. Tables of encounter histories for previous years can be found in previous annual reports.

Table 1. Encounter history frequencies (numbers of survey points) in the 2019 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	388
-	0	0	1	14
-	0	1	NA	23
-	1	NA	NA	61
0	0	0	0	378
0	0	0	1	15
0	0	1	NA	19
0	1	NA	NA	28
1	0	0	0	1
1	0	0	1	2
1	0	1	NA	3
1	1	NA	NA	9
2	0	0	0	4
2	0	0	1	0
2	0	1	NA	1
2	1	NA	NA	3
3	0	0	0	2
3	0	0	1	0
3	0	1	NA	2
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 Core Team 2018) 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, 2015–2019).

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 2551 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 3.5.0 (R Core Team 2018) using the 'colext()' function from the package 'unmarked' (Fiske and Chandler 2011).

Results

Scope of Survey Work Completed

In 2019 we completed surveys fully to protocol at 50 fires distributed across 9 of the 10 focal National Forests (our random draw yielded no fires to visit on the Lake Tahoe Basin Management Unit; Table 2), including broadcast surveys and habitat assessments at 964 survey points and passive, multi-species point counts at 478 of those points. All surveys were conducted between 17 May and 10 July, 2019 and surveyed fires encompassed nearly the full latitudinal range of the surveyed National Forests. Combined with data collected during 2009–2018 we now have broadcast surveys and habitat assessment data at 2,551 unique survey points within 133 fires. We provide summary information about fires surveyed once or more between 2009 and 2019 in Table 2.

Black-backed Woodpecker Detections

In 2019 we detected Black-backed Woodpeckers at 198 survey points distributed across 34 of the 50 fires we surveyed (Figs. 2-4). We detected Black-backed Woodpeckers at one or more fires at 8 of 9 National Forest units surveyed in our study area in 2019. Woodpeckers were not detected on the Tahoe National Forest, where we only conducted surveys at a single, six year old, fire in 2019 (Table 2), where Black-backed Woodpecker detections have occurred 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 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 most southerly fire we surveyed (the Cedar fire on the Sequoia NF; Fig. 5).

Table 2. Summary information for each fire surveyed during 2019 field season of Black-backed Woodpecker MIS monitoring on Sierra Nevada National Forests. Summary information for previous years sampling can be found in previous annual reports (Siegel et al. 2012, 2014a, b, 2015–2019).

Primary National Forest	Fire name	Year of fire	Dominant pre-fire habitat[1]	Number of points surveyed in 2019
Eldorado	Table	2017	SMC	16
Eldorado	Trailhead	2016	MHC	20
Inyo	Clark	2016	JPN	20
Inyo	Owens River	2016	JPN	20
Inyo	Walker	2015	JPN	16
Lassen	Bald	2014	EPN	20
Lassen	Brown	2009	SMC	19
Lassen	Eiler	2014	SMC	18
Lassen	Reading	2012	SMC	20
Lassen	Sugar Loaf	2009	SMC	21
Lassen	Whaleback	2018	PPN	20
Modoc	Barry Point	2012	EPN	20
Modoc	Cougar	2011	PPN	20
Modoc	Cove	2017	EPN	20
Modoc	Frog	2015	SMC	20
Modoc	Parker 2	2017	EPN	20
Modoc	Soup 2	2016	WFR	20
Modoc	Steele	2017	EPN	20
Modoc	Stone	2018	EPN	20
Plumas	Bar	2010	SMC	19
Plumas	Camp	2018	SMC	20
Plumas	Chips	2012	SMC	20
Plumas	Minerva 5	2017	SMC	20
Plumas	Peak	2012	SMC	20
Plumas	Silver	2009	SMC	11
Sequoia	Cabin	2015	JPN	19
Sequoia	Cedar	2016	SMC	20
Sequoia	Fish	2013	SMC	20
Sequoia	George	2012	JPN	20
Sequoia	Granite	2009	SMC	20
Sequoia	Jacoboson	2016	SMC	19
Sequoia	Lion	2009	LPN	20
Sequoia	Lion 11	2011	JPN	20
Sequoia	Lion 17	2017	SMC	20
Sequoia	Meadow	2016	SMC	12
Sequoia	Pier	2017	SMC	20
Sequoia	Soda	2014	JPN	20

Primary National Forest	Fire name	Year of fire	Dominant pre-fire habitat[1]	Number of points surveyed in 2019
Sierra	Aspen	2013	SMC	20
Sierra	Ferguson	2018	SMC	20
Sierra	French	2014	SMC	20
Sierra	Railroad	2017	SMC	20
Sierra	Rough	2015	SMC	19
Stanislaus	Donnell	2018	SMC	20
Stanislaus	El Portal	2014	SMC	16
Stanislaus	Knight	2009	SMC	19
Stanislaus	McCormick	2017	SMC	20
Stanislaus	Power 13	2013	MHC	20
Stanislaus	Ramsey	2012	SMC	20
Stanislaus	Rim	2013	SMC	20
Tahoe	American	2013	SMC	20

[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.

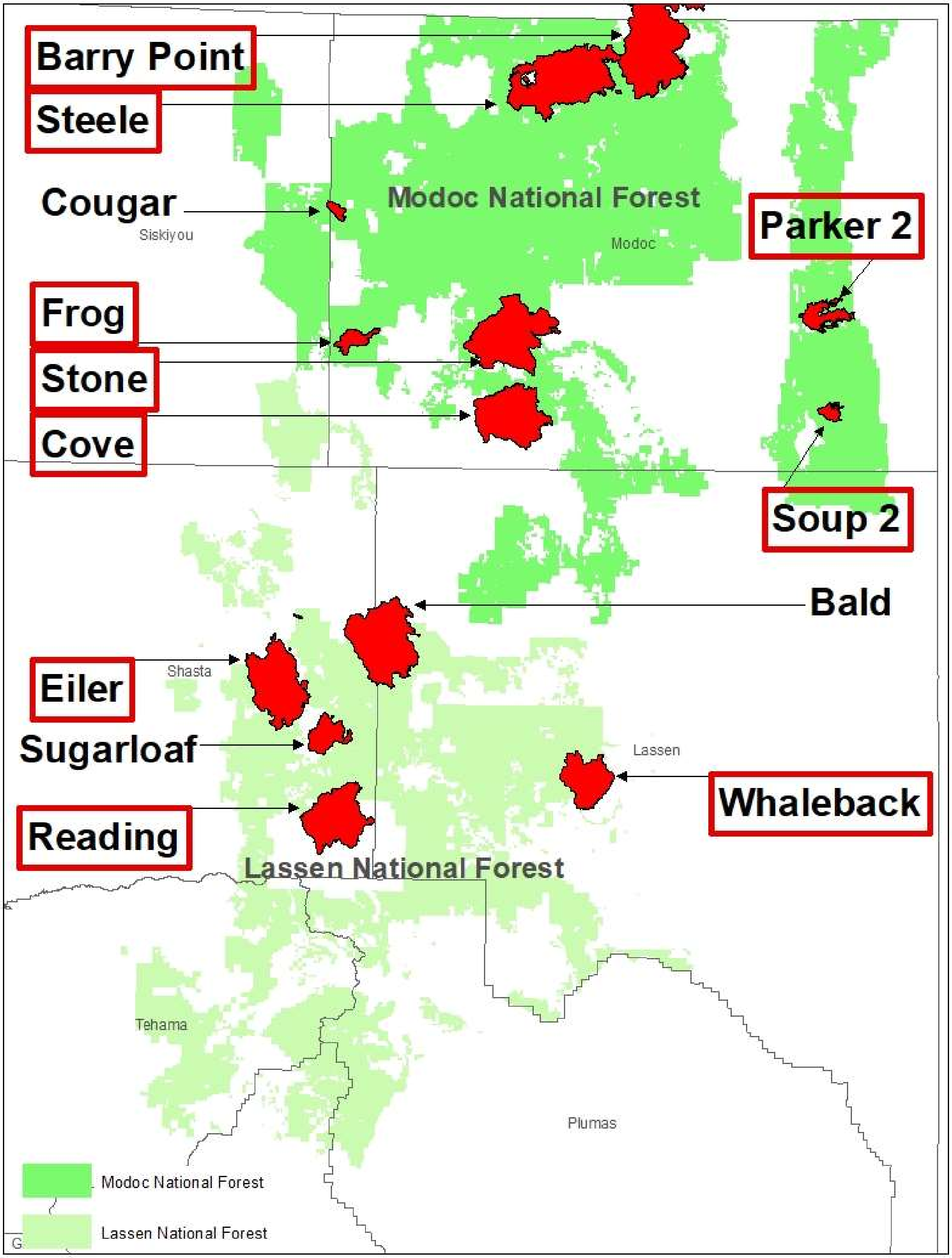

Figure 2. Fires (red shading) on the Modoc and Lassen National Forests surveyed for Black-backed Woodpeckers during the 2019 MIS monitoring field season. Names of fires where Black-backed Woodpeckers were detected are enclosed in red boxes. Lack of detection does not necessarily mean Black-backed Woodpeckers were absent (see text for discussion of detection probability during this survey).

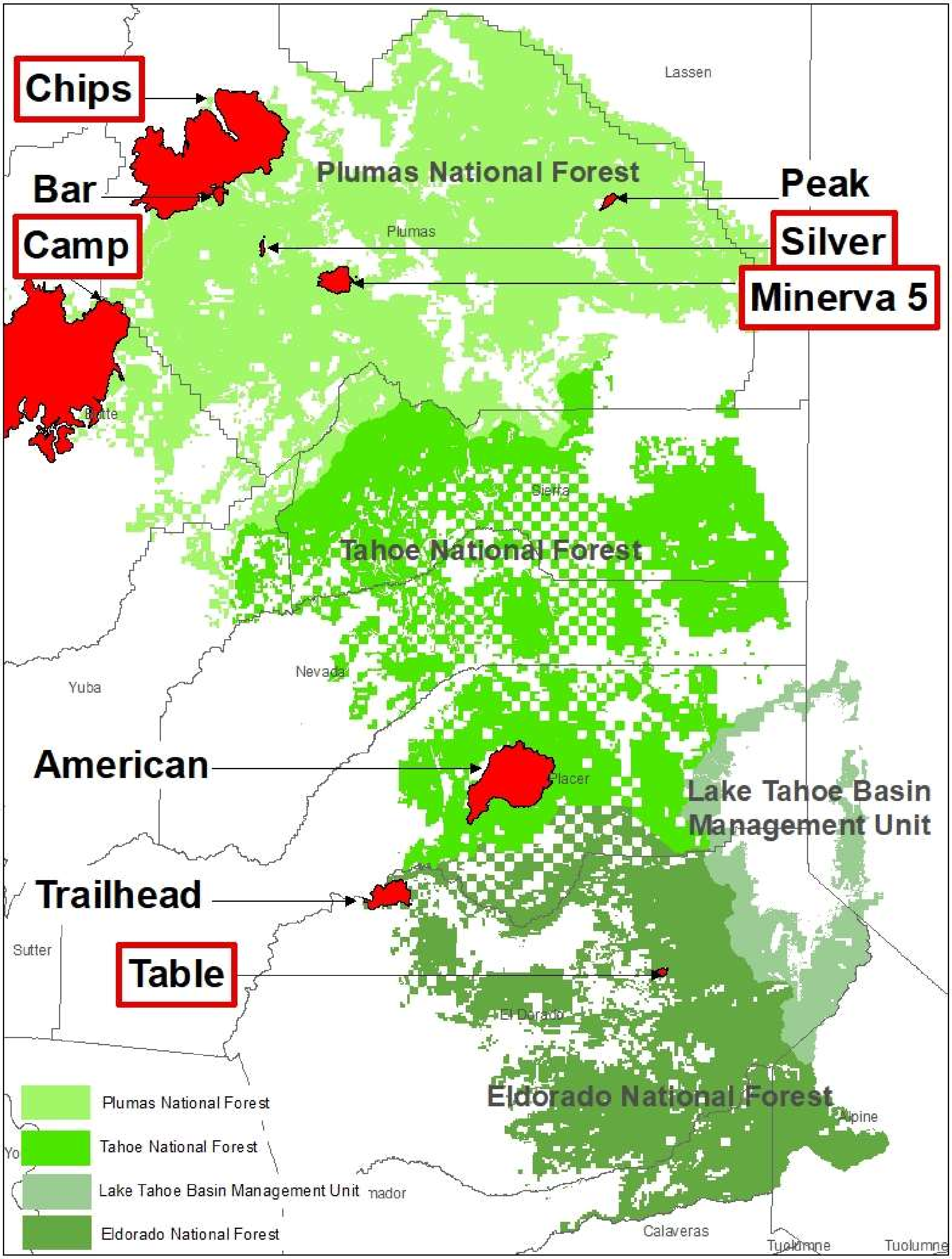

Figure 3. Fires (red shading) on the Plumas, Tahoe, and Eldorado National Forests and the Lake Tahoe Basin Management Unit surveyed for Black-backed Woodpeckers during the 2019 MIS monitoring field season. Names of fires where Black-backed Woodpeckers were detected are enclosed in red boxes. Lack of detection does not necessarily mean Black-backed Woodpeckers were absent (see text for discussion of detection probability during this survey).

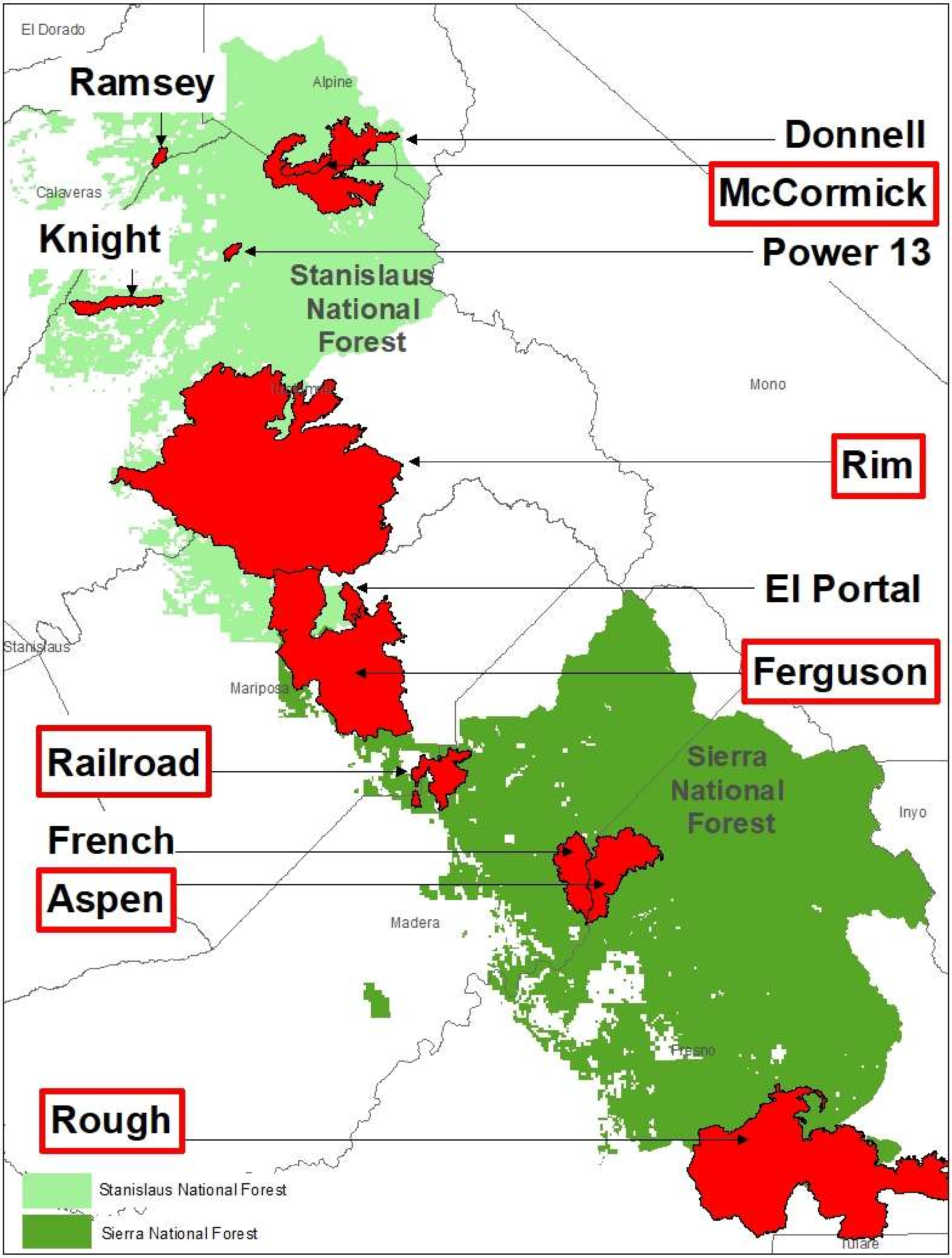

Figure 4. Fires (red shading) on the Stanislaus and Sierra National Forests surveyed for Black-backed Woodpeckers during the 2019 MIS monitoring field season. Names of fires where Black-backed Woodpeckers were detected are enclosed in red boxes. Lack of detection does not necessarily mean Black-backed Woodpeckers were absent (see text for discussion of detection probability during this survey).

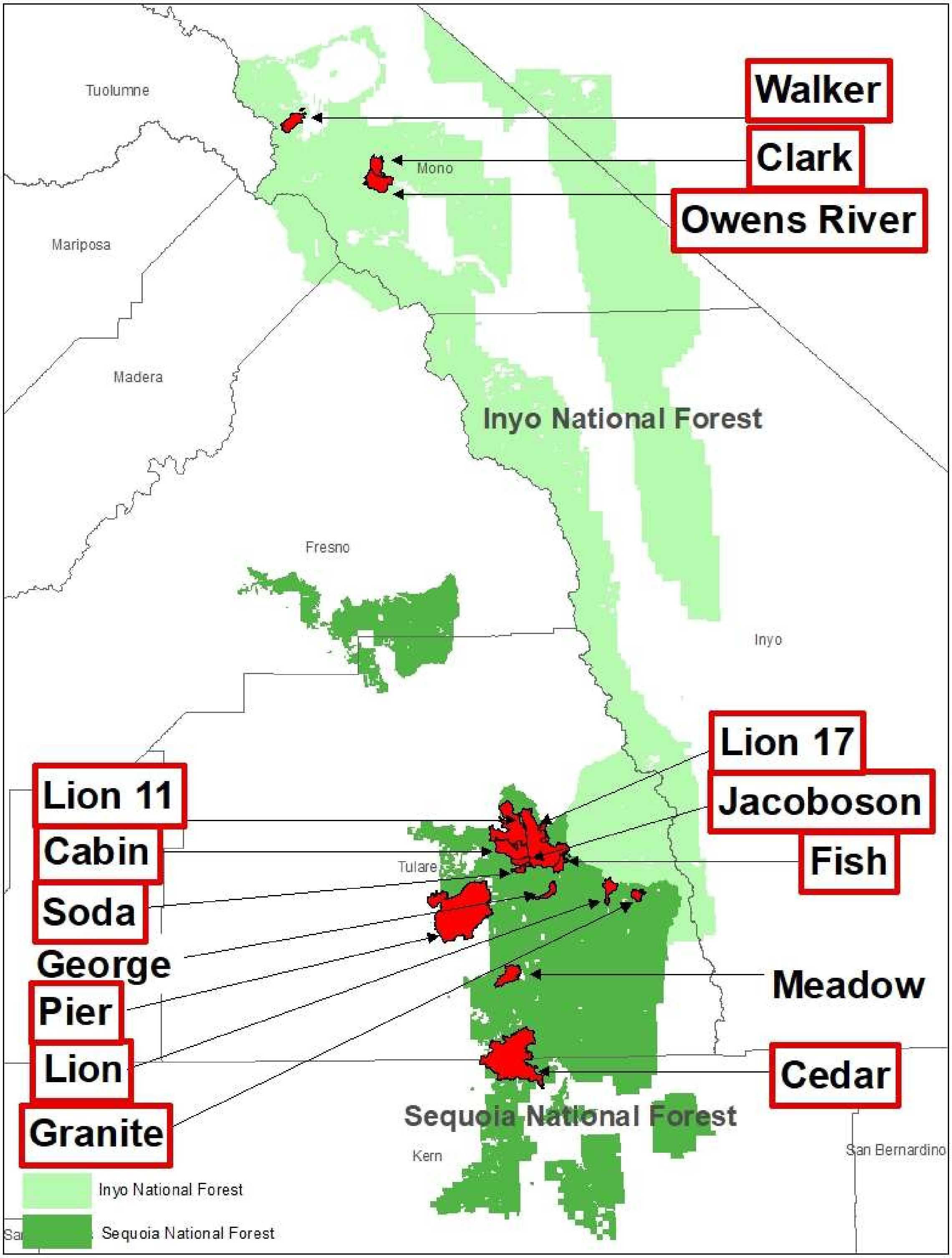

Figure 5. Fires (red shading) on the Inyo and Sequoia National Forests surveyed for Black-backed Woodpeckers during the 2019 MIS monitoring field season. Names of fires where Black-backed Woodpeckers were detected are enclosed in red boxes. Lack of detection does not necessarily mean Black-backed Woodpeckers were absent (see text for discussion of detection probability during this survey).

Analysis of Annual Occupancy

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 2019, the estimated proportion of occupied fires was 65%, which represents the second-highest estimate, but still within the observed range of variation over the last decade (Figure 6a).

Mean occupancy probability for points in fires surveyed in 2019 was 0.23 (95% credible interval: 0.22–0.25; Fig. 6b). Point-level occupancy probability has varied substantially over the 11 years of the study, and the estimate obtained for 2019 is within the range of variation observed between 2010–2018 (Fig. 6b). Table 3 summarizes detections and Tables 4 and 5 summarize predicted occupancy probabilities for each fire surveyed in 2009 through 2019 (point-level, Table 4; fire-level, Table 5).

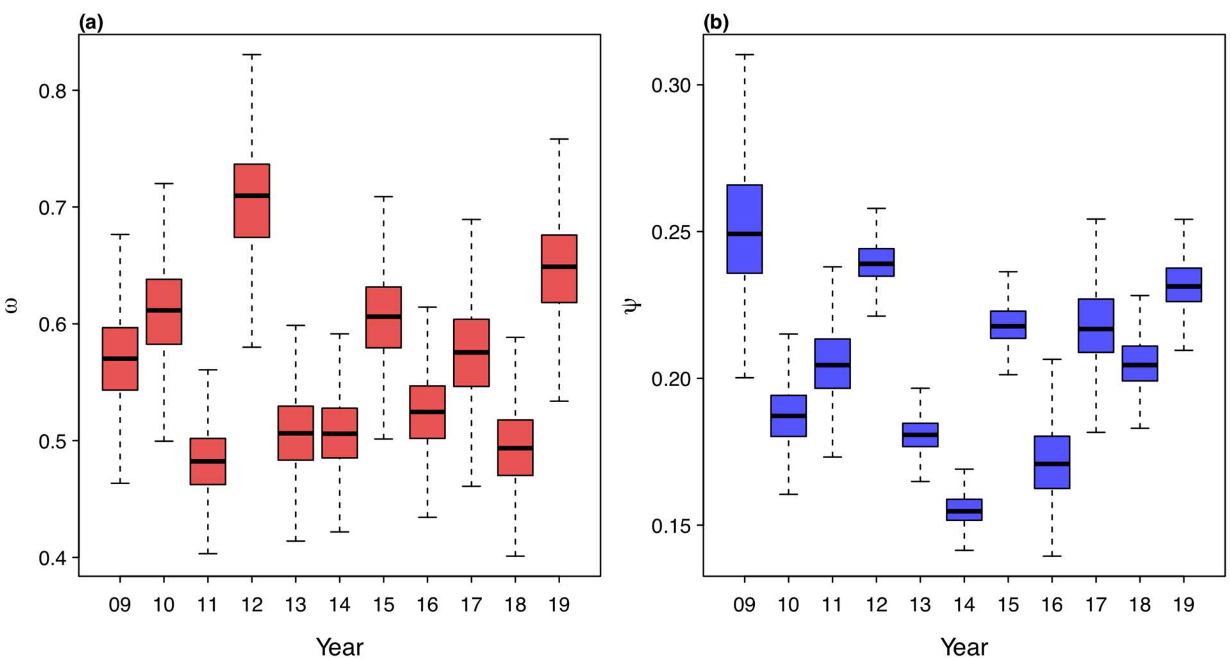

Figure 6. Mean probability of fire-level (ω, panel 'a') and point-level (ψ, panel 'b') occupancy for Black-backed Woodpeckers as modeled from individual year-based hierarchical models. Plots show median (bold line), 50% (box) and 95% (whiskers) Bayesian credible intervals of posterior distribution of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

Table 3. Summary of Black-backed Woodpecker positive detections at surveyed points for each fire visited during 2009 - 2019.

	Number of detections (Number of points surveyed)										
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Albanita	1 (21)	0 (21)	0 (21)	6 (21)	0 (21)	-	-	-	-	-	-
American	-	-	-	-	-	0 (20)	-	-	6 (20)	-	0 (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)	2 (20)
Azusa	0 (8)	-	-	-	-	-	-	-	-	-	-
Bald	-	-	-	-	-	-	6 (20)	2 (20)	0 (20)	0 (20)	0 (20)
Barry Point	-	-	-	-	17 (20)	15 (20)	14 (20)	-	-	5 (20)	8 (20)
Bar	-	-	-	-	-	-	-	0 (19)	1 (19)	0 (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)	0 (19)
Bucks	0 (20)	-	-	-	-	-	-	-	-	-	-
Cabin	-	-	-	-	-	-	-	4 (18)	4 (9)	12 (18)	9 (19)
Camp	-	-	-	-	-	-	-	-	-	-	2 (20)
Cedar	-	-	-	-	-	-	-	-	0 (20)	7 (20)	6 (20)
Chips	-	-	-	-	1 (20)	5 (20)	4 (20)	8 (20)	-	-	4 (20)
Clark	-	-	-	-	-	-	-	-	12 (20)	17 (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)	0 (20)
Cove	-	-	-	-	-	-	-	-	-	12 (20)	1 (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)	-

Fire name	Number of detections (Number of points surveyed)										
	2009	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Deep	0 (11)	0 (11)	0 (11)	0 (11)	0 (11)	0 (11)	-	-	-	-	-
Devils Gap	0 (20)	-	-	-	-	-	-	-	-	-	-
Dexter	6 (16)	1 (16)	-	7 (16)	0 (16)	-	-	-	-	-	-
Donnell	-	-	-	-	-	-	-	-	-	-	5 (20)
Dome Rock	-	-	-	-	-	6 (19)	2 (19)	4 (19)	-	0 (19)	-
Eiler	-	-	-	-	-	-	13 (20)	15 (20)	8 (18)	-	6 (18)
El Portal	-	-	-	-	-	-	-	0 (16)	0 (16)	-	0 (16)
Fall	0 (10)	1 (10)	0 (10)	1 (10)	4 (19)	4 (18)	3 (19)	-	2 (19)	0 (19)	-
Ferguson	-	-	-	-	-	-	-	-	-	-	4 (20)
Fish	-	-	-	-	-	7 (20)	14 (19)	4 (20)	-	6 (19)	8 (20)
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)	-	0 (20)
Frey	-	0 (20)	0 (18)	-	0 (20)	0 (20)	-	0 (18)	0 (20)	0 (19)	-
Frog	-	-	-	-	-	-	-	14 (20)	15 (20)	7 (20)	4 (20)
Gap	-	0 (20)	0 (19)	-	-	-	-	-	-	-	-
George	-	-	-	-	2 (20)	1 (20)	6 (20)	6 (20)	0 (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)	12 (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)	12 (19)
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)	-	0 (19)
Lion 17	-	-	-	-	-	-	-	-	-	2 (20)	3 (20)
Lion 11	-	-	-	4 (20)	-	0 (20)	1 (20)	0 (20)	-	-	1 (20)
Lion	-	7 (20)	2 (20)	6 (20)	7 (20)	-	10 (20)	5 (20)	10 (20)	5 (20)	8 (20)
Lookout	0 (21)	-	-	-	-	-	-	-	-	-	-
Manter	0 (21)	0 (20)	-	-	-	-	-	-	-	-	-
McCormick	-	-	-	-	-	-	-	-	-	-	0 (20)
Mclaughlin	-	0 (13)	1 (13)	-	-	-	-	-	-	-	-

	Number of detections (Number of points surveyed)										
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
McNally	0 (19)	0 (17)	0 (16)	0 (17)	-	-	-	-	-	-	-
Meadow	-	-	-	-	-	-	-	-	0 (12)	-	0 (12)
Minerva 5	-	-	-	-	-	-	-	-	-	8 (20)	3 (20)
Moonlight	11 (20)	5 (20)	11 (20)	11 (20)	-	4 (20)	4 (20)	2 (20)	1 (20)	-	-
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)	10 (20)
Parker 2	-	-	-	-	-	-	-	-	-	-	10 (20)
Peak	-	-	-	-	-	-	17 (20)	12 (20)	6 (20)	0 (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)	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)	0 (20)
Power	1 (20)	0 (20)	0 (20)	2 (20)	0 (20)	0 (20)	-	-	-	-	-
Railroad	-	-	-	-	-	-	-	-	-	1 (20)	3 (20)
Ramsey	-	-	-	-	8 (20)	10 (20)	3 (20)	2 (20)	3 (20)	-	0 (20)
Reading	-	-	-	-	12 (20)	8 (20)	15 (20)	8 (20)	11 (20)	-	1 (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)	-	1 (20)
Rough	-	-	-	-	-	-	-	-	3 (20)	0 (20)	1 (19)
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)	1 (11)
Soda	-	-	-	-	-	-	4 (20)	0 (20)	0 (20)	2 (20)	3 (20)
Soup 2	-	-	-	-	-	-	-	-	12 (18)	14 (18)	14 (20)
Star	-	6 (20)	1 (20)	-	-	-	-	-	-	-	-
Steele	-	-	-	-	-	-	-	-	-	15 (20)	13 (20)

	Number of detections (Number of points surveyed)										
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Stone	-	-	-	-	-	-	-	-	-	-	4 (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)	0 (21)
Summit	-	-	0 (16)	-	0 (16)	-	-	-	-	-	-
Table	-	-	-	-	-	-	-	-	-	-	3 (16)
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)	0 (20)
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)	1 (16)
Whaleback	-	-	-	-	-	-	-	-	-	-	15 (20)
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)	198 (964)

Table 4. Summary of Black-backed Woodpecker posterior estimates of fire-level (ω) occupancy probability for all fires surveyed during 2009–2019. For point-level (ψ) occupancy predictions, see Table 5.

	Estimated probability of fire-level occupancy (ω)										
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Albanita	0.84	0.12	0.13	0.84	0.04	-	-	-	-	-	-
American	-	-	-	-	-	0.28	-	-	0.86	-	0.21
Antelope Complex	0.90	0.89	0.86	0.86	0.83	0.82	0.83	0.83	0.81	-	-
Angora	0.90	0.89	0.87	0.86	0.83	0.82	0.83	0.13	0.12	-	-
Aspen	-	-	-	-	-	0.93	0.33	0.87	0.23	0.34	0.80
Azusa	0.12	-	-	-	-	-	-	-	-	-	-
Bald	-	-	-	-	-	-	0.91	0.88	0.18	0.27	0.23
Barry Point	-	-	-	-	0.96	0.92	0.89	-	-	0.80	0.77
Bar	-	-	-	-	-	-	-	0.14	0.84	0.12	0.10
Bassetts	0.89	0.88	-	0.85	0.79	0.80	0.10	0.83	-	-	-
Bear	-	-	-	-	0.96	0.92	0.89	0.87	-	0.79	-
Belden	-	0.61	0.18	0.28	0.49	0.34	0.36	0.19	-	-	-
Bell	0.11	0.10	0.11	-	-	-	-	-	-	-	-
Bell West	0.77	-	-	-	-	-	-	-	-	-	-
Birch	0.13	-	-	-	-	-	-	-	-	-	-
Blue	0.81	0.78	0.79	-	-	-	-	-	-	-	-
Boulder Complex	0.88	0.88	-	-	0.79	0.10	-	-	-	-	-
Broder Beck	-	0.87	0.16	0.85	0.80	0.79	0.82	0.83	-	-	-
Brown	-	0.92	0.88	0.86	0.90	0.19	0.86	0.14	0.17	0.11	0.10
Bucks	0.09	-	-	-	-	-	-	-	-	-	-
Cabin	-	-	-	-	-	-	-	0.88	0.87	0.89	0.86
Camp	-	-	-	-	-	-	-	-	-	-	0.93
Cedar	-	-	-	-	-	-	-	-	0.21	0.92	0.89
Chips	-	-	-	-	0.96	0.92	0.89	0.87	-	-	0.77
Clark	-	-	-	-	-	-	-	-	0.88	0.92	0.89
Clover	-	0.91	0.19	0.86	-	-	-	-	0.13	0.07	-
Cold	-	-	-	0.86	0.87	0.84	-	0.84	0.82	0.64	-
Comb	-	-	-	0.21	0.09	0.10	-	-	-	-	-
Cone	0.82	-	0.81	-	-	-	-	-	-	-	-
Cooney	-	-	-	0.84	0.04	-	-	-	-	-	-
Corral	-	-	-	0.86	0.87	0.84	0.84	0.13	0.82	0.07	-
Cougar	-	-	-	0.86	-	0.90	0.88	-	-	0.76	0.12
Cove	-	-	-	-	-	-	-	-	-	0.94	0.91
Crag 04	0.86	-	0.14	0.85	0.06	-	-	-	-	-	-
Crag 05	0.19	0.16	0.16	0.15	0.08	0.08	0.10	-	-	-	-
Crater	0.81	0.77	0.79	-	-	-	-	-	-	-	-
Cub	-	0.91	0.88	0.86	0.86	0.85	0.84	0.84	-	0.08	-
Deep	0.49	0.30	0.15	0.40	0.14	0.15	-	-	-	-	-

	Estimated probability of fire-level occupancy (ω)										
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Devils Gap	0.09	-	-	-	-	-	-	-	-	-	-
Dexter	0.84	0.82	-	0.85	0.04	-	-	-	-	-	-
Donnell	-	-	-	-	-	-	-	-	-	-	0.92
Dome Rock	-	-	-	-	-	0.85	0.84	0.84	-	0.07	-
Eiler	-	-	-	-	-	-	0.91	0.87	0.87	-	0.83
El Portal	-	-	-	-	-	-	-	0.24	0.27	-	0.25
Fall	0.42	0.91	0.19	0.86	0.86	0.84	0.84	-	0.82	0.07	-
Ferguson	-	-	-	-	-	-	-	-	-	-	0.93
Fish	-	-	-	-	-	0.93	0.90	0.87	-	0.83	0.80
Fletcher	0.90	0.90	0.86	0.86	0.14	0.12	-	0.83	-	-	-
Fox	-	-	0.18	-	0.45	0.28	0.24	0.16	0.25	0.10	-
Freds	0.17	-	0.14	0.14	0.06	0.08	-	-	-	-	-
French	-	-	-	-	-	-	0.20	0.19	0.87	-	0.21
Frey	-	0.49	0.18	-	0.38	0.21	-	0.15	0.22	0.10	-
Frog	-	-	-	-	-	-	-	0.88	0.87	0.89	0.86
Gap	-	0.10	0.11	-	-	-	-	-	-	-	-
George	-	-	-	-	0.96	0.91	0.89	0.86	0.23	0.28	0.19
Gondola	0.83	0.80	-	0.84	-	-	-	-	-	-	-
Government	0.91	0.91	0.88	-	0.87	0.84	0.13	-	0.82	0.64	-
Granite	-	0.92	0.88	-	0.90	0.87	0.86	0.16	0.83	0.09	0.66
Grease	-	-	-	0.15	0.11	0.10	-	0.12	-	-	-
Harding	0.87	0.86	0.14	0.14	0.09	0.09	0.10	-	-	-	-
High	-	0.87	0.86	0.85	-	0.80	-	0.83	-	-	-
Highway	-	-	0.11	-	-	-	-	-	-	-	-
Hiram	0.10	-	-	-	-	-	-	-	-	-	-
Hooker	0.14	0.12	0.13	0.14	-	-	-	-	-	-	-
Horton 2	0.77	-	-	-	-	-	-	-	-	-	-
Inyo Complex	0.26	-	-	-	-	-	-	-	-	-	-
Jacoboson	-	-	-	-	-	-	-	-	0.88	0.92	0.88
Kibbie	0.85	-	0.81	0.84	0.05	-	-	-	-	-	-
King	-	-	-	-	-	-	-	0.87	-	-	-
Knight	-	0.61	0.20	0.24	0.44	0.22	0.27	0.16	0.21	-	0.12
Lion 17	-	-	-	-	-	-	-	-	-	0.94	0.91
Lion 11	-	-	-	0.87	-	0.21	0.87	0.20	-	-	0.73
Lion	-	0.92	0.88	0.87	0.90	-	0.85	0.85	0.83	0.68	0.66
Lookout	0.10	-	-	-	-	-	-	-	-	-	-
Manter	0.14	0.08	-	-	-	-	-	-	-	-	-
McCormick	-	-	-	-	-	-	-	-	-	-	0.31
Mclaughlin	-	0.10	0.79	-	-	-	-	-	-	-	-
McNally	0.35	0.23	0.12	0.37	-	-	-	-	-	-	-
Meadow	-	-	-	-	-	-	-	-	0.37	-	0.37

	Estimated probability of fire-level occupancy (ω)										
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Minerva 5	-	-	-	-	-	-	-	-	-	0.93	0.91
Moonlight	0.90	0.90	0.86	0.86	-	0.82	0.83	0.84	0.82	-	-
Motor	-	-	-	0.39	-	-	-	-	-	-	-
Mountain	-	0.82	0.82	0.84	-	-	-	-	-	-	-
Mud	0.85	0.81	0.82	0.85	0.68	-	-	-	-	-	-
North Fork	0.25	0.17	0.12	-	-	-	-	-	-	-	-
Oliver	-	-	0.87	-	0.44	-	0.16	0.17	0.18	-	-
Onion 2	-	0.30	0.18	0.86	0.23	0.16	0.84	0.14	0.15	0.08	-
Owens River	-	-	-	-	-	-	-	-	0.88	0.92	0.89
Parker 2	-	-	-	-	-	-	-	-	-	-	0.91
Peak	-	-	-	-	-	-	0.89	0.87	0.85	0.18	0.15
Peavine	0.54	-	-	-	-	-	0.84	0.16	-	0.09	-
Peterson Complex	0.92	0.91	0.87	0.86	0.19	0.15	0.12	-	0.82	-	-
Piute 08	0.37	0.23	-	-	0.18	0.15	0.13	0.20	0.13	0.08	-
Pidgen	0.09	-	-	-	-	-	-	-	-	-	-
Pier	-	-	-	-	-	-	-	-	-	0.93	0.91
Pit	-	-	-	0.86	0.45	-	0.23	-	0.26	0.10	-
Plum	0.29	0.22	0.12	0.23	-	-	-	-	-	-	-
Power 13	-	-	-	-	-	-	0.30	-	-	0.33	0.23
Power	0.86	0.18	0.13	0.85	0.06	0.07	-	-	-	-	-
Railroad	-	-	-	-	-	-	-	-	-	0.94	0.91
Ramsey	-	-	-	-	0.96	0.92	0.89	0.86	0.85	-	0.15
Reading	-	-	-	-	0.96	0.91	0.89	0.87	0.85	-	0.77
Rich	0.91	0.91	-	0.86	-	0.15	0.84	0.14	0.82	-	-
Rim	-	-	-	-	-	0.26	0.19	0.21	0.86	-	0.80
Rough	-	-	-	-	-	-	-	-	0.87	0.31	0.86
Sawmill 06	-	-	0.16	-	0.11	-	0.10	-	-	-	-
Sawmill 00	0.17	-	-	-	-	-	-	-	-	-	-
Scotch	0.91	0.29	-	0.86	0.86	0.85	0.84	-	-	0.07	-
Sheep	-	-	-	0.86	0.41	0.27	-	-	-	-	-
Sherwin	-	-	-	-	0.87	0.15	-	-	0.13	0.07	-
Shotgun	-	-	-	0.86	-	-	0.14	0.19	-	0.68	-
Showers	0.82	0.79	-	0.84	-	-	-	-	-	-	-
Silver	-	-	0.88	0.87	0.90	0.87	0.85	0.85	0.28	0.14	0.67
Soda	-	-	-	-	-	-	0.91	0.23	0.22	0.86	0.83
Soup 2	-	-	-	-	-	-	-	-	0.88	0.92	0.89
Star	-	0.77	0.79	-	-	-	-	-	-	-	-
Steele	-	-	-	-	-	-	-	-	-	0.94	0.91
Stone	-	-	-	-	-	-	-	-	-	-	0.93
Storrie	0.80	-	-	-	-	-	-	-	-	-	-
Straylor	-	-	-	0.85	0.06	0.07	-	-	-	-	-

Fire name	Estimated probability of fire-level occupancy (ω)										
	2009	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Stream	0.11	0.09	0.11	-	-	-	-	-	-	-	-
Sugar Loaf	-	0.92	0.88	0.15	0.23	0.18	0.16	0.14	0.16	0.10	0.09
Summit	-	-	0.14	-	0.04	-	-	-	-	-	-
Table	-	-	-	-	-	-	-	-	-	-	0.91
Tamarack	-	-	-	0.85	0.11	0.10	0.11	0.15	-	-	-
Tehipite	-	-	-	0.86	0.87	-	0.84	0.84	0.82	0.64	-
Trailhead	-	-	-	-	-	-	-	-	-	0.73	0.58
Treasure	0.80	0.77	-	-	-	-	-	-	-	-	-
Vista	0.90	0.90	0.86	0.85	-	0.82	0.83	0.84	-	-	-
Walker	-	-	-	-	-	-	-	0.18	0.87	0.89	0.86
Whaleback	-	-	-	-	-	-	-	-	-	-	0.93
White	0.23	0.20	0.12	-	-	-	-	-	-	-	-
Whit	0.84	-	0.82	0.84	0.67	-	-	-	-	-	-
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)	0.65 (0.56, 0.72)

Table 5. Summary of Black-backed Woodpecker posterior estimates of average point-level (ψ) occupancy probability for all fires surveyed during 2009–2019. For fire-level (ω) occupancy predictions, see Table 4.

	Estimated probability of average point-level occupancy (ψ)										
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Albanita	0.10	0.00	0.00	0.30	0.00	-	-	-	-	-	-
American	-	-	-	-	-	0.00	-	-	0.32	-	0.00
Antelope Complex	0.62	0.23	0.41	0.42	0.26	0.13	0.34	0.20	0.40	-	-
Angora	0.78	0.61	0.73	0.70	0.71	0.54	0.19	0.00	0.00	-	-
Aspen	-	-	-	-	-	0.32	0.00	0.11	0.00	0.00	0.10
Azusa	0.00	-	-	-	-	-	-	-	-	-	-
Bald	-	-	-	-	-	-	0.34	0.18	0.00	0.00	0.00
Barry Point	-	-	-	-	0.86	0.76	0.74	-	-	0.31	0.45
Bar	-	-	-	-	-	-	-	0.00	0.17	0.00	0.00
Bassetts	0.48	0.44	-	0.30	0.16	0.09	0.00	0.10	-	-	-
Bear	-	-	-	-	0.78	0.59	0.19	0.10	-	0.28	-
Belden	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-
Bell	0.00	0.00	0.00	-	-	-	-	-	-	-	-
Bell West	0.15	-	-	-	-	-	-	-	-	-	-
Birch	0.00	-	-	-	-	-	-	-	-	-	-
Blue	0.59	0.32	0.34	-	-	-	-	-	-	-	-
Boulder Complex	0.54	0.09	-	-	0.09	0.00	-	-	-	-	-
Broder Beck	-	0.41	0.00	0.12	0.21	0.28	0.29	0.28	-	-	-
Brown	-	0.37	0.75	0.52	0.12	0.00	0.07	0.00	0.00	0.00	0.00
Bucks	0.00	-	-	-	-	-	-	-	-	-	-
Cabin	-	-	-	-	-	-	-	0.27	0.48	0.70	0.48
Camp	-	-	-	-	-	-	-	-	-	-	0.11
Cedar	-	-	-	-	-	-	-	-	0.00	0.38	0.33
Chips	-	-	-	-	0.07	0.27	0.24	0.44	-	-	0.22
Clark	-	-	-	-	-	-	-	-	0.70	0.88	0.87
Clover	-	0.42	0.00	0.08	-	-	-	-	0.00	0.00	-
Cold	-	-	-	0.62	0.61	0.39	-	0.46	0.43	0.50	-
Comb	-	-	-	0.00	0.00	0.00	-	-	-	-	-
Cone	0.47	-	0.36	-	-	-	-	-	-	-	-
Cooney	-	-	-	0.07	0.00	-	-	-	-	-	-
Corral	-	-	-	0.56	0.42	0.17	0.18	0.00	0.21	0.00	-
Cougar	-	-	-	0.68	-	0.46	0.44	-	-	0.34	0.00
Cove	-	-	-	-	-	-	-	-	-	0.67	0.21
Crag 04	0.29	-	0.00	0.07	0.00	-	-	-	-	-	-
Crag 05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-
Crater	0.48	0.20	0.39	-	-	-	-	-	-	-	-
Cub	-	0.17	0.25	0.11	0.27	0.27	0.19	0.20	-	0.00	-
Deep	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-

	Estimated probability of average point-level occupancy (ψ)										
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Devils Gap	0.00	-	-	-	-	-	-	-	-	-	-
Dexter	0.53	0.19	-	0.47	0.00	-	-	-	-	-	-
Donnell	-	-	-	-	-	-	-	-	-	-	0.27
Dome Rock	-	-	-	-	-	0.40	0.15	0.27	-	0.00	-
Eiler	-	-	-	-	-	-	0.70	0.79	0.51	-	0.38
El Portal	-	-	-	-	-	-	-	0.01	0.01	-	0.00
Fall	0.02	0.16	0.00	0.14	0.23	0.23	0.21	-	0.16	0.00	-
Ferguson	-	-	-	-	-	-	-	-	-	-	0.24
Fish	-	-	-	-	-	0.37	0.75	0.26	-	0.36	0.41
Fletcher	0.90	0.40	0.53	0.56	0.00	0.00	-	0.25	-	-	-
Fox	-	-	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	-
Freds	0.00	-	0.00	0.00	0.00	0.00	-	-	-	-	-
French	-	-	-	-	-	-	0.00	0.00	0.12	-	0.00
Frey	-	0.00	0.00	-	0.00	0.00	-	0.00	0.00	0.00	-
Frog	-	-	-	-	-	-	-	0.75	0.78	0.39	0.24
Gap	-	0.00	0.00	-	-	-	-	-	-	-	-
George	-	-	-	-	0.11	0.06	0.31	0.33	0.00	0.00	0.00
Gondola	0.74	0.43	-	0.25	-	-	-	-	-	-	-
Government	0.10	0.20	0.31	-	0.34	0.20	0.00	-	0.26	0.08	-
Granite	-	0.37	0.53	-	0.54	0.52	0.62	0.00	0.35	0.00	0.62
Grease	-	-	-	0.00	0.00	0.00	-	0.00	-	-	-
Harding	0.41	0.14	0.00	0.00	0.00	0.00	0.00	-	-	-	-
High	-	0.07	0.36	0.60	-	0.08	-	0.48	-	-	-
Highway	-	-	0.00	-	-	-	-	-	-	-	-
Hiram	0.00	-	-	-	-	-	-	-	-	-	-
Hooker	0.00	0.00	0.00	0.00	-	-	-	-	-	-	-
Horton 2	0.51	-	-	-	-	-	-	-	-	-	-
Inyo Complex	0.00	-	-	-	-	-	-	-	-	-	-
Jacoboson	-	-	-	-	-	-	-	-	0.50	0.43	0.63
Kibbie	0.33	-	0.21	0.27	0.00	-	-	-	-	-	-
King	-	-	-	-	-	-	-	0.29	-	-	-
Knight	-	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00
Lion 17	-	-	-	-	-	-	-	-	-	0.14	0.17
Lion 11	-	-	-	0.21	-	0.00	0.06	0.00	-	-	0.06
Lion	-	0.41	0.15	0.32	0.39	-	0.53	0.29	0.56	0.34	0.44
Lookout	0.00	-	-	-	-	-	-	-	-	-	-
Manter	0.00	0.00	-	-	-	-	-	-	-	-	-
McCormick	-	-	-	-	-	-	-	-	-	-	0.00
Mclaughlin	-	0.00	0.13	-	-	-	-	-	-	-	-
McNally	0.00	0.00	0.00	0.00	-	-	-	-	-	-	-
Meadow	-	-	-	-	-	-	-	-	0.01	-	0.01

	Estimated probability of average point-level occupancy (ψ)										
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Minerva 5	-	-	-	-	-	-	-	-	-	0.47	0.18
Moonlight	0.61	0.28	0.61	0.58	-	0.25	0.24	0.23	0.14	-	-
Motor	-	-	-	0.00	-	-	-	-	-	-	-
Mountain	-	0.21	0.32	0.46	-	-	-	-	-	-	-
Mud	0.54	0.65	0.44	0.42	0.47	-	-	-	-	-	-
North Fork	0.00	0.00	0.00	-	-	-	-	-	-	-	-
Oliver	-	-	0.43	-	0.00	-	0.00	0.00	0.00	-	-
Onion 2	-	0.00	0.00	0.08	0.00	0.00	0.12	0.00	0.00	0.00	-
Owens River	-	-	-	-	-	-	-	-	0.69	0.63	0.56
Parker 2	-	-	-	-	-	-	-	-	-	-	0.59
Peak	-	-	-	-	-	-	0.86	0.66	0.40	0.00	0.00
Peavine	0.01	-	-	-	-	-	0.07	0.00	-	0.00	-
Peterson Complex	0.51	0.37	0.74	0.20	0.00	0.00	0.00	-	0.12	-	-
Piute 08	0.00	0.00	-	-	0.00	0.00	0.00	0.00	0.00	0.00	-
Pidgen	0.00	-	-	-	-	-	-	-	-	-	-
Pier	-	-	-	-	-	-	-	-	-	0.18	0.18
Pit	-	-	-	0.11	0.00	-	0.00	-	0.00	0.00	-
Plum	0.00	0.00	0.00	0.00	-	-	-	-	-	-	-
Power 13	-	-	-	-	-	-	0.00	-	-	0.00	0.00
Power	0.10	0.00	0.00	0.12	0.00	0.00	-	-	-	-	-
Railroad	-	-	-	-	-	-	-	-	-	0.09	0.20
Ramsey	-	-	-	-	0.43	0.54	0.18	0.21	0.23	-	0.00
Reading	-	-	-	-	0.62	0.42	0.77	0.48	0.61	-	0.13
Rich	0.12	0.08	-	0.31	-	0.00	0.22	0.00	0.10	-	-
Rim	-	-	-	-	-	0.00	0.00	0.01	0.11	-	0.08
Rough	-	-	-	-	-	-	-	-	0.23	0.00	0.09
Sawmill 06	-	-	0.00	-	0.00	-	0.00	-	-	-	-
Sawmill 00	0.01	-	-	-	-	-	-	-	-	-	-
Scotch	0.22	0.01	-	0.09	0.12	0.05	0.08	-	-	0.00	-
Sheep	-	-	-	0.06	0.00	0.00	-	-	-	-	-
Sherwin	-	-	-	-	0.45	0.00	-	-	0.00	0.00	-
Shotgun	-	-	-	0.20	-	-	0.00	0.00	-	0.21	-
Showers	0.52	0.72	-	0.55	-	-	-	-	-	-	-
Silver	-	-	0.68	0.56	0.46	0.10	0.28	0.28	0.01	0.00	0.10
Soda	-	-	-	-	-	-	0.21	0.00	0.00	0.13	0.16
Soup 2	-	-	-	-	-	-	-	-	0.74	0.84	0.76
Star	-	0.35	0.18	-	-	-	-	-	-	-	-
Steele	-	-	-	-	-	-	-	-	-	0.78	0.67
Stone	-	-	-	-	-	-	-	-	-	-	0.27
Storrie	0.48	-	-	-	-	-	-	-	-	-	-
Straylor	-	-	-	0.13	0.00	0.00	-	-	-	-	-

	Estimated probability of average point-level occupancy (ψ)										
Fire name	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Stream	0.00	0.00	0.00	-	-	-	-	-	-	-	-
Sugar Loaf	-	0.17	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Summit	-	-	0.00	-	0.00	-	-	-	-	-	-
Table	-	-	-	-	-	-	-	-	-	-	0.23
Tamarack	-	-	-	0.16	0.00	0.00	0.00	0.00	-	-	-
Tehipite	-	-	-	0.44	0.55	-	0.86	0.22	0.39	0.53	-
Trailhead	-	-	-	-	-	-	-	-	-	0.00	0.00
Treasure	0.29	0.42	-	-	-	-	-	-	-	-	-
Vista	0.52	0.50	0.17	0.29	-	0.31	0.36	0.25	-	-	-
Walker	-	-	-	-	-	-	-	0.00	0.41	0.23	0.20
Whaleback	-	-	-	-	-	-	-	-	-	-	0.78
White	0.00	0.01	0.00	-	-	-	-	-	-	-	-
Whit	0.36	-	0.41	0.49	0.28	-	-	-	-	-	-
Mean (95% CI)	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)	0.23 (0.22, 0.25)

With eleven years of data we can assess the presence of 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 2019 for either point-level occupancy (mean ± se: -0.0008 ± 0.0030; $P = 0.79$) or fire-level occupancy (mean ± se: -0.0004 ± 0.0069; $P = 0.95$).

We compared modeled covariate relationships with occupancy and detectability for each of the nine annual occupancy models (Table 6). Covariate signs showed general consistency across years, with 2019 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 2019, the parameter mean was almost exactly zero, indicating no relationship. Of the eleven years, the parameter has been significantly negative twice, and significantly positive once (Table 6). Pre-fire canopy cover likely also interacts with burn severity, which could lead to the switching in directions over years as snags fall. Consistent with previous years, the effect of fire age on fire-level occupancy was significant in 2019. Generally, fire age is particularly important in years with low overall occupancy (e.g., 2009, 2010, 2013, 2014), although 2019 was above average in this respect. 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), although interval duration (longer is better) and survey date (later is better) were both significant in 2019.

Table 6. Posterior summaries (means and 95% credible intervals) for intercepts and regression coefficients for single-year occupancy models as applied to 2009–2019 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	2019
σ_f (variance of random	6.5	6.34	6.2	6.4	6.2	6.3	6.6	6.3	6.1	4.8	5.1
fire effect)	(0.93, 9.87)	(1.05, 9.85)	(0.57, 9.86)	(0.89, 9.86)	(0.45, 9.88)	(0.97, 9.86)	(0.94, 9.88)	(1.07,9.85)	(0.92, 9.84)	(0.29, 9.53)	(0.41, 9.71)
γ_1 (fire age)	**-2.76**	**-3.23**	-1.83	-0.49	**-5.81**	**-3.23**	-2.04	-0.85	-1.08	**-3.31**	**-3.01**
	(-6.58, -0.14)	(-7.42, -0.39)	(-5.15, 0.44)	(-3.77, 2.49)	(-11.9, -1.35)	(-7.67, -0.38)	(-5.76, 0.60)	(-3.39, 1.37)	(-3.68, 1.00)	(-6.67, -0.98)	(-6.31, -0.78)
Point-level occupancy probability											
β_0	**-1.01**	**-1.17**	**-0.45**	**-0.97**	**-1.01**	**-0.98**	**-0.80**	**-0.94**	**-0.88**	**-0.98**	**-0.90**
	(-1.37, -0.61)	(-1.47, -0.86)	(-0.76, -0.11)	(-1.19, -0.77)	(-1.33, -0.70)	(-1.25, -0.71)	(-1.03, -0.57)	(-1.27, -0.56)	(-1.20, -0.52)	(-1.30, -0.66)	(-1.12, -0.67)
β_1 (latitude)	**0.54**	-0.26	0.22	**0.53**	-0.06	-0.01	0.18	**0.49**	-0.03	**0.28**	-0.08
	(0.17, 1.01)	(-0.53, 0.00)	(-0.06, 0.52)	(0.34, 0.73)	(-0.33, 0.21)	(-0.24, 0.22)	(-0.05, 0.41)	(0.24, 0.74)	(-0.29, 0.25)	(0.04, 0.54)	(-0.27, 0.11)
β_2 (elevation)	**1.20**	**0.81**	-0.07	**0.53**	**1.00**	**0.54**	**0.77**	0.14	**0.68**	**0.77**	**0.76**
	(0.70, 1.91)	(0.45, 1.16)	(-0.37, 0.24)	(0.27, 0.80)	(0.60, 1.41)	(0.20, 0.90)	(0.48, 1.07)	(-0.19, 0.50)	(0.37, 1.02)	(0.46, 1.09)	(0.52, 1.00)
β_3 (snag density)	0.08	**0.29**	0.10	**0.36**	**0.45**	**0.40**	**0.84**	**0.29**	0.13	**0.46**	**0.25**
	(-0.18, 0.32)	(0.00, 0.60)	(-0.15, 0.36)	(0.18, 0.54)	(0.23, 0.70)	(0.12, 0.68)	(0.56, 1.13)	(0.05, 0.57)	(-0.14, 0.39)	(0.24, 0.68)	(0.04, 0.47)
β_4 (burn severity)	**0.37**	0.21	0.20	0.03	**0.25**	0.12	-0.04	-0.13	0.13	-0.11	0.02
	(0.06, 0.72)	(-0.05, 0.47)	(-0.09, 0.49)	(-0.18, 0.22)	(0.00, 0.50)	(-0.12, 0.36)	(-0.27, 0.17)	(-0.37, 0.10)	(-0.14, 0.40)	(-0.39, 0.17)	(-0.22, 0.24)
β_5 (pre-fire canopy	0.06	**0.35**	0.22	**-0.21**	-0.31	**-0.28**	-0.06	-0.22	-0.15	-0.13	0.01
cover)	(-0.22, 0.33)	(0.06, 0.63)	(-0.03, 0.48)	(-0.41, -0.01)	(-0.31, 0.24)	(-0.55, -0.02)	(-0.27, 0.18)	(-0.49, 0.05)	(-0.36, 0.05)	(-0.34, 0.09)	(-0.18, 0.20)
Detection probability											
α_0	**-3.45**	**-1.57**	**-1.2**	**-0.94**	**-1.33**	**-1.12**	**-0.96**	**-1.98**	**-1.83**	**-1.09**	**-1.48**
	(-4.41, -2.65)	(-1.89, -1.25)	(-1.58, -0.83)	(-1.24, -0.63)	(-1.71, -0.97)	(-1.59, -0.77)	(-1.33, -0.62)	(-2.61, -1.39)	(-2.40, -1.29)	(-1.48, -0.73)	(-1.82, -1.13)
α_1 (interval duration)	**1.94**	**0.72**	0.09	0.25	0.23	0.44	0.21	0.46	-0.44	0.23	**0.55**
	(1.11, 2.91)	(0.14, 1.31)	(-0.51, 0.68)	(-0.25, 0.75)	(-0.39, 0.84)	(-0.22, 1.09)	(-0.39, 0.80)	(-0.34, 1.26)	(-1.25, 0.31)	(-0.34, 0.79)	(0.02, 1.06)
α_2 (survey type)	**2.83**	**1.05**	**0.67**	**0.92**	**1.37**	**1.30**	**1.09**	**1.78**	**1.25**	**0.95**	**1.33**
	(2.03, 3.77)	(0.65, 1.47)	(0.22, 1.12)	(0.53, 1.30)	(0.92, 1.83)	(0.78, 1.83)	(0.65, 1.54)	(1.19, 2.42)	(0.75, 1.75)	(0.52, 1.39)	(0.93, 1.76)
α_3 (day of year)	-0.24	-0.16	0.01	0.07	0.03	**0.43**	0.23	0.40	0.15	-0.19	**0.34**
	(-0.54, 0.06)	(-0.41, 0.08)	(-0.21, 0.22)	(-0.11, 0.26)	(-0.20, 0.26)	(0.15, 0.72)	(-0.01, 0.47)	(-0.08, 0.86)	(-0.25, 0.55)	(-0.46, 0.08)	(0.13, 0.56)

Analysis of Dynamic Occupancy

Of the 2,551 individual points surveyed across 133 fires, 2,043 points (80%) have been surveyed in more than one year, and 38 points (1.5%) have been surveyed for ten straight years (from 2 fires). The median point has been visited in 4 separate years.

Our analysis of eleven years of data exploring 48 model parameterizations of detectability and initial occupancy resulted in strong support for three similar models, which together represented over 75% of the total AIC model weight. These three 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 = 0.34; AIC = 4635) 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.

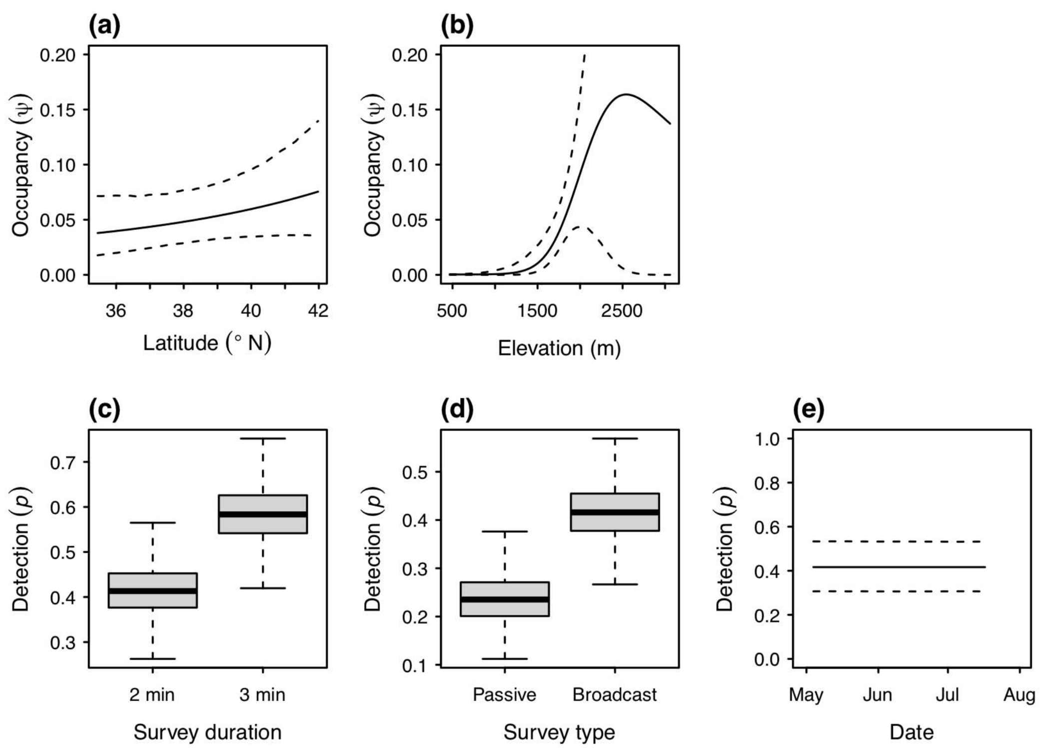

Figure 7. Model-averaged covariate relationships for occupancy (a, b) and detection (c–e) probabilities. Mean covariate relationships are depicted by a solid black line (a, b, e) or a bold horizontal line (c, d). Dotted black lines indicate 95% confidence intervals on relationships, estimated from parametric 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 point-level postfire occupancy was low (generally < 0.2) but increased weakly with latitude and strongly with elevation (Figure 7a-b) in models that accounted for correlation between latitude and elevation. 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 7. Top models (Δ_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	4540.8	0.00	0.10
Snag density + fire age	Burn severity + canopy cover	12	4541.7	0.84	0.07
Snag density + fire age	-	10	4542.4	1.53	0.05
Snag density + fire age + burn severity	Burn severity	12	4542.5	1.69	0.04
Snag density + fire age	Burn severity + snag density	12	4542.8	1.99	0.04
Snag density + fire age	Burn severity + fire age	12	4542.8	1.99	0.04
Snag density + fire age + canopy cover	Burn severity	12	4542.8	1.99	0.04

Model support for colonization and extinction models was broadly distributed across many similar candidate models (Table 7). Seven models were within 2 AIC units of each other and together comprised nearly 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 nearly all extinction models included burn severity (Table 7). Compared to previous analyses with fewer years of data, the covariates selected were highly consistent with previous results, and continue to show consistent support that survey points with higher burn severity show lower extinction rates (Siegel et al. 2019).

The cumulative AIC weight in support of the tested variables shows strong differences in support for colonization versus extinction covariates (Table 8). 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 moderate support (0.62) appearing for burn severity (Table 8). Eleven percent of AIC weight supported models where extinction occurred randomly at a fixed probability.

Table 8. 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	0.30
Fire age	1.00	0.27
Burn severity	0.35	0.62
Pre-fire canopy cover	0.28	0.40

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 an uncertain, moderate effect that extinction probability decreases with greater burn severity.

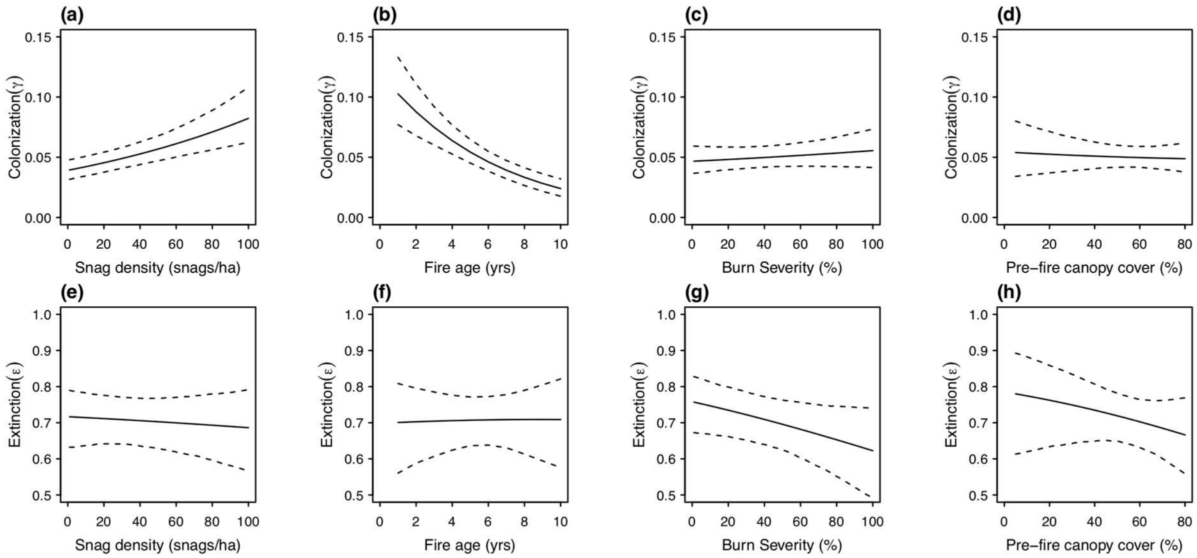

Figure 8. Modeled relationships between *a priori* covariates and probabilities of colonization (a-d) and local extinction (e-h). Plots show model-averaged mean covariate relationships (solid black line) and 95% confidence interval for slopes (dotted black line). Confidence intervals were estimated through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

Analysis of Avian Communities in Burned Forests

A total of 148 bird species have been detected near observers (<100 m) during passive bird surveys at Black-backed Woodpecker survey points (Table 9). In 2019, only one new species was discovered and added to the species list, the Northern Mockingbird. As expected, the number of new species added each year has plateaued, with only 6 species added over the last 4 years (Figure 9). Combined with community models, such data can provide robust estimates of true community size and how communities are structured relative to fire regimes (Tingley et al. 2016a, Tingley et al. 2020a).

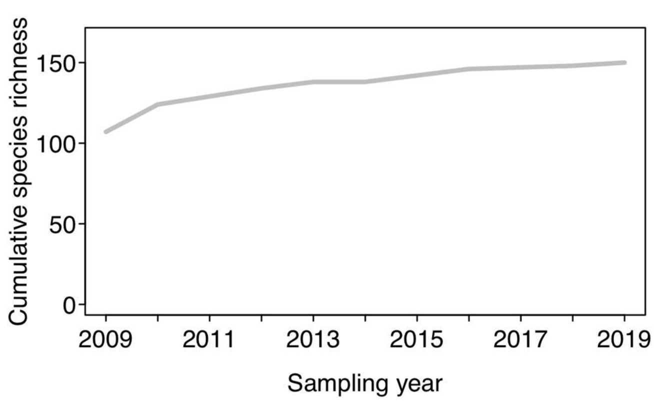

Figure 9. Empirical species accumulation curve for the number of species detected <100 m from observers during passive bird surveys at Black-backed Woodpecker points, 2009–2019.

Table 9. All bird species recorded within 100-m of observers during passive bird surveys sorted taxonomically. Also presented is the year each species was first recorded in surveys, the number of years (of 11 possible) that they have been recorded at least once, and the average % of survey points (across the eleven survey years) at which the species was detected.

Species Name	Scientific Name	Year of First Record	Number of Recorded Years	Average Annual Occurrence
Canada Goose	*Branta canadensis*	2010	4	0.10%
Mallard	*Anas platyrhynchos*	2009	6	0.20%
Common Merganser	*Mergus merganser*	2010	2	0.10%
Mountain Quail	*Oreortyx pictus*	2009	11	9.30%
California Quail	*Callipepla californica*	2009	10	0.90%
Sooty Grouse	*Dendragapus fuliginosus*	2009	10	0.80%
Band-tailed Pigeon	*Patagioenas fasciata*	2009	11	0.90%
Eurasian Collared-Dove	*Streptopelia decaocto*	2016	2	0.10%
Mourning Dove	*Zenaida macroura*	2009	11	8.00%
Common Nighthawk	*Chordeiles minor*	2009	10	0.50%
Common Poorwill	*Phalaenoptilus nuttallii*	2009	2	0.10%
Vaux's Swift	*Chaetura vauxi*	2016	3	0.10%
White-throated Swift	*Aeronautes saxatalis*	2012	4	0.20%
Anna's Hummingbird	*Calypte anna*	2009	11	3.10%
Costa's Hummingbird	*Calypte costae*	2009	1	0.10%
Rufous Hummingbird	*Selasphorus rufus*	2009	10	0.60%
Calliope Hummingbird	*Stellula calliope*	2009	11	1.00%
Killdeer	*Charadrius vociferus*	2009	4	0.10%
Western Sandpiper	*Calidris mauri*	2010	1	0.00%
Wilson's Snipe	*Gallinago delicata*	2013	2	0.00%
Spotted Sandpiper	*Actitis macularius*	2010	2	0.10%
Greater Yellowlegs	*Tringa melanoleuca*	2009	1	0.00%
California Gull	*Larus californicus*	2010	1	0.00%
Turkey Vulture	*Cathartes aura*	2010	6	0.20%
Osprey	*Pandion haliaetus*	2009	8	0.30%
Sharp-shinned Hawk	*Accipiter striatus*	2009	4	0.10%
Cooper's Hawk	*Accipiter cooperii*	2016	1	0.00%
Northern Goshawk	*Accipiter gentilis*	2012	3	0.10%
Bald Eagle	*Haliaeetus leucocephalus*	2009	4	0.10%
Red-tailed Hawk	*Buteo jamaicensis*	2009	11	1.00%
Flammulated Owl	*Otus flammeolus*	2013	1	0.00%
Western Screech-Owl	*Megascops kennicottii*	2010	1	0.00%
Great Horned Owl	*Bubo virginianus*	2009	3	0.10%
Northern Pygmy-Owl	*Glaucidium gnoma*	2009	9	0.40%

Species Name	Scientific Name	Year of First Record	Number of Recorded Years	Average Annual Occurrence
Belted Kingfisher	*Ceryle alcyon*	2010	1	0.00%
Lewis's Woodpecker	*Melanerpes lewis*	2009	11	1.60%
Acorn Woodpecker	*Melanerpes formicivorus*	2009	11	2.60%
Williamson's Sapsucker	*Sphyrapicus thyroideus*	2009	11	1.30%
Red-breasted Sapsucker	*Sphyrapicus ruber*	2009	11	5.30%
Black-backed Woodpecker	*Picoides arcticus*	2009	11	4.40%
Downy Woodpecker	*Picoides pubescens*	2010	10	1.10%
Nuttall's Woodpecker	*Picoides nuttallii*	2012	4	0.10%
Hairy Woodpecker	*Picoides villosus*	2009	11	21.70%
White-headed Woodpecker	*Picoides albolarvatus*	2009	11	11.50%
Northern Flicker	*Colaptes auratus*	2009	11	19.30%
Pileated Woodpecker	*Dryocopus pileatus*	2009	11	1.20%
American Kestrel	*Falco sparverius*	2009	11	1.10%
Peregrine Falcon	*Falco peregrinus*	2012	1	0.00%
Ash-throated Flycatcher	*Myiarchus cinerascens*	2009	5	0.30%
Western Kingbird	*Tyrannus verticalis*	2009	9	0.40%
Olive-sided Flycatcher	*Contopus cooperi*	2009	11	16.40%
Western Wood-Pewee	*Contopus sordidulus*	2009	11	37.10%
Willow Flycatcher	*Empidonax traillii*	2016	1	0.00%
Hammond's Flycatcher	*Empidonax hammondii*	2009	11	2.70%
Gray Flycatcher	*Empidonax wrightii*	2009	11	4.10%
Dusky Flycatcher	*Empidonax oberholseri*	2009	11	24.70%
Pacific-slope Flycatcher	*Empidonax difficilis*	2009	11	1.70%
Black Phoebe	*Sayornis nigricans*	2010	5	0.20%
Hutton's Vireo	*Vireo huttoni*	2009	10	1.10%
Cassin's Vireo	*Vireo cassinii*	2009	11	8.50%
Plumbeous Vireo	*Vireo plumbeus*	2015	2	0.00%
Warbling Vireo	*Vireo gilvus*	2009	11	8.50%
Canada Jay	*Perisoreus canadensis*	2010	2	0.00%
Pinyon Jay	*Gymnorhinus cyanocephalus*	2009	5	0.20%
Steller's Jay	*Cyanocitta stelleri*	2009	11	33.20%
Blue Jay	*Cyanocitta cristata*	2018	1	0.00%
California Scrub-Jay	*Aphelocoma californica*	2009	11	1.40%
Clark's Nutcracker	*Nucifraga columbiana*	2009	11	4.50%
Black-billed Magpie	*Pica hudsonia*	2009	3	0.10%
American Crow	*Corvus brachyrhynchos*	2011	2	0.00%
Common Raven	*Corvus corax*	2009	11	3.30%
Tree Swallow	*Tachycineta bicolor*	2009	10	1.40%

Species Name	Scientific Name	Year of First Record	Number of Recorded Years	Average Annual Occurrence
Violet-green Swallow	*Tachycineta thalassina*	2009	9	1.20%
Purple Martin	*Progne subis*	2011	5	0.30%
Cliff Swallow	*Petrochelidon pyrrhonota*	2009	3	0.10%
Mountain Chickadee	*Poecile gambeli*	2009	11	44.90%
Chestnut-backed Chickadee	*Poecile rufescens*	2009	6	0.20%
Oak Titmouse	*Baeolophus inornatus*	2009	4	0.10%
Juniper Titmouse	*Baeolophus ridgwayi*	2009	2	0.10%
Bushtit	*Psaltriparus minimus*	2009	9	0.80%
Red-breasted Nuthatch	*Sitta canadensis*	2009	11	31.20%
White-breasted Nuthatch	*Sitta carolinensis*	2009	11	12.10%
Pygmy Nuthatch	*Sitta pygmaea*	2009	11	5.60%
Brown Creeper	*Certhia americana*	2009	11	23.90%
Rock Wren	*Salpinctes obsoletus*	2009	11	5.70%
Canyon Wren	*Catherpes mexicanus*	2009	7	0.20%
House Wren	*Troglodytes aedon*	2009	11	22.90%
Pacific Wren	*Troglodytes pacificus*	2010	10	0.70%
Bewick's Wren	*Thryomanes bewickii*	2009	11	2.40%
Blue-gray Gnatcatcher	*Polioptila caerulea*	2011	9	1.10%
American Dipper	*Cinclus mexicanus*	2012	3	0.10%
Golden-crowned Kinglet	*Regulus satrapa*	2009	11	5.10%
Ruby-crowned Kinglet	*Regulus calendula*	2010	8	0.50%
Wrentit	*Chamaea fasciata*	2009	11	1.30%
Western Bluebird	*Sialia mexicana*	2009	11	9.30%
Mountain Bluebird	*Sialia currucoides*	2009	11	8.40%
Townsend's Solitaire	*Myadestes townsendi*	2009	11	10.60%
Hermit Thrush	*Catharus guttatus*	2009	11	2.80%
American Robin	*Turdus migratorius*	2009	11	31.20%
Northern Mockingbird	*Mimus polyglottos*	2019	1	0.00%
European Starling	*Sturnus vulgaris*	2009	11	1.10%
Cedar Waxwing	*Bombycilla cedrorum*	2013	2	0.10%
Evening Grosbeak	*Coccothraustes vespertinus*	2009	11	1.70%
Pine Grosbeak	*Pinicola enucleator*	2015	3	0.10%
House Finch	*Carpodacus mexicanus*	2009	10	2.00%
Purple Finch	*Carpodacus purpureus*	2009	11	3.20%
Cassin's Finch	*Carpodacus cassinii*	2009	11	18.60%
Red Crossbill	*Loxia curvirostra*	2009	11	2.30%
Pine Siskin	*Spinus pinus*	2009	11	2.90%
Lesser Goldfinch	*Spinus psaltria*	2009	11	3.40%

Species Name	Scientific Name	Year of First Record	Number of Recorded Years	Average Annual Occurrence
Lawrence's Goldfinch	*Spinus lawrencei*	2010	8	1.40%
American Goldfinch	*Spinus tristis*	2009	4	0.10%
Grasshopper Sparrow	*Ammodramus savannarum*	2013	1	0.00%
Black-throated Sparrow	*Amphispiza bilineata*	2009	3	0.20%
Lark Sparrow	*Chondestes grammacus*	2009	5	0.20%
Chipping Sparrow	*Spizella passerina*	2009	11	17.90%
Black-chinned Sparrow	*Spizella atrogularis*	2010	5	0.20%
Brewer's Sparrow	*Spizella breweri*	2009	11	2.00%
Fox Sparrow	*Passerella iliaca*	2009	11	31.20%
Dark-eyed Junco	*Junco hyemalis*	2009	11	46.90%
White-crowned Sparrow	*Zonotrichia leucophrys*	2011	8	0.70%
Golden-crowned Sparrow	*Zonotrichia atricapilla*	2015	1	0.00%
Sage Sparrow[1]	*Amphispiza belli*	2009	4	0.30%
Vesper Sparrow	*Pooecetes gramineus*	2009	10	0.80%
Song Sparrow	*Melospiza melodia*	2009	11	1.30%
Lincoln's Sparrow	*Melospiza lincolnii*	2009	11	1.90%
California Towhee	*Melozone crissalis*	2011	5	0.20%
Rufous-crowned Sparrow	*Aimophila ruficeps*	2015	2	0.00%
Green-tailed Towhee	*Pipilo chlorurus*	2009	11	19.50%
Spotted Towhee	*Pipilo maculatus*	2009	11	22.20%
Western Meadowlark	*Sturnella neglecta*	2009	9	1.30%
Bullock's Oriole	*Icterus bullockii*	2009	11	0.70%
Red-winged Blackbird	*Agelaius phoeniceus*	2009	9	0.50%
Brown-headed Cowbird	*Molothrus ater*	2009	11	6.40%
Brewer's Blackbird	*Euphagus cyanocephalus*	2009	11	3.80%
Orange-crowned Warbler	*Vermivora celata*	2009	11	2.50%
Nashville Warbler	*Leiothlypis ruficapilla*	2009	11	12.00%
MacGillivray's Warbler	*Geothlypis tolmiei*	2009	11	11.30%
Common Yellowthroat	*Geothlypis trichas*	2009	1	0.00%
Yellow Warbler	*Setophaga petechia*	2009	11	3.00%
Yellow-rumped Warbler	*Setophaga coronata*	2009	11	27.70%
Black-throated Gray Warbler	*Setophaga nigrescens*	2010	10	3.30%
Townsend's Warbler	*Setophaga townsendi*	2010	3	0.10%
Hermit Warbler	*Setophaga occidentalis*	2009	11	6.90%
Wilson's Warbler	*Cardellina pusilla*	2009	11	2.00%
Western Tanager	*Piranga ludoviciana*	2009	11	41.20%
Black-headed Grosbeak	*Pheucticus melanocephalus*	2009	11	15.40%
Lazuli Bunting	*Passerina amoena*	2009	11	18.10%

[1] Sage Sparrow complex includes individuals of both Bell's Sparrow and Sagebrush Sparrow.

Discussion

<u>Black-backed Woodpecker Annual Occupancy</u>

Our eleventh year of surveys indicates 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 2019 ~~in~~ on the Tahoe National Forest, we have detected woodpeckers within this unit previously and do not consider this a trend. Additionally, we only surveyed 1 fire within the Tahoe NF in 2019 (American), which burned in 2013. 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 this 6-year old fire would not necessarily be expected.

Overall, the proportion of occupied fires and the proportion of occupied points in 2019 were at the upper end of the observed range of 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, 21% in 2018, and most recently, 23% in 2019. The estimated percentage of occupied fires within the sampling frame has shown even 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, 49% in 2018, and now 65% in 2019. With eleven 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.

<u>Black-backed Woodpecker Dynamic Occupancy</u>

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 (i.e., colonization of sites that were unoccupied in a previous post-fire year was quite low

(<15%), while average extinction probability was much higher (50–90%). 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 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 species composition) or population density. Additional years of data have 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. 2016b, 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 targeted retention of early post-fire stands with high snag densities (Tingley et al. 2018).

Avian Communities in Burned Forests

Our analyses strongly support the notion that bird communities change in a complex manner in the decade immediately post-fire (Tingley et al. 2016a). A surprisingly high number of species (1) have now been recorded during surveys on post-fire landscapes, representing approximately one third of all regularly-occurring bird species in California (undoubtedly it would be a much higher percentage if the total species pool were restricted to California's breeding species). This diversity illustrates how post-fire landscapes are highly heterogenous over time and space, and that this dynamic landscape represents important habitat for a large number of species.

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