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Management Indicator Species (MIS) Surveys on Sierra Nevada National Forests: Black-backed Woodpecker

2009 Annual Report

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Above: A male Black-backed Woodpecker forages on a charred snag.

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Summary

The Black-backed Woodpecker (*Picoides arcticus*) was recently 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 personnel on a pilot study that developed and field-tested survey procedures and collected 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 inform the design of a long-term MIS monitoring program for Black-backed Woodpecker across ten national forest units of the Sierra Nevada, which we implemented in 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 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.

During the 2009 field season, we used passive and broadcast surveys to assess Black-backed Woodpecker occupancy at 899 survey stations arrayed across 51 recent fire areas (1-10 years post-fire) throughout our study area. We also collected on-the-ground habitat data at each survey station, and collated additional habitat data from existing GIS sources. In addition, we conducted passive point counts for other bird species at 465 of the Black-backed Woodpecker survey stations.

We detected Black-backed Woodpeckers at 169 survey stations distributed across 28 of the 51 fire areas we surveyed, including fire areas on nine of the ten national forest units in our study area—the only forest where we did not detect the species was Sierra NF, where our random sample yielded only one fire area to survey. 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 area we surveyed and the third most southerly fire area we surveyed.

Prior to formal analysis, we examined the distribution of stations with detections and those without detections (non-detection stations) in relation to environmental covariates expected to influence Black-backed Woodpecker occupancy rates. Specifically, we examined habitat type (California Wildlife Habitat Relationships [CWHR] classification), elevation, pre-fire canopy cover, number of years since fire, fire-induced change in canopy cover, and latitude. For our formal Black-backed Woodpecker occupancy analysis, we used a novel hierarchical modeling approach that incorporated separate but linked models for the observation (detection) and state (occupancy) processes. For the occupancy probability model, we defined a logit-linear model that included covariates examined or derived as part of our data exploration. Covariates included fire age, latitude, snag basal area, change in percent canopy cover, and elevation adjusted for latitude (residuals of a regression of latitude on elevation). For our detection probability model we defined a logit-linear model that included indicator variables to account for variation in detection probability associated with count duration (2- vs. 3-minute interval) and count type (passive vs. broadcast survey interval).

Mean occupancy probability for stations surveyed during 2009 was 0.253 (95% credible interval: 0.222 – 0.289). Assuming that our sample was representative of habitat yielded by all fires in the study area that burned between 1999 and 2008, we estimate that approximately 81,814 ha (i.e., 25.3%) of the 323,358 ha of burned forest on the ten national forest units within our sampling frame was occupied by Black-backed Woodpeckers in 2009 (or a range based on the 95% credible interval of 71,921 – 93,610 ha).

Home range size estimates from elsewhere in the range of Black-backed Woodpecker would suggest that this amount of occupied habitat could represent between 470 and 1,341 pairs of birds (assuming non-overlapping home ranges), but such estimates will only be conjectural until home range size estimates from the Sierra Nevada are available. Moreover, our sampling frame only included fires that occurred between 1999 and 2008, comprised at least 50 ha of conifer forest that burned at mid-severity and/or high-severity, and that occurred at least partially on one or more of the ten national forest units in our study area. Black-backed Woodpeckers occupying habitat in fire areas that burned more than ten years prior to our study, fire areas that did not include any land on national forests, or fire areas that burned <50 ha of conifer forest are not accounted for in our estimate. Our estimates also do not account for any Black-backed Woodpeckers that may have held territories partly or entirely within 'green forest'—areas that have not recently burned.

Our logit-linear model for occupancy probability suggested strong spatial variation in Black-backed Woodpecker occurrence related primarily to latitude (more common in the north), elevation (more common at higher elevations within the range of elevations we surveyed), and fire age (more common in recent fire areas). Our findings with respect to fire age are in general agreement with published data from other studies conducted elsewhere in the Black-backed Woodpecker range that find the species to be most common within a few years of a high-severity fire. Basal area of snags and fire-induced change in percent canopy cover (a measure of fire severity) appeared to be of relatively minor importance. However, this could simply reflect our sampling design which focused on fires with at least 50 ha exhibiting mid- or high-severity fire impacts. Inclusion of smaller and lower severity fires (or unburned areas) would likely yield different conclusions about these variables. We found some evidence that snag basal area was of greater importance in older fire areas, suggesting that areas with many snags better retain their value over time as potential Black-backed Woodpecker habitat. Factors that may have affected inference from our model include the resolution at which covariates were measured (or summarized) and collinearity among predictor variables.

Both count duration and, especially, count type had marked effects on detection probability. Our estimate of overall probability of detection during 5-min passive point counts was 0.230 (95% credible interval: 0.162 – 0.307). We estimate the detection probability during a 6-min broadcast survey was 0.702 (95% credible interval: 0.580 – 0.806). Most of the birds detected during passive point counts were also detected during subsequent broadcast surveys, so there was little difference between the overall broadcast survey detectability of 0.702 and the overall detectability based on the combined passive and call-broadcast surveys: 0.769 (95% credible interval: 0.661 – 0.858). Our survey objectives did not include meeting any particular detection probability threshold. Nevertheless, we note that in some instances, land managers could need to determine with a known level of certainty whether Black-backed Woodpeckers are present in a project area. Our estimates of detection probability indicate that using just passive, 5-min point counts, an observer would need to visit an occupied survey station 12 times in a breeding season to achieve a 95% probability of detecting one or more Black-backed Woodpeckers there. In contrast, using a 6-min broadcast survey would yield a 95% detection probability within 3 visits. Using the two methods together in sequence provides only a slight improvement to the broadcast-only detection probability, and would still just barely require 3 visits to reach the 95% probability threshold (2 visits would yield an estimated detection probability of 0.947).

In addition to Black-backed Woodpecker, our 461 passive point counts yielded detections of 109 other bird species within the fire areas. The five most frequently detected species were Mountain Chickadee (*Poecile gambeli,* 323 detections), Dark-eyed Junco (*Junco hyemalis*; 319 detections), Western Wood-Pewee (*Contopus sordidulus*, 318 detections), Western Tanager (*Piranga ludoviciana*; 316 detections), and Steller's Jay (*Cyanocitta stelleri*, 278 detections); these and dozens of additional species were detected frequently enough to facilitate analysis of the effects of fire severity and spatial configuration on bird assemblages in post-fire forest stands, which we intend to conduct after our 2010 field season as part of that year's annual reporting.

In the next few months we hope to reorganize the results presented here into two manuscripts for publication in peer-reviewed journals. The first manuscript will describe and generalize our modeling approach, and is tentatively titled *Hierarchical occupancy modeling for interval point surveys*. The second manuscript will focus on Black-backed Woodpecker biology and habitat relationships, and is tentatively titled *Distribution and relative abundance of Black-backed Woodpecker in recent fire areas of the Sierra Nevada, CA.*

We are pleased to be now preparing for our 2010 field season—the second year of full-scale Black-backed Woodpecker MIS monitoring on greater Sierra Nevada national forests. Multiple years of data will allow an assessment of whether the amount and proportion of burned forest habitat occupied by Black-backed Woodpeckers is stable, increasing, or decreasing. Once we have a second year of monitoring data we are also anticipating describing between-year occupancy dynamics of Black-backed Woodpeckers in recent fire areas, as well as analyzing our multi-species point count data to study the effects of fire severity on post-fire bird communities in the Sierra Nevada.

Introduction

The Black-backed Woodpecker (*Picoides arcticus*) was recently 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 (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 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 Woodpecker throughout the Sierra Nevada is not well-monitored by other multi-species, regional monitoring programs. Two large-scale, annual bird monitoring programs, the Breeding Bird Survey (BBS; Sauer et al. 2008) and the Monitoring Avian Productivity and Survivorship Program (MAPS; DeSante et al. 2008), detect Black-backed Woodpecker throughout the region in small numbers, but due in part to the ephemeral nature of the species' preferred habitat, neither program yields data that are adequate for regional MIS monitoring. Although Black-backed Woodpecker was detected on 13 Sierra Nevada BBS routes on or adjacent to Sierra Nevada national forests between 1991 and 2006 (Sauer et al. 2008), the data are too sparse for estimating the species' regional population trend (Sauer et al. 2008). Black-backed Woodpeckers were captured at five of 29 MAPS stations that operated in the Sierra Nevada physiographic province (including MAPS stations operating on national forests, national parks and private lands), but only rarely; overall just 0.023 adults and 0.005 young were captured per 600 net-hours in the region (Siegel and Kaschube 2007). These data are insufficient for estimating population trends and adult survival rates, or for calculating meaningful productivity indices.

Most of what is known about Black-backed Woodpecker ecology and population dynamics comes from elsewhere in the species' range. Black-backed Woodpeckers occur in conifer forests from western Alaska to northern Saskatchewan and central Labrador, south to southeastern British Columbia, central California, northwestern Wyoming, southwestern South Dakota, central Saskatchewan, northern Minnesota, southeastern Ontario, and northern New England (NatureServe 2007; Fig 1a). Outside of the breeding season, individuals may move to areas south of the breeding range, with occasional large irruptions (Dixon et al. 2000). In California, Black-backed Woodpeckers occur from the Siskiyou Mountains, Mount Shasta, and Warner Mountains south through the Cascade Range and the Sierra Nevada to Tulare County (California Department of Fish and Game 2005; Fig. 1b). California Department of Fish and Game (2005) suggest that throughout the Sierra Nevada some Black-backed Woodpeckers move downslope during winter, but other published sources suggest Black-backed Woodpecker is generally a non-migratory resident species lacking in predictable seasonal movements (Farris 2001).

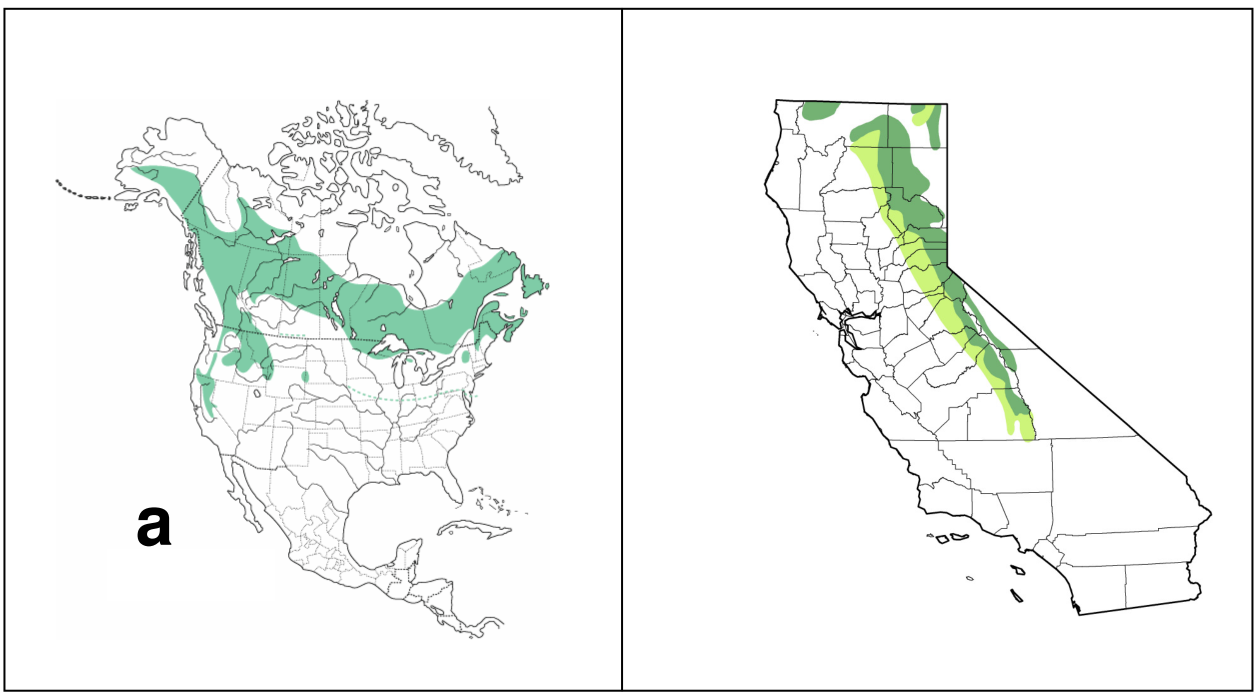

Figure 1. Distribution of Black-backed Woodpecker across (a) North America (figure from Dixon et al. 2000) and (b) California (figure from California Department of Fish and Game 2005). In part (b), light green indicates winter range, dark green indicates year-round range.

Although Black-backed Woodpecker can be found in unburned forest stands throughout its range, the species appears to be most abundant in stands of recently fire-killed snags (Hutto 1995, Kotliar et al. 2002, Smucker et al. 2005). 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). Although 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) they 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). Black-backed Woodpecker preference for wood-boring beetles could thus either drive or result from the species' proclivity to forage and nest in or near forest stands that have recently burned.

Although 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).

In 2008 The Institute for Bird Populations collaborated with Region personnel on a pilot study that developed and field-tested survey procedures and collected 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 inform the 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.

In 2009 we fully implemented the first year of Sierra-wide MIS monitoring for Black-backed Woodpeckers. Here we detail the results of this first year of full-scale MIS monitoring in recently burned forest stands.

Methods

Sample Design

Starting with the GIS data layer VegBurnSeverity08_1.mdb (obtained from http://www.fs.fed.us/r5/rsl/clearinghouse/gis-download), which indicates fire boundaries and fire severity of fires throughout California, we extracted data for all fires that occurred between 1999 and 2008, 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. In a few cases we were unable to determine in advance whether individual fire areas included burned conifer forest; these information gaps were resolved with site visits, after which the fire area was either included in the sampling frame, or discarded.

These selection criteria yielded 72 fire areas, to which we assigned a random priority order. Our intention was to survey the first 50 fire areas on the list in 2009, but if that proved impossible, we would discard fire areas according the priority order, to avoid biasing the sample.

Data Collection

Establishing survey stations. The fire areas we selected varied greatly in size, from 96 ha (2001 White Fire on Stanislaus NF) to 56,683 ha (2002 McNally Fire on Sequoia NF). At the smaller fire areas, a 2-person team could easily saturate the fire area with survey effort in a single morning; however saturating the larger fire areas 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 stations.

To determine where within a fire area to place our survey stations, we used GIS to randomly select a 'survey target point' somewhere within the perimeter of each fire area, and indicated that point on field maps given to field crews. Crews were instructed to establish their survey stations as close to the survey target point as possible, using the following rules:

> 1 – If trails or roads passed through the fire area, survey stations 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 stations, spaced 250 m apart. Survey stations 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 area, crews established an array of evenly spaced (250 m between stations) off-trail survey stations, as close to the target survey point as reasonably possible, without compromising safety or requiring additional days of hiking to access.

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

Broadcast surveys. At each survey station we conducted a 6-min broadcast survey to elicit responses from Black-backed Woodpeckers. We used FoxPro ZR2 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. 2) at each survey station 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 approximately half (465 of 899) of the survey stations (generally every second station), we *preceded* the broadcast survey with a 5-min passive point count to count all birds of any species (including Black-backed Woodpecker). The 5-min point count consisted of a 3-min interval immediately followed by a 2-min interval (Fig. 2); point counts were divided into two intervals to allow comparison with the 3-min counts used in the national Breeding Bird Survey, as well as to yield additional information for assessing detection probability of Black-backed Woodpecker and other species detected during passive point counts. 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 methodology are provided in Siegel et al. 2009.

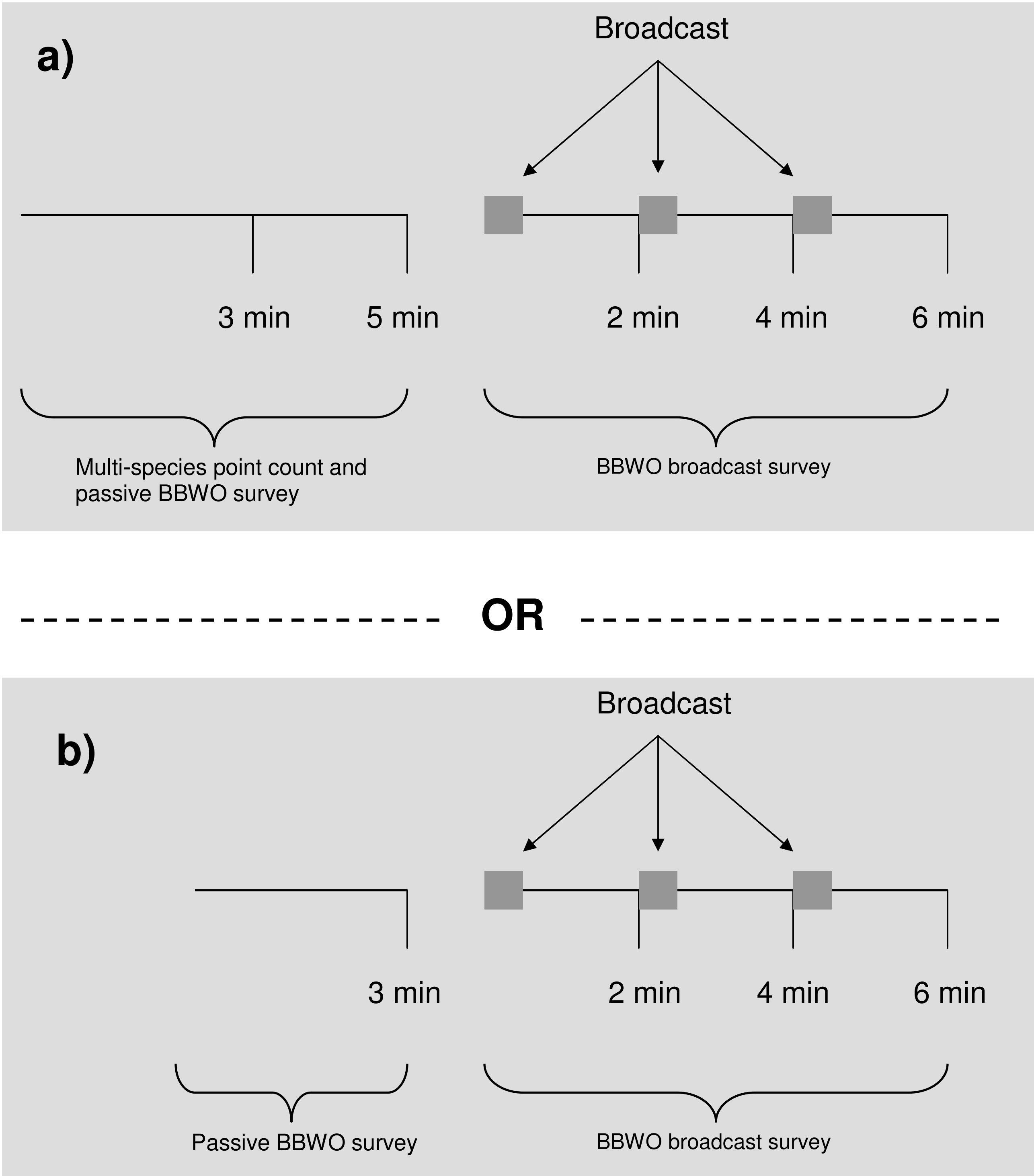

Figure 2. Schematic diagram of our survey methodology for detecting Black-backed Woodpeckers. Dark gray squares indicate period of actively broadcasting Black-backed Woodpecker drumming and vocalizations; black line segments indicate periods of passive observation. Observers alternated between method (a) and method (b) at successive survey stations.

To save time (allowing for more stations to be surveyed in a morning), at alternating survey stations we conducted a 3-min passive Black-Backed Woodpecker survey instead of a 5-min point count (Fig. 2). The passive Black-backed Woodpecker survey consisted of simply listening and looking for Black-backed Woodpeckers (prior to conducting the broadcast survey) for three minutes while standing at the survey station.

Habitat and other ancillary data. After completing point counts and broadcast surveys each day, observers returned to the survey stations to collected cursory habitat data. In addition to recording UTM coordinates, they classified the habitat within a 50-m radius plot centered on the survey station, 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 timber-cruising crutch, 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. 2009.

Data Analysis

Exploratory analyses. Prior to formal modeling, we examined the distribution of stations with detections and those without detections (non-detection stations) in relation to environmental covariates that we expected to influence Black-backed Woodpecker occupancy rates. Our preconceptions of important predictors of woodpecker occupancy were based on our own field experience as well as on previous research conducted on the species (Hanson and North 2008, Hutto 2008, Tremblay et al. 2009). We expected woodpecker occupancy to be influenced by fire age (higher occupancy in more recently burned areas), fire severity (higher occupancy in more severely burned areas), and pre- and post-fire habitat characteristics. Because habitat type is closely allied with elevation, we also examined the relationship between detections and elevation. In addition, upon completing the 2009 survey, it appeared that there was also a geographic gradient in woodpecker distribution, with occupancy being more common in the northern latitudes of the study area than in the southern latitudes. Specific variables we examined included:

- California Wildlife Habitat Relationships (CWHR) classification (Mayer and Laudenslayer 1988), as determined on the ground by our crew.
- Elevation, determined in the field from GPS and USGS topographic maps.
- Basal area of snags (standing dead trees) recorded at the survey station based on the Bitterlich variable plot method (see Mueller-Dombois and Ellenberg 1974 for detail).
- Pre-fire % tree cover calculated from 100-m resolution California Multi-source Land Cover Data (http://frap.cdf.ca.gov/data/frapgisdata/download.asp?spatialdist=1&rec=fveg02_2). We calculated this variable using the Spatial Analyst Toolbox in ArcGIS (Ver. 9.2, Environmental Systems Research Institute, Redlands, CA) by averaging midpoints of the % tree cover variable (WHRDENSITY) at 300 × 300 m resolution.
- 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 cc_i 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 (http://cran.r-project.org/web/packages/raster/vignettes/Raster.pdf). See Fig. 3 for an example map showing percent canopy cover change values for the Gondola fire surveyed in 2009.
- Latitude (in decimal degrees) recorded from USGS topographic maps.

We examined the distribution of stations with detections and non-detection stations in relation to these predictor variables using bean plots, which we generated using the 'beanplot' package (Kampstra 2008) in R (R Development Core Team 2009). Bean plots facilitate comparison of distributions of data points by simultaneously displaying the data along with normal density traces of the data.

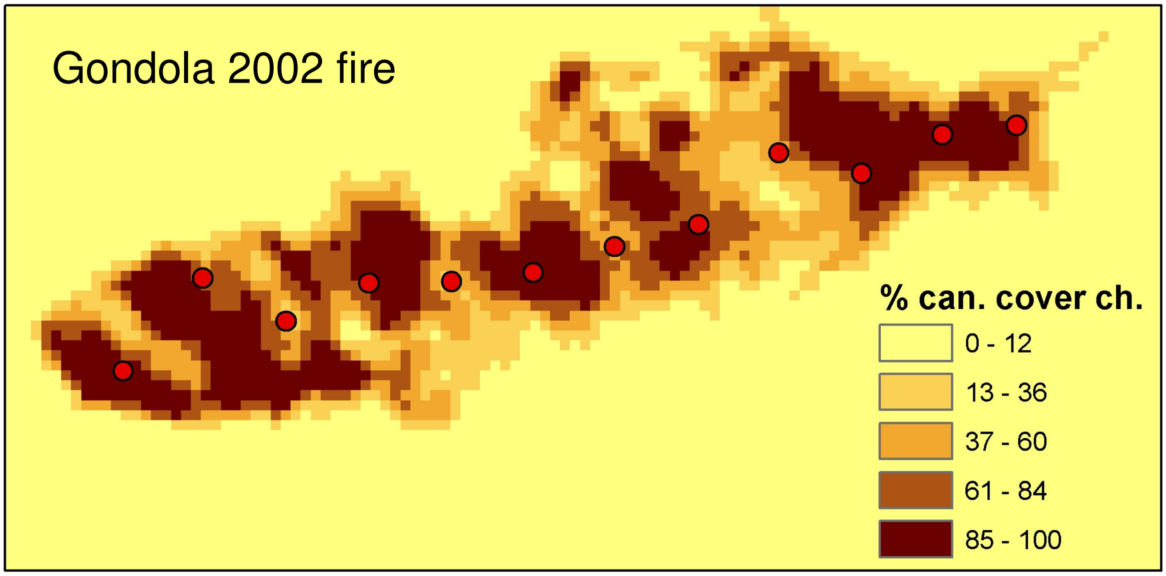

Figure 3. Example map of change in percent canopy cover values based on satellite derived relativized difference normalized burn ratio score RdNBR (Miller et al. 2009) for the Gondola fire surveyed in 2009. Values were summarized at 90-m^2 resolution by averaging 30-m^2 values from GIS layers.

Occupancy modeling. We developed a model based on $i = 1, \ldots, N$ survey stations, $j = 1, \ldots, M$ fire areas, and $k = 1, \ldots, K$ survey intervals. In 2009 we surveyed N = 899 stations within M = 51 fire areas with (up to) K = 5 intervals (1-2 passive survey intervals and 1-3 call broadcast survey intervals). Based on a hierarchical modeling framework (Royle and Dorazio 2008), we developed separate but linked models for the observation (detection) and state (occupancy) processes.

We modeled detections, $y(i, j, k)$, conditional on occupancy, $z(i, j)$, such that:

$$y(i, j, k) \mid z(i, j) \sim \text{Bern}(z(i, j)p_{ijk})$$

where $y(i, j, k) = 1$ if at least one Black-backed Woodpecker was observed at station *i* in fire area *j* during sampling interval k_i and $y(i, j, k) = 0$ otherwise; and $z(i, j)$ represents the true occupancy state of the station, such that $z(i, j) = 1$ if one or more woodpeckers were at the station and $z(i, j) = 0$ if no woodpecker was present. The probability of detecting at least one individual at an occupied station *i* in fire area *j* and interval k (i.e.,

$\Pr(y(i,j,k)=1 \mid z(i,j)=1)$) is a Bernoulli trial with success (i.e., detection) probability $p_{ijk} \times 1 = p_{ijk}$. The model assumes that the probability of identifying an unoccupied station as being occupied (i.e., $\Pr(y(i,j,k)=1 \mid z(i,j)=0)$ is a Bernoulli trial with probability $p_{ijk} \times 0 = 0$.

The data for this model, our observations $y(i,j,k)$, thus consisted of encounter histories for each station. 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. Passive and active intervals following a detection and missed passive intervals (which occurred by design at stations where we conducted only a 3-min passive count rather than a full 5-min passive, multi-species point count) were recorded as missing data, which can be handled easily in a Bayesian implementation of the model by the prior distribution assigned to *p* (see below). This resulted in 16 possible encounter histories, whose frequencies in the 2009 survey data are summarized in Table 1.

We modeled the latent occupancy state indicator variable, $z(i,j)$, as:

$$z(i,j) \sim \mathrm{Bern}(\psi_{ij}),$$

such that ψ_{ij} is the Bernoulli probability of station *i* at fire *j* being occupied by at least one Black-backed Woodpecker. We defined a logit-linear model to relate ψ_{ij} to a random fire area effect ($\texttt{fire}_j$) and four covariates (regression coefficients represented by β's) believed to be important in influencing occupancy rates (see *Exploratory analyses,* above):

$$\mathrm{logit}(\psi_{ij}) = \beta_0 + \texttt{fire}_j + \beta_1\texttt{fire.age}_j + \beta_2\texttt{lat}_i + \beta_3\texttt{snag.ba}_i + \beta_4\texttt{cc}_i + \beta_5\texttt{elev.res}_i$$

Covariate definitions are as follows:

- $\texttt{fire.age}_j$ - Number of years since fire for fire area *j* (range = 1 to 10 years)

- `latitude`$_i$ - Latitude in decimal degrees for survey station *i*
- `snag.ba`$_i$ - Basal area of snags at survey station *i* (see *Methods: Exploratory Analyses* for detail)
- `cc`$_i$ - Change in percent canopy cover (see *Methods: Exploratory Analyses* for detail)
- `elev.res`$_i$ - Residuals from a regression of elevation on latitude (see *Results: Exploratory Analyses* for detail)

Table 1. Encounter history frequencies (numbers of survey stations) in the 2009 Black-backed Woodpecker survey data. Ones indicate detections, zeros indicate nondetections, and NAs indicate missing data (by design, see text for detail). Overall, Black-backed Woodpeckers were detected at 169 of the 899 points that we surveyed.

Passive survey		Broadcast survey			
Interval 1	Interval 2	Interval 3	Interval 4	Interval 5	Frequency
0	0	0	0	0	380
0	0	0	0	1	17
0	0	0	1	NA	17
0	0	1	NA	NA	22
0	1	0	0	0	1
0	1	0	0	1	0
0	1	0	1	NA	0
0	1	1	NA	NA	4
0	NA	0	0	0	349
0	NA	0	0	1	14
0	NA	0	1	NA	20
0	NA	1	NA	NA	34
1	NA	0	0	0	11
1	NA	0	0	1	1
1	NA	0	1	NA	5
1	NA	1	NA	NA	23

We also defined a logit-linear model for detection probability p_{ijk}:

$$\text{logit}(p_{ijk}) = \alpha_0 + \alpha_1 \texttt{effort}_k + \alpha_2 \texttt{type}_k,$$

where regression coefficients are represented by α's (α_0 = overall mean); the variable $\texttt{effort}_k$ represents interval length effort, such that $\texttt{effort}_k$ = 1 if the interval length was 3 min (just the first interval; *k* = 1) the second passive count interval), and zero otherwise; $\texttt{type}_k$ represents an indicator variable to denote whether the count interval was a passive survey ($\texttt{type}_k = 0$) or a call broadcast survey ($\texttt{type}_k = 1$). Note that accounting for differences in interval lengths and survey type could be accounted for by developing separate models for passive and broadcast intervals and imposing additional model structure to describe how *p* changes over time (e.g., Alldredge et al. 2007). However, by defining a single logit-linear model for *p* we can account for these effects and include additional covariates to account for spatial heterogeneity in *p*. In a separate analysis (not reported here) we considered a model with a covariate representing basal area of live trees; however, there was little indication that this variable affected detectability. We ignore it here.

We implemented a Bayesian analysis of the model using Markov chain Monte Carlo (MCMC) methods (Gilks et al. 1996) in the software package WinBUGS (Spiegelhalter et al. 2003). We used vague prior distributions for all model parameters. For the β covariate effects in the model for ψ we used Norm(0, 0.001) priors. We assigned a prior of Norm(0, τ) for the random site effect ($\texttt{fire}_j$) in the model for ψ, and a prior of Gamma(0.001, 0.001) for the precision parameter τ (where $\tau = 1/\sigma^2$). For the α covariates in the model for *p* we restricted the parameter space or priors somewhat to include only reasonable values; specifically we used U(-10, 10). For the intercepts of these models, we defined priors for inverse-logit transformed parameters using U(0, 1). We conducted the WinBUGS analysis from R (R Development Core Team 2009) using the R2WinBUGS package (Sturtz et al. 2005). We provide WinBUGS model code in Appendix 1.

Results

Scope of Survey Work Completed

We completed surveys fully to protocol at 51 fire areas (Table 2), including broadcast surveys and habitat assessments at 899 survey stations and passive, multi-species point counts at 465 of those stations. All surveys were conducted between 17 May and 7 July, 2009. We provide summary information about each fire area in Table 2.

Black-backed Woodpecker Detections

We detected Black-backed Woodpeckers at 169 survey stations (Table 2) distributed across 28 of the 51 fire areas we surveyed (Figs. 4-7). We detected Black-backed Woodpeckers on nine of the ten national forest units in our study area—the only forest where we did not detect the species was Sierra NF, where our random sample yielded only one fire area (the North Fork fire area; Fig. 6) to survey. 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 area we surveyed (the Fletcher fire area on the Modoc NF, which spans the California – Oregon border; Fig. 4), and the third most southerly fire area we surveyed (the Vista fire area on the Sequoia NF; Fig. 7). We provide UTM coordinates of all survey stations and maps indicating locations where Black-backed Woodpeckers were detected at: http://birdpop.org/Sierra/bbwo_results.htm.

Table 2. Summary information for each fire area surveyed during our 2009 field season of Black-backed Woodpecker MIS monitoring on Sierra Nevada national forests.

Primary national forest	Fire name	Year of fire	Years since fire	Burned area (ha) on national forest land[1]	Dominant pre-fire habitat[2]	No. of stations surveyed
Eldorado	Freds	2004	5	3,082	Sierra Mixed Conifer	20
Eldorado	Plum	2002	7	461	Sierra Mixed Conifer	12
Eldorado	Power	2004	5	6,490	Sierra Mixed Conifer	20
Inyo	Azusa	2000	9	309	Pinyon-Juniper	8
Inyo	Birch	2002	7	1,043	Pinyon-Juniper	19
Inyo	Crater	2001	8	1,866	Jeffrey Pine	20
Inyo	Dexter	2003	6	870	Jeffrey Pine	16
Inyo	Inyo Complex	2007	2	14,143	Ponderosa Pine	16
Inyo	Sawmill	2000	9	134	Ponderosa Pine	5
LTBMU	Angora	2007	2	1,212	Sierra Mixed Conifer	19
LTBMU	Gondola	2002	7	257	Red Fir	12
LTBMU	Showers	2002	7	121	Sierra Mixed Conifer/Jeffrey Pine	9
Lassen	Cone	2002	7	769	Eastside Pine	21
Lassen	Peterson Complex	2008	1	2,721	Sierra Mixed Conifer	20
Modoc	Bell	2001	8	1,092	Eastside Pine	20
Modoc	Bell West	1999	10	409	Eastside Pine	21
Modoc	Blue	2001	8	10,789	Eastside Pine	20
Modoc	Fletcher	2007	2	3,276	Ponderosa Pine	19
Plumas	Antelope Complex	2007	2	8,916	Eastside Pine	21
Plumas	Boulder Complex	2006	3	1,439	Eastside Pine	20
Plumas	Bucks	1999	10	12,560	Sierra Mixed Conifer	20

Table 2, continued.

Primary national forest	Fire name	Year of fire	Years since fire	Burned area (ha) on national forest land[1]	Dominant pre-fire habitat[2]	No. of stations surveyed
Plumas	Devil's Gap	1999	10	552	Sierra Mixed Conifer	20
Plumas	Horton2	1999	10	1,521	Sierra Mixed Conifer	20
Plumas	Lookout	1999	10	955	Sierra Mixed Conifer	21
Plumas	Moonlight	2007	2	24,774	Eastside Pine	20
Plumas	Pidgeon	1999	10	1,727	Sierra Mixed Conifer	18
Plumas	Rich	2008	1	2,506	Sierra Mixed Conifer	21
Plumas	Scotch	2008	1	5,108	Sierra Mixed Conifer	21
Plumas	Storrie	2000	9	18,038	Red Fir	15
Plumas	Stream	2001	8	1,423	Eastside Pine	20
Sequoia	Albanita	2003	6	863	Jeffrey Pine	21
Sequoia	Crag 04	2004	5	339	Jeffrey Pine	19
Sequoia	Crag 05	2005	4	437	Jeffrey Pine	21
Sequoia	Deep	2004	5	1,164	Sierra Mixed Conifer	11
Sequoia	Hooker	2003	6	891	Jeffrey Pine	20
Sequoia	Manter	2000	9	27,875	Pinyon-Juniper	21
Sequoia	McNally	2002	7	55,683	Sierra Mixed Conifer	19
Sequoia	Piute 08	2008	1	14,152	Jeffrey Pine/White Fir	20
Sequoia	Vista	2007	2	170	Red Fir	19
Sierra	North Fork	2001	8	1,636	Sierra Mixed Conifer	20
Stanislaus	Hiram	1999	10	884	Jeffrey Pine	10
Stanislaus	Kibbie	2003	6	2,556	Sierra Mixed Conifer	21
Stanislaus	Mud	2003	6	1,641	Red Fir	21

Table 2, continued.

Primary national forest	Fire name	Year of fire	Years since fire	Burned area (ha) on national forest land[1]	Dominant pre-fire habitat[2]	No. of stations surveyed
Stanislaus	Whit	2003	6	406	Red Fir	20
Stanislaus	White	2001	8	96	Sierra Mixed Conifer	8
Tahoe	Bassetts	2006	3	870	Sierra Mixed Conifer	18
Tahoe	Fall	2008	1	656	Sierra Mixed Conifer	10
Tahoe	Government	2008	1	7,626	Sierra Mixed Conifer	19
Tahoe	Harding	2005	4	903	Ponderosa Pine	21
Tahoe	Peavine	2008	1	202	Sierra Mixed Conifer	16
Tahoe	Treasure	2001	8	143	Sierra Mixed Conifer	10
					Total	**899**

[1]Includes low, medium, and high severity affected areas.

[2]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 stations in a particular fire area, based on our own on-the-ground assessments.

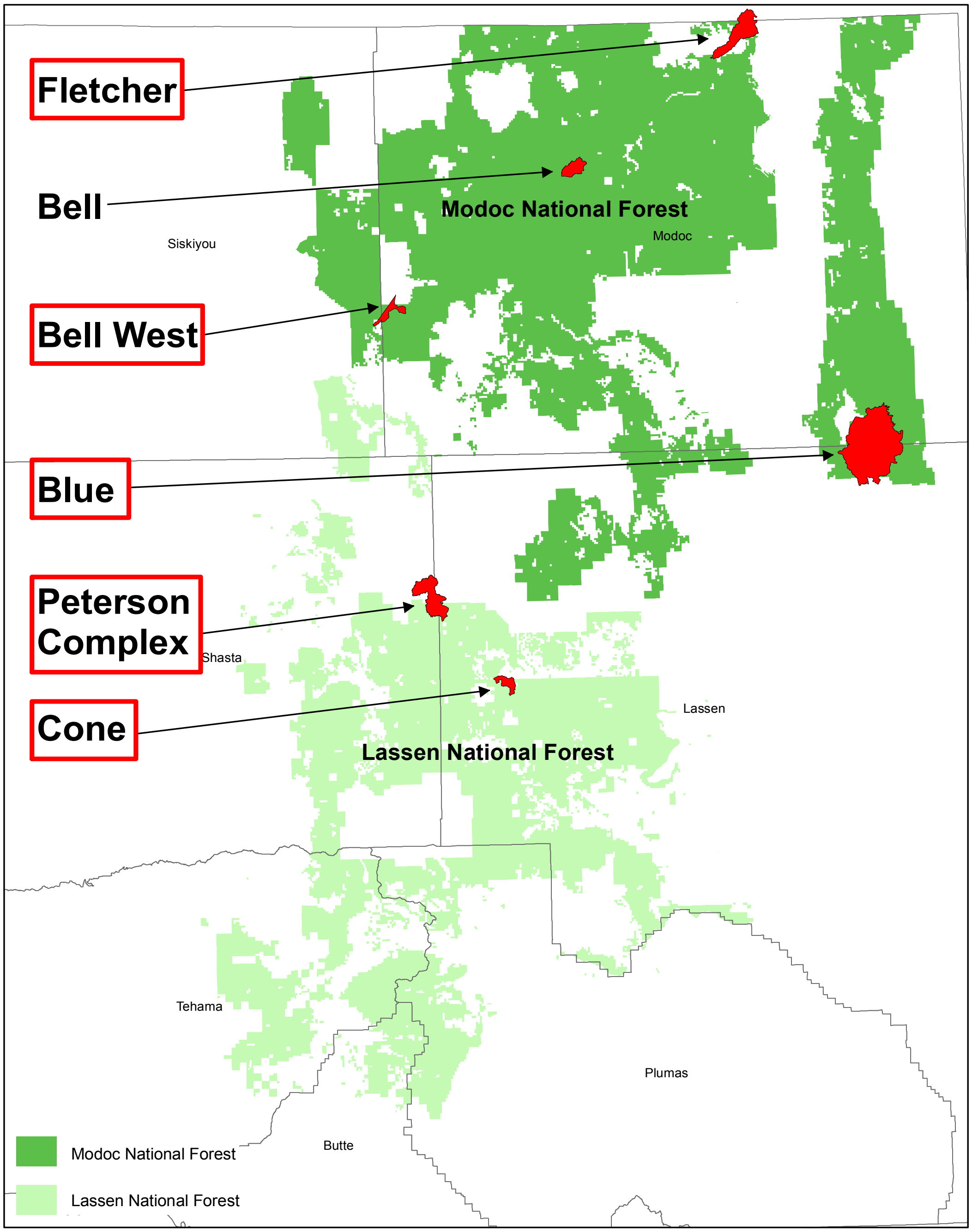

Figure 4. Fire areas (red shading) on the Modoc and Lassen National Forests that we surveyed for Black-backed Woodpeckers during the 2009 Black-backed Woodpecker MIS monitoring field season. Names of fire areas where Black-backed Woodpeckers were detected are enclosed in red boxes. Fire area names without red boxes indicate that no Black-backed Woodpeckers were detected; note that lack of detection does not necessarily mean Black-backed Woodpeckers were absent (see text for discussion of detection probability during this survey).

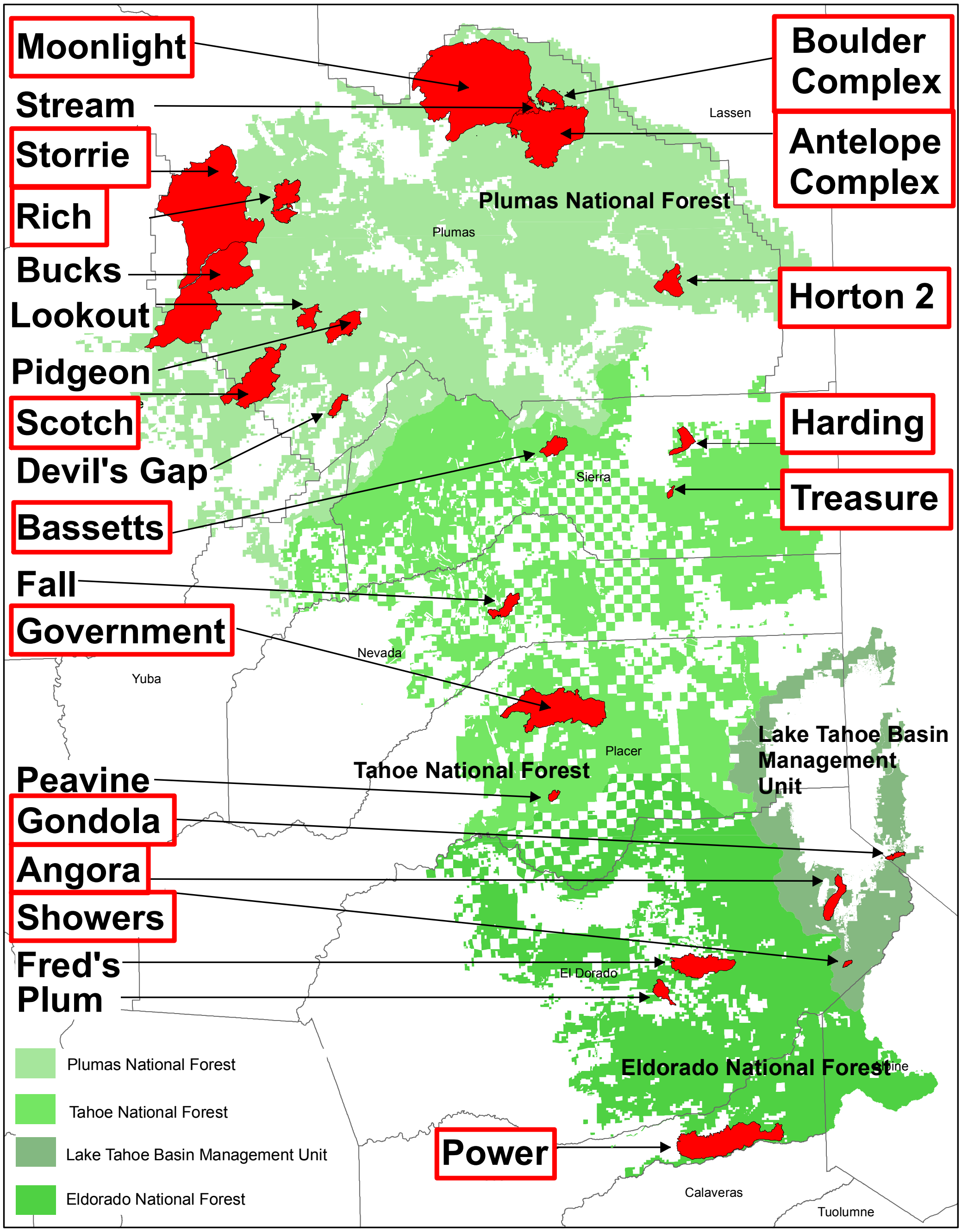

Figure 5. Fire areas (red shading) on the Plumas, Tahoe, and Eldorado National Forests and the Lake Tahoe Basin Management Unit that we surveyed for Black-backed Woodpeckers during the 2009 Black-backed Woodpecker MIS monitoring field season. Names of fire areas where Black-backed Woodpeckers were detected are enclosed in red boxes. Fire area names without red boxes indicate that no Black-backed Woodpeckers were detected; note that lack of detection does not necessarily mean Black-backed Woodpeckers were absent (see text for discussion of detection probability during this survey).

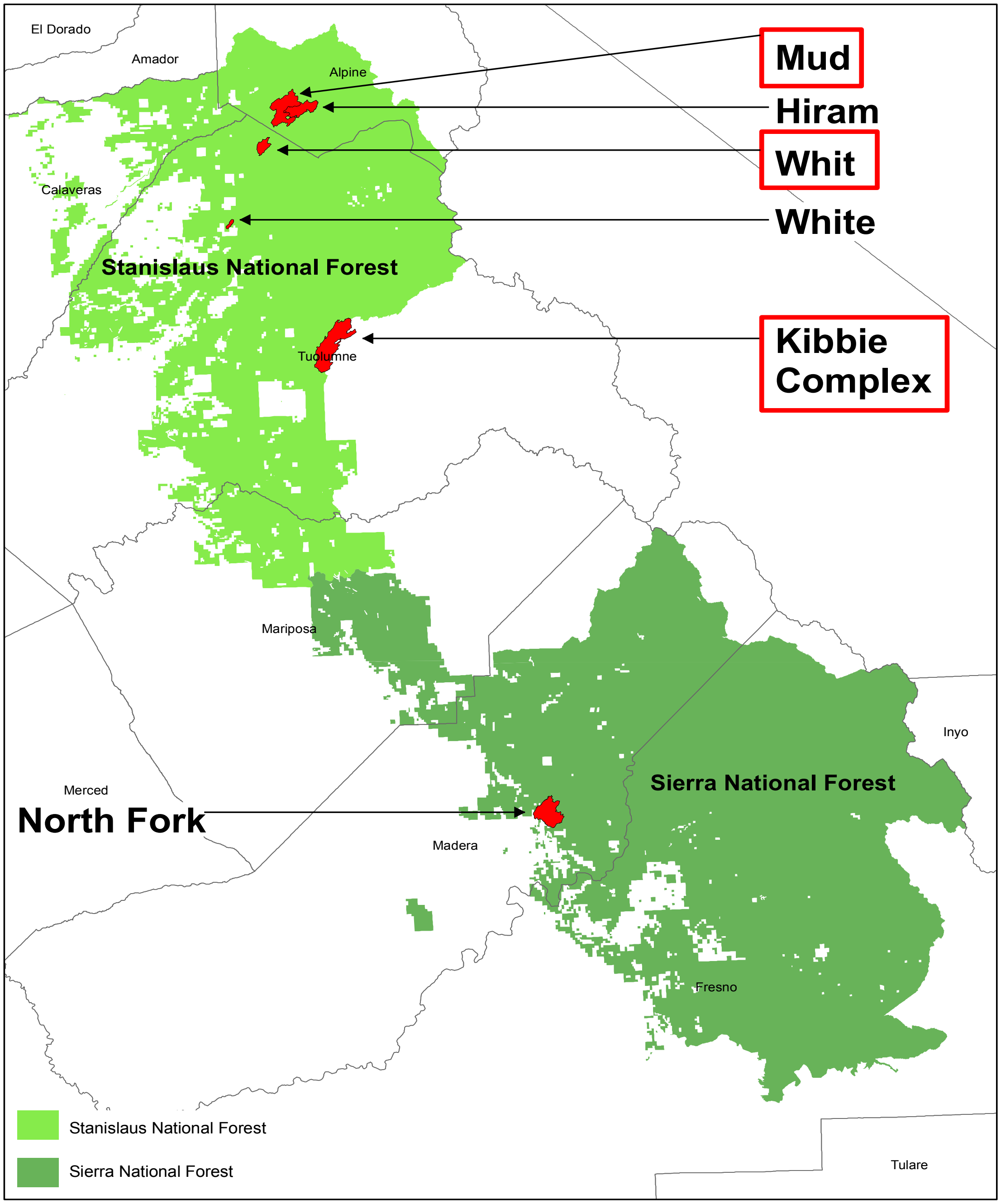

Figure 6. Fire areas (red shading) on the Stanislaus and Sierra National Forests that were surveyed for Black-backed Woodpeckers during the 2009 Black-backed Woodpecker MIS monitoring field season. Names of fire areas where Black-backed Woodpeckers were detected are enclosed in red boxes. Fire area names without red boxes indicate that no Black-backed Woodpeckers were detected; note that lack of detection does not necessarily mean Black-backed Woodpeckers were absent (see text discussion of detection probability during this survey).

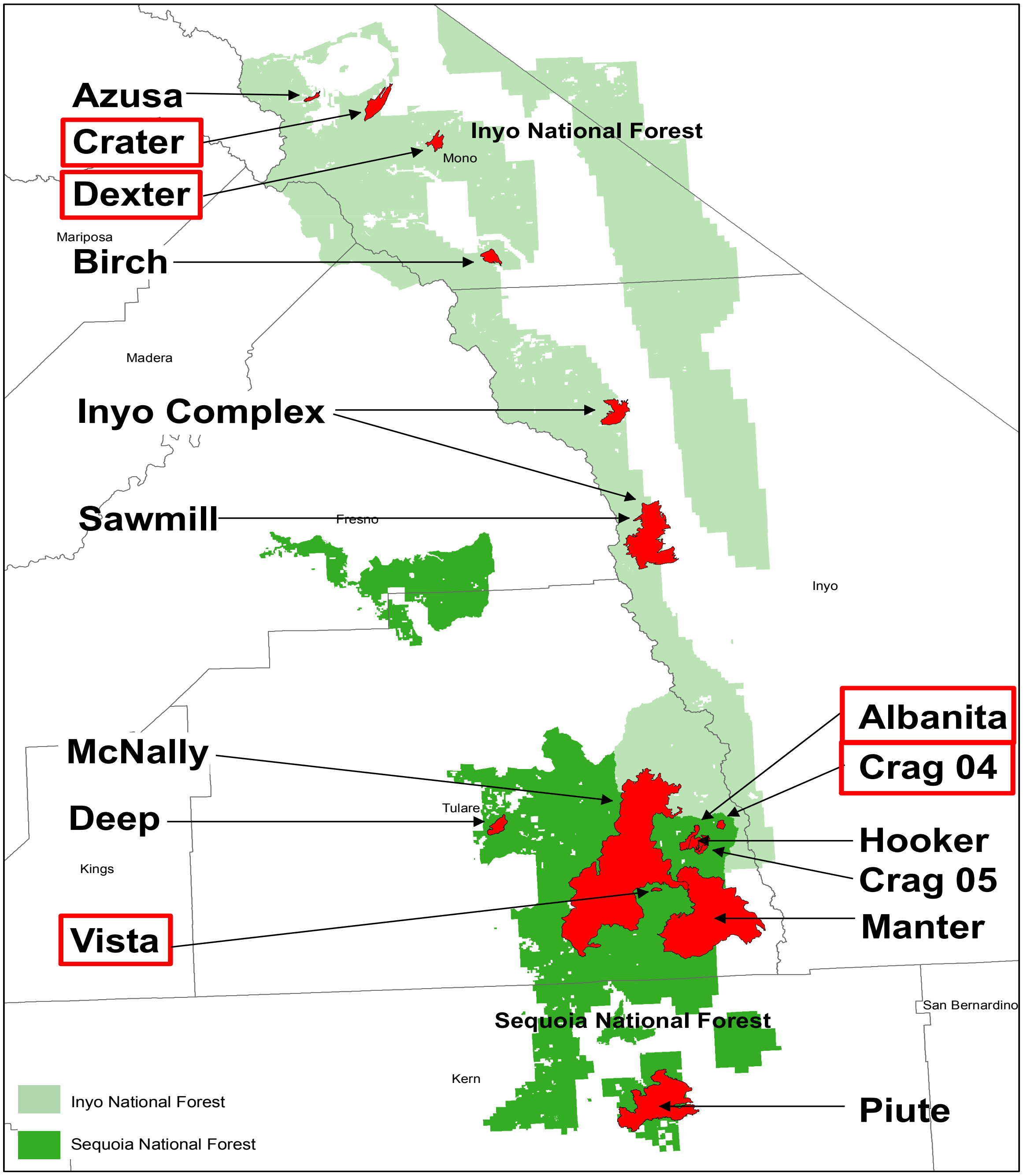

Figure 7. Fire areas (red shading) on the Inyo and Sequoia National Forests that were surveyed for Black-backed Woodpeckers during the 2009 Black-backed Woodpecker MIS monitoring field season. Names of fire areas where Black-backed Woodpeckers were detected are enclosed in red boxes. Fire area names without red boxes indicate that no Black-backed Woodpeckers were detected; note that lack of detection does not necessarily mean Black-backed Woodpeckers were absent (see text discussion of detection probability during this survey).

Exploratory Analyses

Black-backed Woodpecker detections during the 2009 survey varied somewhat by major habitat type (Fig. 8). Of five major habitat types sampled by ≥ 50 stations, Sierra Mixed Conifer (SMC) had the lowest percentage of stations with detections (12%), followed by Jeffrey Pine (JPN; 21%), Eastside Pine (EPN; 25%), Ponderosa Pine (PPN; 31%) and Red Fir (33%). Of the habitat types with fewer stations surveyed, Pinyon-Juniper (PJN) was notable in that of 47 stations surveyed, no detections were recorded.

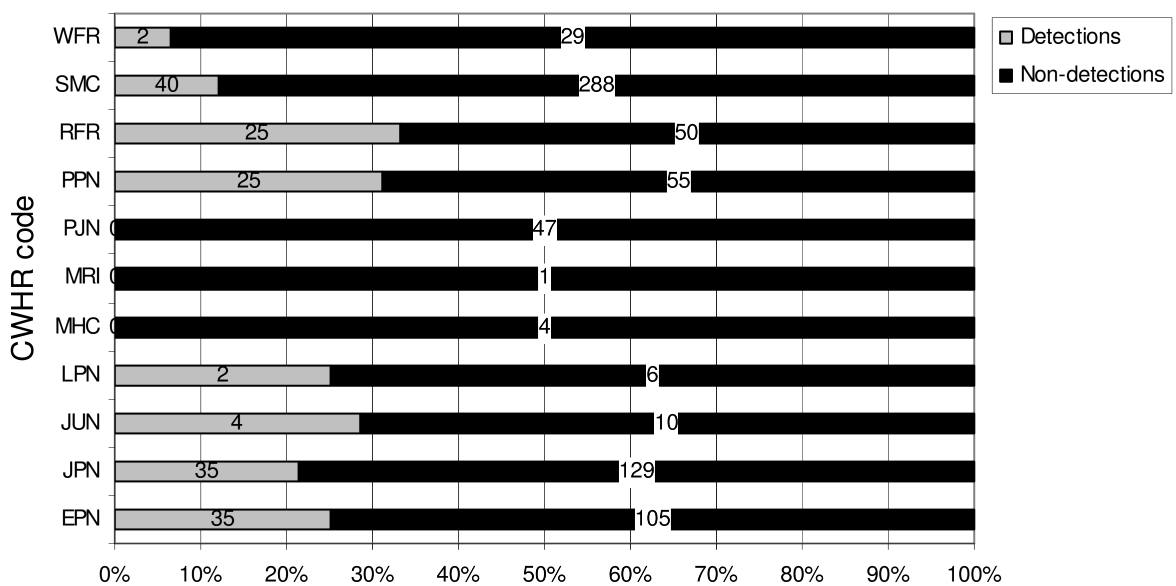

Figure 8. Numbers of stations with detections and without detections (non-detections) by major habitat type for 899 stations surveyed during 2009. Y-axis labels are as follows: WFR = White Fir, SMC = Sierra Mixed Conifer, RFR = Red Fir, PJN = Pinyon-Juniper; MRI = Montane Riparian, MHC = Mixed Hardwood/Conifer, LPN = Lodgepole Pine, JUN = Juniper, JPN = Jeffrey Pine, and EPN = Eastside Pine.

Some of the habitat-related variation in detections might be explained by elevation (Fig. 9). For example, in habitats at elevations representing the low end of the elevation gradient, such as Juniper (JUN) and Sierra Mixed Conifer (SMC), Black-backed Woodpecker detections tended to occur at the higher stations sampled. In contrast, woodpecker detections in higher elevation habitats such as Jeffrey Pine (JPN) and Lodgepole Pin (LPN) tended to occur at the lower-elevation survey stations.

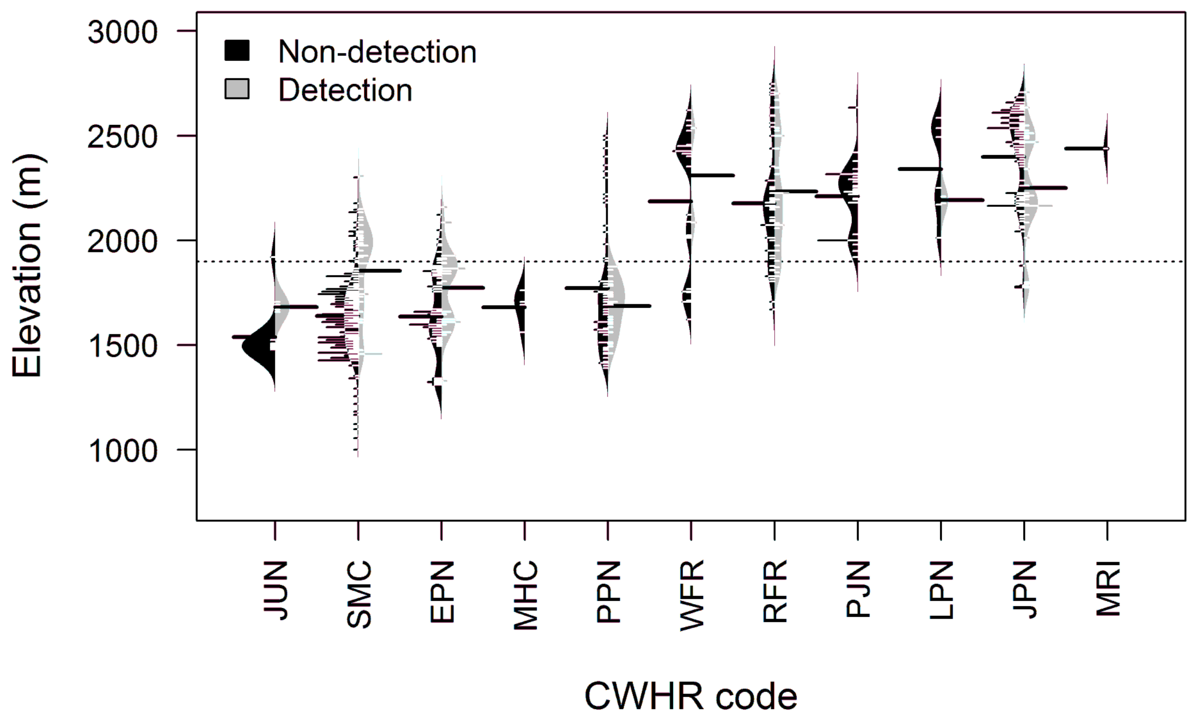

Figure 9. Bean plots showing the elevational (m) distribution of non-detection stations (left density traces in black) and detection stations (right density traces in gray) by major habitat type (California Wildlife Habitat Relationships [CWHR] classification). The dashed line shows the overall mean elevation of stations that were surveyed in 2009. Bold black lines show means for non-detections (left) and detections (right) for each habitat type. Data points are represented by thin lines. See Figure 8 caption for key to CWHR codes.

Overall, detections occurred most frequently at the middle elevations that were surveyed (Fig. 10). The potential importance of elevation in explaining detections (and occupancy), however, was somewhat complicated by a strong negative correlation between elevation and latitude (Fig. 11). That is, the more southerly fire areas we surveyed tended to be at higher elevations, and the more northerly fire areas we surveyed were at lower elevations.

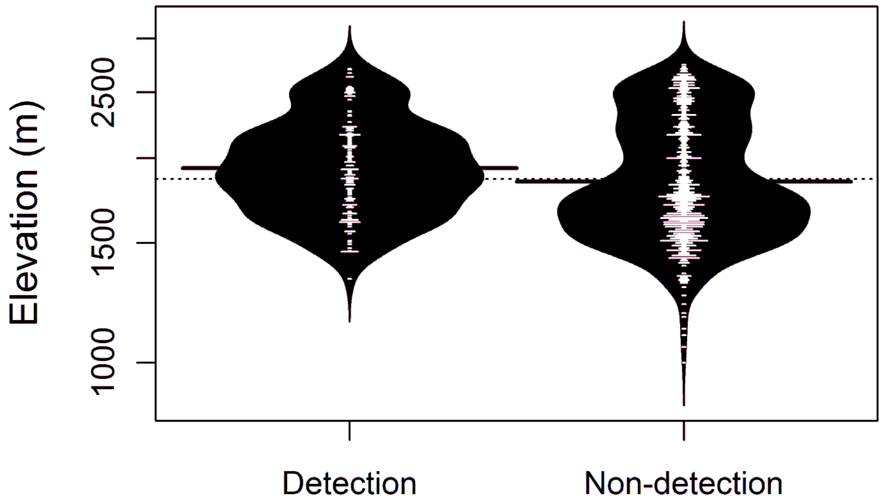

Figure 10. Elevational distribution (m) of detections and non-detections for stations surveyed for Black-backed Woodpeckers in 2009. There was not much difference in the mean elevations for stations with detections and those without (solid black lines); however, detections were generally clustered around the middle elevations, while a preponderance of non-detections were at lower elevations (below the dashed line, which represents the overall mean for both detection and non-detection stations).

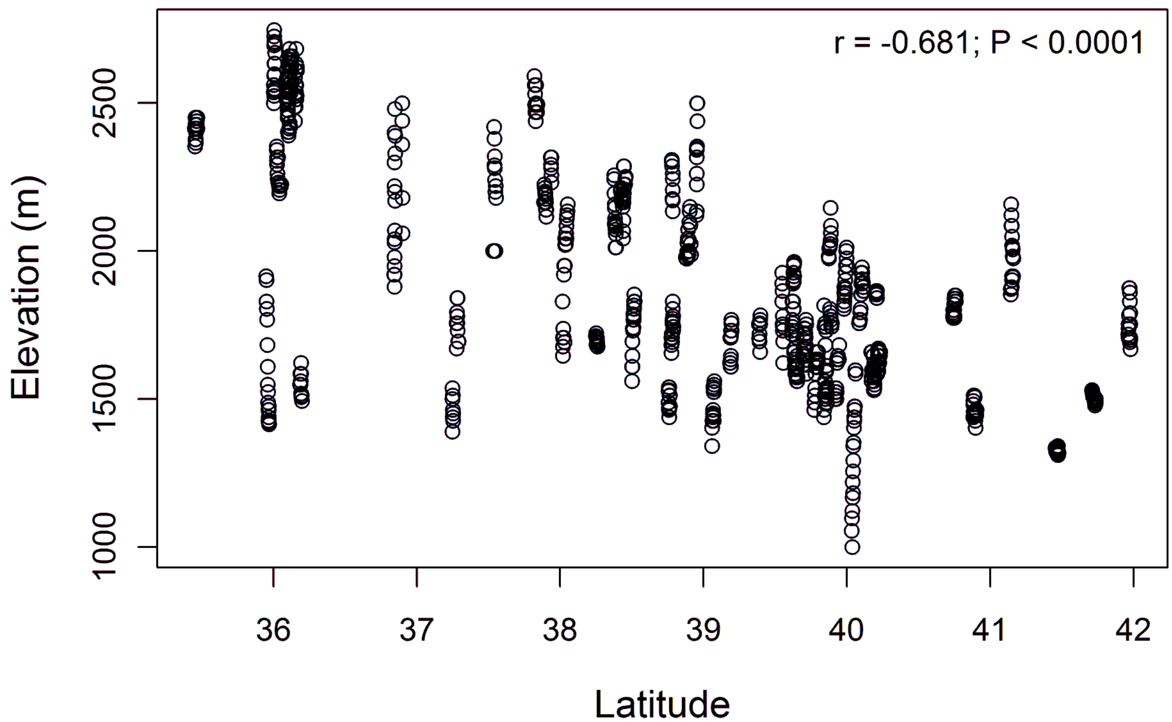

Figure 11. Correlation between elevation (m) and latitude (degrees) for sites surveyed for Black-backed Woodpeckers in 2009 was strong and negative.

We also found a latitudinal gradient in detections, with detections more common at higher latitude fire areas (Fig 12). Because of the strong correlation between latitude and elevation, and apparent relationships between detections and both of these variables, we regressed elevation on latitude and used residuals from this regression as our elevation covariate in the occupancy model (below). This resolves the issue of collinearity between these two variables in the linear model (Graham 2003); the elevation variable considered here can thus be interpreted as 'elevation effects after controlling for latitude effects'. Detections tended to occur at higher elevations for any given latitude (Fig. 13).

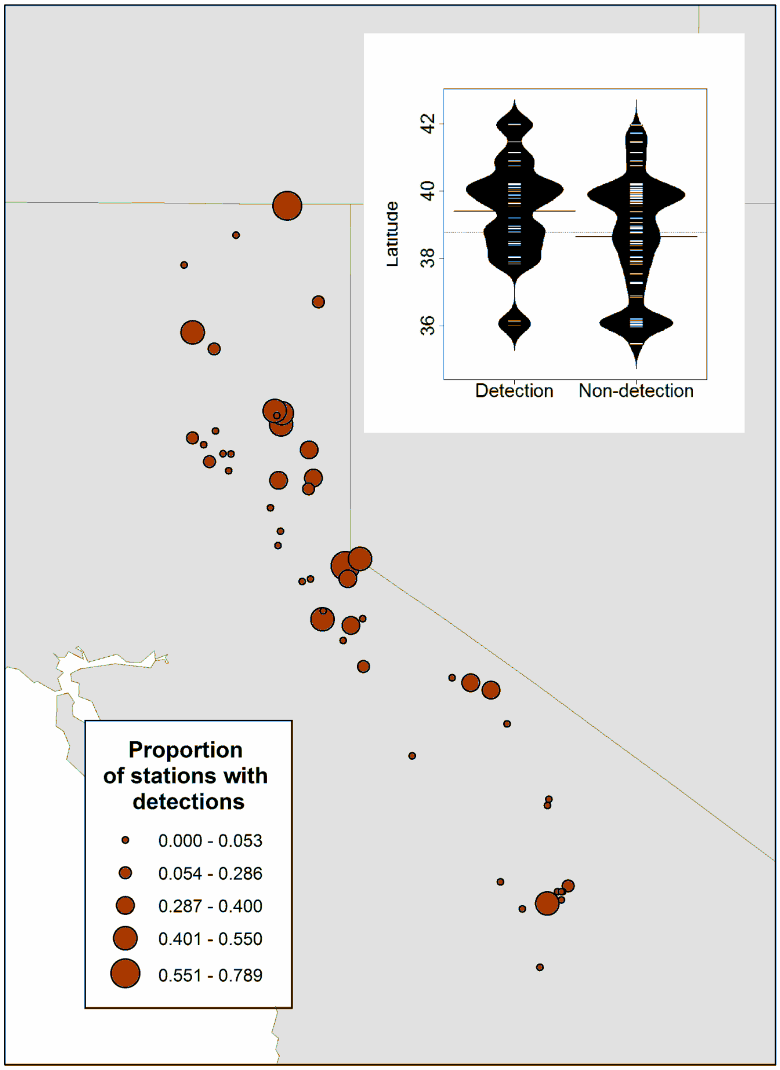

Figure 12. Map illustrating the distribution of the 51 fire areas surveyed during the 2009 field season and the proportion of stations at those fire areas with detections. Detections were generally more frequent at higher latitude stations. This pattern is highlighted by the bean plot (inset), which shows the latitudinal distribution of stations with detections (left) and non-detection stations (right). The dashed line in the bean plot shows the overall mean latitude of survey stations, and the solid black lines indicate the mean station latitude for the two groups (detection and non-detection). The 'beans' (black shaded regions) in the plot are normal density traces of the data; individual data points are represented by white bars within the beans.

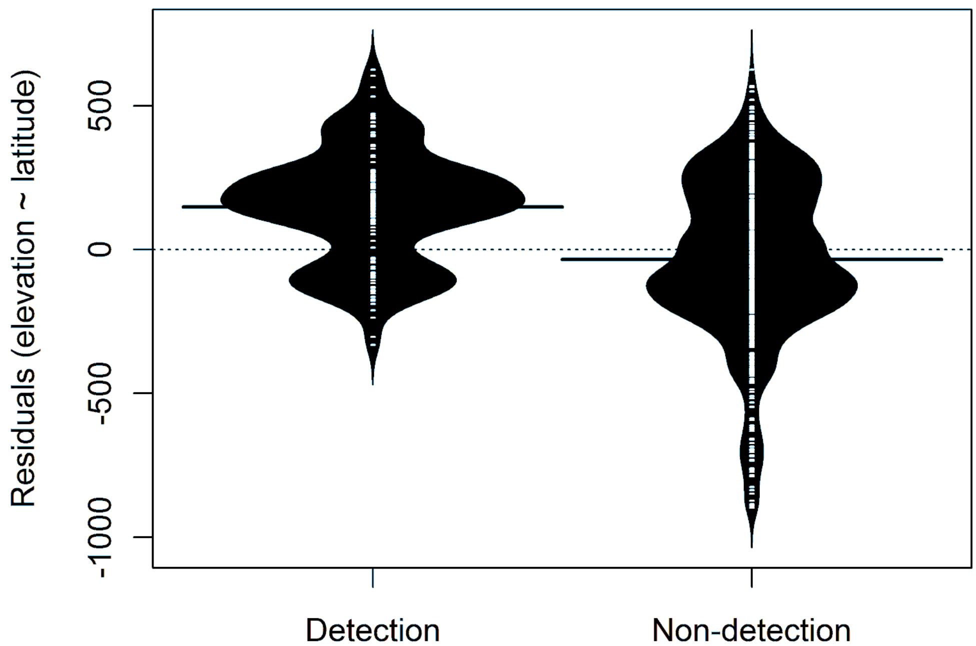

Figure 13. Bean plot showing the distributions of detections and non-detections in relation to residuals from a regression of elevation on latitude. The y-axis scale represents meters below (negative values) or above (positive values) the mean elevation surveyed at a given latitude.

There seemed to be some evidence of a relationship between Black-backed Woodpecker detections and each of the remaining predictor variables considered except pre-fire canopy cover (Fig. 14). Because of the lack of relationship between pre-fire canopy cover and detections, we did not consider this variable in our linear model for occupancy probability (below).

Occupancy Modeling

Because detectability is imperfect, inference about occupancy probability of woodpeckers must be based on models that consider both the detection (observations) and occupancy (partially observed state) processes. Here we summarize model results for occupancy and detection probabilities.

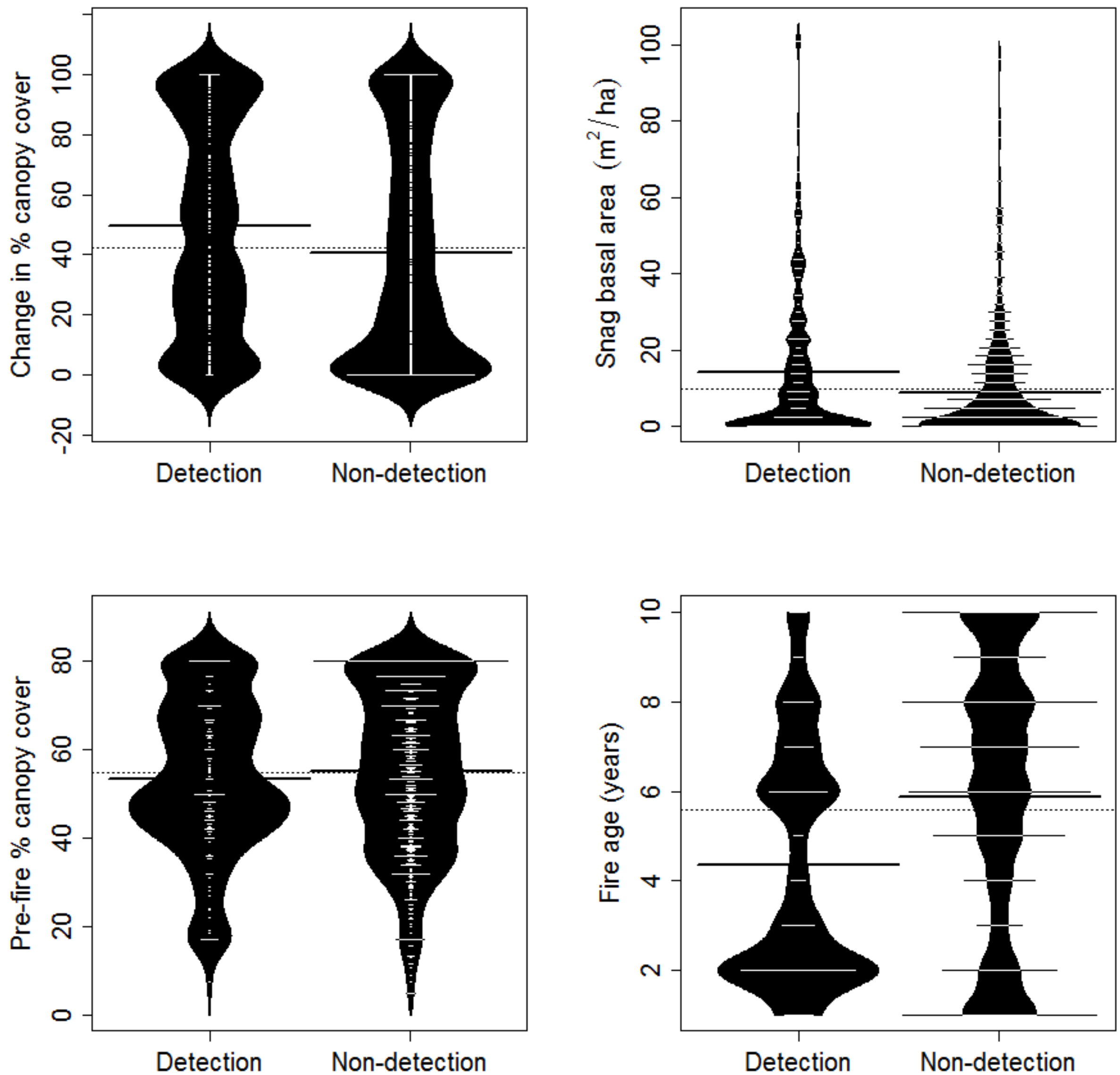

Figure 14. Bean plots for remaining variables considered in exploratory analyses. Survey stations with Black-backed Woodpecker detections averaged greater fire-induced change in canopy cover, greater snag basal area, fewer years since fire than survey stations where Black-backed Woodpecker was not detected. However we did not detect any effect of pre-fire percent canopy cover.

Occupancy Probability. Mean occupancy probability for stations surveyed during 2009 was 0.253 (95% credible interval: 0.222 – 0.289). Assuming that our sample was representative of woodpecker habitat yielded by fire areas that burned between 1999 and 2008, we estimate that approximately 81,814 ha (i.e., 25.3%) of the 323,358 ha of burned forest on the ten national forest units within our sampling frame was occupied by Black-backed Woodpeckers in 2009 (or a range based on the 95% credible interval of 71,921 – 93,610 ha). Table 3 summarizes detections and predicted occupancy probabilities for each fire area surveyed in 2009.

Table 3. Summary of Black-backed Woodpecker detections and posterior distributions of station-level predictions of occupancy probability for 51 fire areas surveyed during 2009.

Fire name	No. of stations surveyed	No. of stations with detections	Mean station-level occupancy probability	Mean lower 95% credible interval	Mean upper 95% credible interval
Albanita	21	1	0.060	0.005	0.193
Angora	19	13	0.852	0.591	0.992
Antelope Complex	21	9	0.594	0.326	0.871
Azusa	8	0	0.063	0.002	0.261
Bassetts	18	7	0.502	0.237	0.814
Bell	20	0	0.067	0.004	0.219
Bell West	21	1	0.060	0.005	0.198
Birch	19	0	0.037	0.001	0.145
Blue	20	5	0.372	0.150	0.658
Boulder Complex	20	9	0.569	0.307	0.849
Bucks	20	0	0.018	0.000	0.086
Cone	21	5	0.337	0.131	0.617
Crag 04	19	4	0.267	0.081	0.548
Crag 05	21	0	0.042	0.001	0.154
Crater	20	8	0.461	0.210	0.768
Deep	11	0	0.002	0.000	0.015
Devil's Gap	20	0	0.030	0.001	0.124
Dexter	16	6	0.470	0.206	0.782
Fall	10	0	0.107	0.005	0.352
Fletcher	19	15	0.944	0.780	0.999
Freds	20	0	0.034	0.001	0.135
Gondola	12	6	0.688	0.363	0.953
Government	19	1	0.107	0.014	0.292
Harding	21	7	0.438	0.189	0.756
Hiram	10	0	0.041	0.001	0.181
Hooker	20	0	0.033	0.001	0.133
Horton2	20	7	0.456	0.206	0.750
Inyo Complex	16	0	0.059	0.002	0.206
Kibbie	21	6	0.305	0.114	0.569

Table 3, continued.

Fire name	No. of stations surveyed	No. of stations with detections	Mean station-level occupancy probability	Mean lower 95% credible interval	Mean upper 95% credible interval
Lookout	21	0	0.017	0.000	0.079
Manter	21	0	0.007	0.000	0.042
McNally	19	0	0.002	0.000	0.013
Moonlight	20	11	0.691	0.418	0.944
Mud	21	10	0.572	0.315	0.847
North Fork	20	0	0.004	0.000	0.022
Peavine	16	0	0.034	0.001	0.141
Peterson Complex	20	9	0.583	0.311	0.880
Pidgeon	18	0	0.027	0.001	0.119
Piute 08	20	0	0.041	0.001	0.159
Plum	12	0	0.011	0.000	0.061
Power	20	1	0.063	0.006	0.205
Rich	21	1	0.096	0.011	0.278
Sawmill	5	0	0.041	0.001	0.205
Scotch	21	3	0.208	0.056	0.446
Showers	9	3	0.460	0.147	0.849
Storrie	15	4	0.330	0.099	0.656
Stream	20	0	0.041	0.002	0.152
Treasure	10	2	0.200	0.039	0.482
Vista	19	9	0.587	0.305	0.888
Whit	20	6	0.365	0.141	0.653
White	8	0	0.017	0.000	0.096
Total	**899**	**169**	**0.253**	**0.222**	**0.289**

Three of the four covariates included in the model for ψ appeared to be important predictors of occupancy probability ($\texttt{fire.age}_j$, $\texttt{latitude}_i$, and $\texttt{elev.res}_i$; Table 4). Standardized regression coefficients (Table 4) and plots showing predicted occupancy probability across observed covariate values (Fig. 15), show $\texttt{elev.res}_i$ (i.e., elevation adjusted for latitude) to have had the strongest effect on occupancy probability, followed by $\texttt{latitude}_i$ and $\texttt{fire.age}_j$. Mean predicted occupancy probability was higher for stations at higher elevations (for a given latitude) higher latitudes, and for stations in more recent fire areas. Standardized regression coefficients for $\texttt{snag.ba}_i$ and $\texttt{cc}_i$ were relatively small in magnitude and 95% credible intervals included zero in both cases, suggesting they were of minor importance in affecting patterns of occupancy. In both cases, however, coefficients were positive, supporting (albeit weakly) the hypothesis that Black-backed Woodpecker occurrence is more likely in areas with higher severity fires and with more standing snags. In addition, although the increase in predicted occupancy probability across the range of $\texttt{snag.ba}_i$ values was relatively small when considered across all fire ages (Fig. 15), high snag basal area may be especially important in maintaining viability of woodpecker habitat in older fire areas. For example, snag basal area was relatively high for stations where detections occurred compared to stations of non-detections in older fire areas (6-10 years old); but was similar for detection and non-detection stations in younger (1-5 years old) fire areas (Fig. 16).

Table 4. Posterior summaries (means, standard deviations [sd], and credible interval boundaries [lower and upper 95%]) for intercepts and regression coefficients (continuous variables, β_{1-5} standardized to facilitate comparison) from the models for occupancy probability (ψ) and for detection probability (*p*) applied to 2009 survey data. See *Methods: Data Analysis: Occupancy Modeling* for variable definitions.

Parameter	mean	sd	lower 95%	upper 95%
Occupancy probability, ψ				
β_0	-2.263	0.342	-2.977	-1.624
β_1 ($\texttt{fire.age}_j$ effect)	-1.092	0.326	-1.796	-0.493
β_2 ($\texttt{snag.ba}_i$ effect)	+0.268	0.158	+0.030	+0.592
β_3 ($\texttt{latitude}_i$ effect)	+1.205	0.355	+0.574	+1.964
β_4 ($\texttt{cc}_i$ effect)	+0.263	0.171	-0.066	+0.611
β_5 ($\texttt{elev.res}_i$ effect)	+1.538	0.345	+0.919	+2.271
Detection probability, p				
α_0	-2.758	0.454	-3.724	-1.941
α_1 ($\texttt{effort}_k$ effect)	+1.204	0.473	+0.332	+2.205
α_2 ($\texttt{type}_k$ effect)	+2.064	0.453	+1.248	+2.348

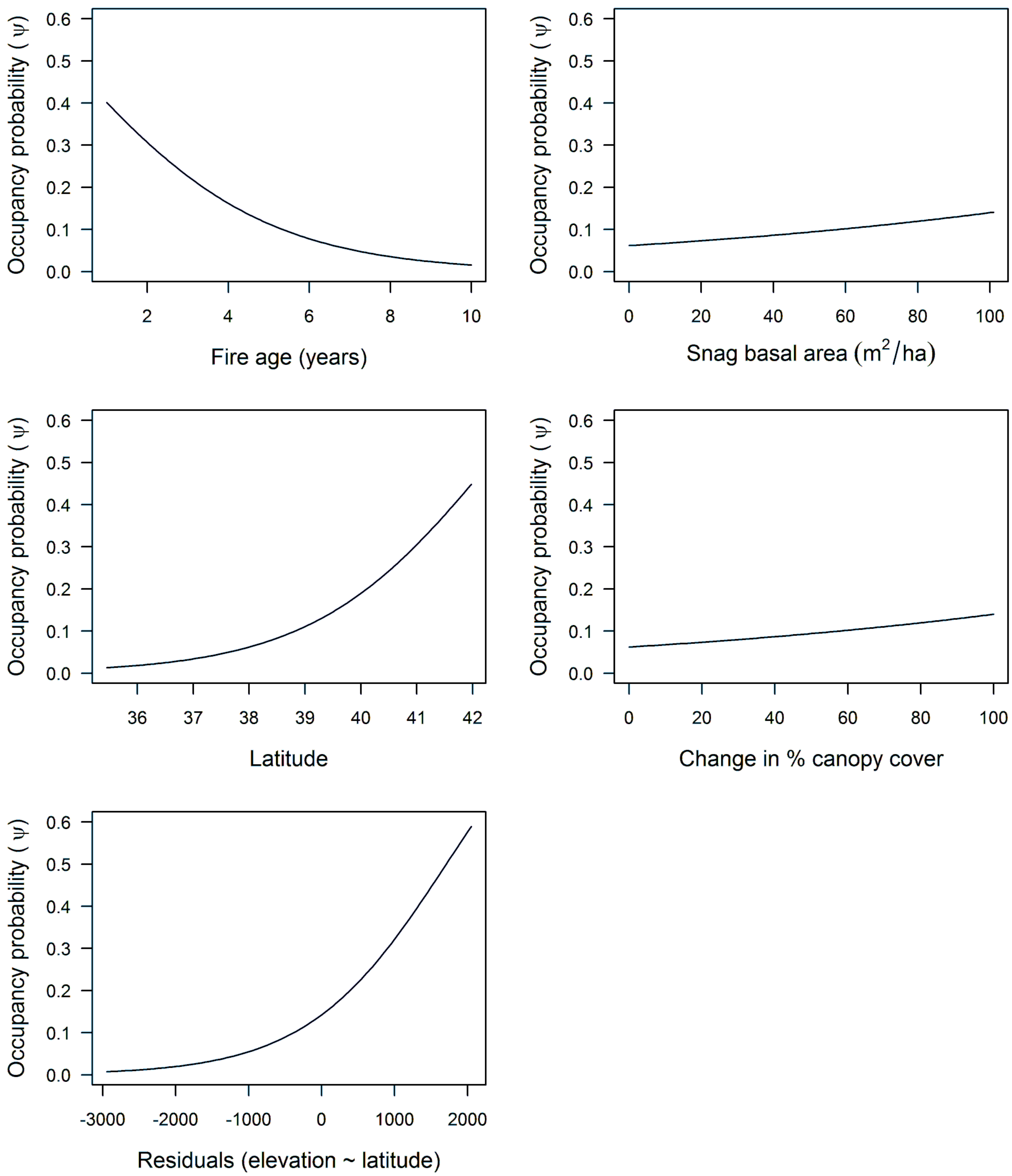

Figure 15. Predicted occupancy probability (ψ) for covariates included in the hierarchical occupancy model for ψ based on application of model to 2009 survey data. See *Methods: Data Analysis: Occupancy Modeling* for variable definitions.

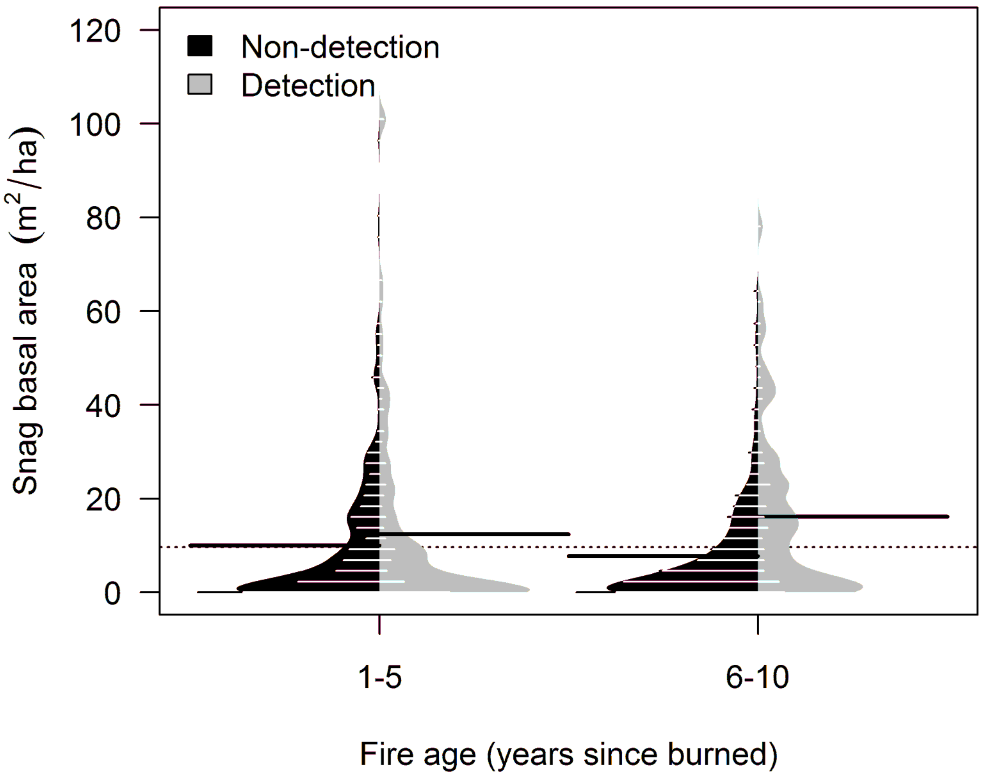

Figure 16. Bean plots showing the distributions of non-detections (left sides of beans in black) versus detections (right sides in gray) for recent (1-5 year-old) fire areas and older (6-10 year-old) fire areas. Shaded (black and gray) regions show density traces of the data; the individual data points are represented by white (inside trace densities) or black (outside trace densities) line segments. Means are indicated by bold black lines. The mean difference in snag basal area between stations with detections and those without detections was much greater for older fire areas (mean of 16.17 m^2/ha × 10 for sites with detections vs. 7.75 m^2/ha for sites without detections) than for newer fire areas (12.41 vs. 9.98 m^2/ha for detections and non-detections, respectively).

Detection Probability. Both $\texttt{effort}_k$ (interval duration) and, especially, $\texttt{type}_k$ (passive v. broadcast interval) were important in affecting detection probability (Table 4). Our estimated detection probability for the 2-minute passive count interval was just 0.065 (95% credible interval: 0.026 – 0.126), and for the 3-minute passive interval 0.176 (95% credible interval: 0.123 – 0.237). Our estimate of overall probability of detection for the two passive intervals was therefore: $1 – (1 – 0.065)(1 – 0.176) = 0.230$ (95% credible interval: 0.162 – 0.307). We estimated the detection probability for a call broadcast interval to be: 0.335 (95% credible interval: 0.251 – 0.421), and the overall detection probability for the three call-broadcast intervals combined of $1 – (1 – 0.335)^3 = 0.702$ (95% credible interval: 0.580 – 0.806). Most of the birds detected during passive count intervals (33 of 45 total passive interval detections) were also detected during the call-broadcast intervals, and there was little difference between the overall call-broadcast interval detectability of 0.702 and the overall detectability based on the combined passive and call-broadcast surveys: $1 – (1 – 0.230)(1 – 0.702) = 0.769$ (95% credible interval: 0.661 – 0.858).

Our survey objectives did not include meeting any particular detection probability threshold. Nevertheless, we note that in some instances, land managers could need to determine with a known level of certainty whether Black-backed Woodpeckers are present in a project area. Our estimates of detection probability indicate that using just passive, 5-min point counts, an observer would need to visit an occupied survey station 12 times in a breeding season to achieve a 95% probability of detecting one or more Black-backed Woodpeckers there (Fig 17). In contrast, using a 6-min broadcast survey would yield a 95% detection probability within 3 visits (Fig. 17). Using the two methods together in sequence provides only a slight improvement to the broadcast-only detection probability, and would still just barely require 3 visits to reach the 95% probability threshold (2 visits would yield an estimated detection probability of 0.947) (Figure 17).

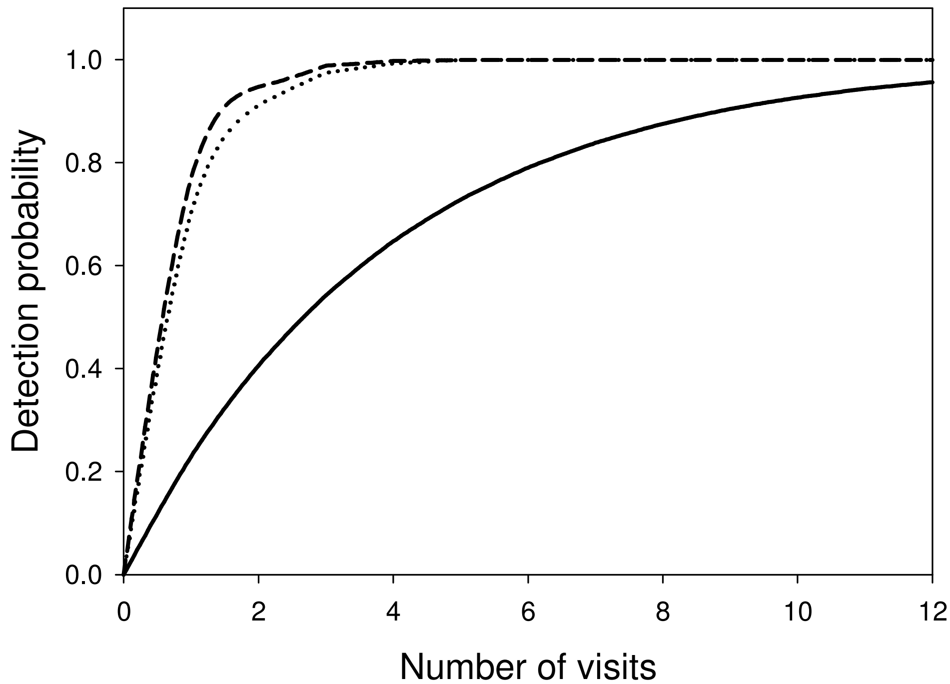

Figure 17. Relationship between number of visits and probability of detecting one or more Black-backed Woodpeckers at an occupied survey station using a passive 5-min survey only (solid line), a 6-min broadcast survey only (dotted line), or both methods in sequence (dashed line).

Other bird species occupying the fire areas

In addition to Black-backed Woodpecker, our 461 passive point counts yielded detections of 109 other bird species within the fire areas (Table 5). The five most frequently detected species were Mountain Chickadee (*Poecile gambeli,* 323 detections), Dark-eyed Junco (*Junco hyemalis*; 319 detections), Western Wood-Pewee (*Contopus sordidulus*, 318 detections), Western Tanager (*Piranga ludoviciana*; 316 detections), and Steller's Jay (*Cyanocitta stelleri*, 278 detections); these and dozens of additional species (Table 5) were detected frequently enough to facilitate analysis of the effects of fire severity and spatial configuration on bird assemblages in post-fire forest stands, which we intend to conduct after our 2010 field season as part of that year's annual reporting.

Table 5. Numbers of each bird species detected during 465 passive point counts conducted in conjunction with Black-backed Woodpecker surveys across 51 fire areas surveyed in 2009.

Common name	Latin name	No. of detections	Detections per station
Canada Goose	*Branta canadensis*	23	0.050
Mallard	*Anas platyrhynchos*	1	0.002
Bufflehead	*Bucephala albeola*	2	0.004
Mountain Quail	*Oreortyx pictus*	182	0.395
California Quail	*Callipepla californica*	11	0.024
Chukar	*Alectoris chukar*	2	0.004
Sooty Grouse	*Dendragapus fuliginosus*	7	0.015
Turkey Vulture	*Cathartes aura*	3	0.007
Osprey	*Pandion haliaetus*	3	0.007
Bald Eagle	*Haliaeetus leucocephalus*	3	0.007
Sharp-shinned Hawk	*Accipiter striatus*	1	0.002
Red-tailed Hawk	*Buteo jamaicensis*	11	0.024
American Kestrel	*Falco sparverius*	4	0.009
Killdeer	*Charadrius vociferus*	2	0.004
Greater Yellowlegs	*Tringa melanoleuca*	1	0.002
Band-tailed Pigeon	*Patagioenas fasciata*	1	0.002
Mourning Dove	*Zenaida macroura*	75	0.163
Great Horned Owl	*Bubo virginianus*	3	0.007
Northern Pygmy-Owl	*Glaucidium gnoma*	2	0.004
Common Nighthawk	*Chordeiles minor*	6	0.013
Common Poorwill	*Phalaenoptilus nuttallii*	2	0.004
Anna's Hummingbird	*Calypte anna*	8	0.017
Costa's Hummingbird	*Calypte costae*	4	0.009
Calliope Hummingbird	*Stellula calliope*	8	0.017
Rufous Hummingbird	*Selasphorus rufus*	3	0.007
Lewis's Woodpecker	*Melanerpes lewis*	5	0.011
Acorn Woodpecker	*Melanerpes formicivorus*	19	0.041
Williamson's Sapsucker	*Sphyrapicus thyroideus*	1	0.002
Red-breasted Sapsucker	*Sphyrapicus ruber*	49	0.106
Hairy Woodpecker	*Picoides villosus*	107	0.232
White-headed Woodpecker	*Picoides albolarvatus*	59	0.128
Black-backed Woodpecker	*Picoides arcticus*	27	0.059
Northern Flicker	*Colaptes auratus*	113	0.245

Table 5, continued.

Common name	Latin name	No. of detections	Detections per station
Pileated Woodpecker	*Dryocopus pileatus*	10	0.022
Olive-sided Flycatcher	*Contopus cooperi*	202	0.438
Western Wood-Pewee	*Contopus sordidulus*	318	0.690
Hammond's Flycatcher	*Empidonax hammondii*	18	0.039
Gray Flycatcher	*Empidonax wrightii*	28	0.061
Dusky Flycatcher	*Empidonax oberholseri*	111	0.241
Pacific-slope Flycatcher	*Empidonax difficilis*	9	0.020
Ash-throated Flycatcher	*Myiarchus cinerascens*	7	0.015
Western Kingbird	*Tyrannus verticalis*	4	0.009
Cassin's Vireo	*Vireo cassinii*	68	0.148
Hutton's Vireo	*Vireo huttoni*	2	0.004
Warbling Vireo	*Vireo gilvus*	67	0.145
Steller's Jay	*Cyanocitta stelleri*	278	0.603
Western Scrub-Jay	*Aphelocoma californica*	1	0.002
Pinyon Jay	*Gymnorhinus cyanocephalus*	4	0.009
Clark's Nutcracker	*Nucifraga columbiana*	41	0.089
Black-billed Magpie	*Pica hudsonia*	7	0.015
Common Raven	*Corvus corax*	29	0.063
Tree Swallow	*Tachycineta bicolor*	13	0.028
Violet-green Swallow	*Tachycineta thalassina*	30	0.065
Cliff Swallow	*Petrochelidon pyrrhonota*	1	0.002
Mountain Chickadee	*Poecile gambeli*	323	0.701
Chestnut-backed Chickadee	*Poecile rufescens*	2	0.004
Oak Titmouse	*Baeolophus inornatus*	7	0.015
Bushtit	*Psaltriparus minimus*	4	0.009
Red-breasted Nuthatch	*Sitta canadensis*	210	0.456
White-breasted Nuthatch	*Sitta carolinensis*	50	0.108
Pygmy Nuthatch	*Sitta pygmaea*	7	0.015
Brown Creeper	*Certhia americana*	107	0.232
Rock Wren	*Salpinctes obsoletus*	41	0.089
Canyon Wren	*Catherpes mexicanus*	1	0.002
Bewick's Wren	*Thryomanes bewickii*	3	0.007
House Wren	*Troglodytes aedon*	143	0.310
Golden-crowned Kinglet	*Regulus satrapa*	12	0.026

Table 5, continued.

Common Name	Latin Name	No. of Detections	Detections per Station
Western Bluebird	*Sialia mexicana*	25	0.054
Mountain Bluebird	*Sialia currucoides*	86	0.187
Townsend's Solitaire	*Myadestes townsendi*	49	0.106
Hermit Thrush	*Catharus guttatus*	12	0.026
American Robin	*Turdus migratorius*	246	0.534
Wrentit	*Chamaea fasciata*	5	0.011
European Starling	*Sturnus vulgaris*	3	0.007
Orange-crowned Warbler	*Vermivora celata*	19	0.041
Nashville Warbler	*Vermivora ruficapilla*	41	0.089
Yellow Warbler	*Dendroica petechia*	22	0.048
Yellow-rumped Warbler	*Dendroica coronata*	204	0.443
Hermit Warbler	*Dendroica occidentalis*	25	0.054
MacGillivray's Warbler	*Oporornis tolmiei*	94	0.204
Common Yellowthroat	*Geothlypis trichas*	1	0.002
Wilson's Warbler	*Wilsonia pusilla*	8	0.017
Green-tailed Towhee	*Pipilo chlorurus*	187	0.406
Spotted Towhee	*Pipilo maculatus*	102	0.221
Chipping Sparrow	*Spizella passerina*	105	0.228
Brewer's Sparrow	*Spizella breweri*	48	0.104
Vesper Sparrow	*Pooecetes gramineus*	7	0.015
Lark Sparrow	*Chondestes grammacus*	6	0.013
Black-throated Sparrow	*Amphispiza bilineata*	11	0.024
Sage Sparrow	*Amphispiza belli*	7	0.015
Fox Sparrow	*Passerella iliaca*	262	0.568
Song Sparrow	*Melospiza melodia*	6	0.013
Lincoln's Sparrow	*Melospiza lincolnii*	15	0.033
Dark-eyed Junco	*Junco hyemalis*	319	0.692
Western Tanager	*Piranga ludoviciana*	316	0.685
Black-headed Grosbeak	*Pheucticus melanocephalus*	97	0.210
Lazuli Bunting	*Passerina amoena*	158	0.343
Red-winged Blackbird	*Agelaius phoeniceus*	11	0.024
Western Meadowlark	*Sturnella neglecta*	20	0.043
Brewer's Blackbird	*Euphagus cyanocephalus*	25	0.054
Brown-headed Cowbird	*Molothrus ater*	31	0.067

Table 5, continued.

Common Name	Latin Name	No. of Detections	Detections per Station
Bullock's Oriole	*Icterus bullockii*	3	0.007
Purple Finch	*Carpodacus purpureus*	23	0.050
Cassin's Finch	*Carpodacus cassinii*	86	0.187
House Finch	*Carpodacus mexicanus*	16	0.035
Red Crossbill	*Loxia curvirostra*	21	0.046
Pine Siskin	*Spinus pinus*	30	0.065
Lesser Goldfinch	*Spinus psaltria*	19	0.041
American Goldfinch	*Spinus tristis*	1	0.002
Evening Grosbeak	*Coccothraustes vespertinus*	8	0.017
	Total	**5,686**	**12.334**

Discussion

Black-backed Woodpecker Habitat Occupancy

Our results indicate that Black-backed Woodpeckers are relatively rare, yet widely distributed, across the ten national forests in our study area. The 72 fire areas in our sampling frame (see Methods) comprised 323,358 ha. Of this area, we estimate that approximately 25.3% (81,814 ha; 95% credible interval = 71,921 – 93,610 ha) was occupied by Black-backed Woodpeckers in 2009. These numbers provide useful benchmarks for assessing future changes in the extent of Black-backed Woodpecker habitat in the study area, the extent of occupied Black-backed Woodpecker habitat in the study area, and the proportion of habitat in the study area that is occupied.

Our study was designed to monitor trends in occupancy rates and area occupied by Black-backed Woodpeckers, rather than to provide annual estimates of the number of Black-backed Woodpeckers in our study area, in part because it is difficult or impossible to distinguish individual birds during playback surveys at adjacent or nearby survey stations.

Reliable estimates of home range size within our study area would allow a rough estimation of the number of Black-backed Woodpecker territories in the study area, at least under the assumption that home ranges do not substantially overlap (or, alternately, using an empirically determined average proportion of overlap to account for overlapping home ranges). Home range size has never been measured for Black-backed Woodpeckers in the Sierra Nevada, and average or median home range estimates from elsewhere in the species' range vary widely, from 61 ha in Vermont (Lisi 1988) to 152 ha in unburned boreal forest (Tremblay et al. 2009) and 174 ha in beetle-killed Lodgepole Pine forest in central Oregon (Goggans et al. 1988). None of these habitats is strongly analogous to the areas we surveyed, so it is unclear which (if any) of them provides the most appropriate surrogate. Nevertheless, dividing our estimate for occupied habitat by home range sizes reported in each of the above studies yields the following estimates:

- Lisi 1988: 1,341 pairs
- Tremblay et al. 2009: 538 pairs
- Goggans et al. 1988: 470 pairs

We emphasize that this preliminary range of population estimates is not reliable until data on home range size (and perhaps information regarding the degree to which home ranges overlap) are available from within the Sierra Nevada region. Moreover, our sampling frame only included fires that occurred between 1999 and 2008, comprised at least 50 ha of conifer forest that burned at mid-severity and/or high-severity, and that occurred at least partially on one or more of the ten national forest units in our study area. Black-backed Woodpeckers occupying habitat in fire areas that burned more than ten years prior to our study, fire areas that did not include any land on national forests, or fire areas that burned <50 ha of conifer forest are not accounted for in our estimate. Our estimates also do not account for any Black-backed Woodpeckers that may have held territories partly or entirely within 'green forest'—areas that have not recently burned.

Black-backed Woodpecker Detection Probability

Our detection probability estimates indicate that broadcast surveys are necessary to determine reliably whether Black-backed Woodpeckers are present at a site. We estimated that 12 5-min, passive point counts would be needed to achieve a 95% chance of detecting Black-backed Woodpeckers at an occupied survey station, an impractical burden for surveyors. In marked contrast, our model indicates that broadcast surveys can meet this detection probability threshold with three visits, and can very nearly meet it with just two visits.

At the same time, broadcast surveys have certain drawbacks as well. In some instances woodpeckers may respond to broadcasts (even if only by silently approaching closer) from perhaps hundreds of meters from the survey station. This makes it somewhat more difficult to associate station-specific habitat attributes with woodpecker habitat preferences or requirements. We therefore believe the best way to study stand-scale (or finer) habitat selection by Black-backed Woodpeckers is to follow radio-tagged focal birds; researchers could thereby assess foraging substrates and other components of habitat selection without the confounding factor of possibly having attracted or moved the birds (even it only hundreds of meters or less) through the use of broadcast techniques.

Black-backed Woodpecker Distribution and Habitat Relationships

Our occupancy model for Black-backed Woodpeckers suggested strong spatial variation in occurrence related primarily to latitude (more common in the north), elevation (more common at higher elevations), and fire age (more common in recent fire areas). Our findings with respect to fire age are in general agreement with published data from other studies conducted elsewhere in the Black-backed Woodpecker range that find the species to be most common within a few years of a high-severity fire (Dixon et al. 2000). It was somewhat surprising to us that variables that are reflective of fire severity, such as change in percent canopy cover and basal area of snags appeared to be relatively unimportant in our analysis, given that characteristics such as these have been found to be principal drivers of Black-backed Woodpecker occurrence in other studies (e.g., Hutto 2008). However, it should be noted that nearly all of the fires that we sampled in

2009 had at least some survey stations that were classified as 'high severity' (i.e., stands with high or nearly complete mortality). Thus, it may be that our failure to detect strong fire severity effects could relate to either our failure to sample sites that experienced relatively low severity fires (which may be uncommon) or unburned areas. Alternatively, it is possible that the variables included in our model failed to measure fire severity at the appropriate scale (e.g., snag basal area measured at the survey station; change in percent canopy cover measured from remote-sensed data and summarized at 90 x 90 m resolution).

It should also be noted that collinearity among predictor variables (with the exception of latitude and the elevation residuals variables), could reduce our power to detect significant effects and provide misleading inferences about the relative importance of individual predictor variables (Graham 2003). For example, the $\texttt{snag.ba}_i$ and $\texttt{cc}_i$ variables were positively correlated (r = 0.255; $P < 0.001$), and inclusion of either in the model without the other could alter conclusions about their significance. We are in the process of conducting a more thorough analysis within a multi-model inference framework (Burnham and Anderson 2002; Royle and Dorazio 2008) to provide stronger inference about covariate effects on occupancy.

Finally, as we suggest is the case with snag basal area, it may be that particular habitat characteristics of recent fire areas could be important not just for determining whether an area is likely to be occupied by Black-backed Woodpeckers after a fire, but also for determining *how long* the area is likely to be occupied. It may be important not only to leave as many standing dead trees as possible (as suggested elsewhere; e.g., Hutto 1995), but also important to leave them standing as long as possible. Future studies could explicitly test how pre-fire stand conditions affect the length of time a post-fire area remains occupied by Black-backed Woodpeckers.

Future Directions for this Project

In the next few months we hope to reorganize the results presented here into two manuscripts for publication in peer-reviewed journals. The first manuscript will describe and generalize our modeling approach, and is tentatively titled *Hierarchical occupancy modeling for interval point* *surveys*. The second manuscript will focus on Black-backed Woodpecker biology, and is tentatively titled *Distribution and relative abundance of Black-backed Woodpecker in recent fire areas of the Sierra Nevada, CA.*

We are pleased to be now preparing for our 2010 field season—the second year of full-scale Black-backed Woodpecker MIS monitoring on greater Sierra Nevada national forests. Multiple years of data will allow an assessment of whether the amount and proportion of burned forest habitat occupied by Black-backed Woodpeckers is stable, increasing, or decreasing. Once we have a second year of monitoring data we are also anticipating describing between-year occupancy dynamics of Black-backed Woodpeckers in recent fire areas, as well as analyzing our multi-species point count data to study the effects of fire severity on post-fire bird communities in the Sierra Nevada. We are hopeful that each of these efforts will yield peer-reviewed publications.

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Appendix 1:

R and WinBUGS code for running Black-backed Woodpecker occupancy model described in the text and producing figures.

```
####################################################################################
# Script to produce results reported in the 2009 Black-backed Woodpecker MIS annual report
# saved as 'bbwo_report_final.r' on Jim's computer in C:/Work/ANAL/BBWO/2009/
# and on IBP Server in Archives/SiegelArchive/BBW/2009_BBWO_Report/
# last edited on 04/27/10 by J. Saracco
####################################################################################

#load R libraries
library("RODBC") #to connect to database.
library("R2WinBUGS")   #to run winBUGS.  Requires 'coda' package
library(reshape)
library(raster)
library(sp)
library(rgdal)
library(boot)
library(beanplot)

####################################################################################
#set working directory
setwd("C:/Work/ANAL/BBWO/2009/")

#connect to bbwo database and read data tables to R data frames
bbwo09 <- odbcConnectAccess("BBWO_2009")
bbwo <- sqlFetch(bbwo09, "tbl_Playback_Surveys", colnames = F, rownames=F)
tmp <- sqlFetch(bbwo09, "tbl_Passive_Point_Counts", colnames = F, rownames=F)
# Extract point type indicator from passive counts table.  Note that for a few points there were 2
counts conducted. For these, I
# selected the Point Type = "S" count that was conducted earlier in the morning.
tmp1 <- aggregate(as.numeric(tmp[,5]), by = list(fire = tmp$Fire_name, point =
tmp$Point_number), max)
names(tmp1) <- c("fire", "point", "type")
tmp1$type <- as.factor(tmp1$type)
tmp1$type <- ifelse(tmp1$type == "2", "S", "M")

# create table to summarize passive point count data. There are 4 possible encounter histories for
passive counts = NANA, 1NA, 01, and 00
bbwo.passive <- aggregate(bbwo$BBWO_pt_ct, by = list(fire = bbwo$Fire_name, point =
bbwo$Point_number), max)  #there are 899 of these
bbwo.passive <- merge(bbwo.passive, tmp1)
```

```
#for the passive counts, this returns value for earliest detection interval (where possible values
are '3' = first interval, '2' = second interval, and NA = not detected)
bbwo.passive$x[is.na(bbwo.passive$x)] <- 0  #convert NAs to zeros(not detected).
bbwo.passive$int.1 <- ifelse(bbwo.passive$x == 3, 1, 0)
bbwo.passive$int.2 <- ifelse(bbwo.passive$x == 2, 1, 0)
bbwo.passive$int.2[bbwo.passive$int.1 == 1] <- NA
bbwo.passive$int.2[bbwo.passive$type == "S"] <- NA
names(bbwo.passive)[3] <- "x1"

# create table to summarize playback
# there are 4 possible encounter histories for playbacks: 1NANA, 01NA, 001, 000
bbwo.playback <- aggregate(bbwo$Time_Interval, by = list(fire = bbwo$Fire_name, point =
bbwo$Point_number), min)  #there are 899 of thesebbwo.passive$x[is.na(bbwo.passive$x)] <- 0
bbwo.playback$x[is.na(bbwo.playback$x)] <- 0
bbwo.playback$int.3 <- ifelse(bbwo.playback$x == 1, 1, 0)
bbwo.playback$int.4 <- ifelse(bbwo.playback$x == 2, 1, ifelse(bbwo.playback$x == 1, NA, 0))
bbwo.playback$int.5 <- ifelse(bbwo.playback$x == 3, 1, ifelse(bbwo.playback$x == 1 |
bbwo.playback$x == 2, NA, 0))

# join passive and playback data to form encounter history (eh) object
bbwo.eh <- merge(bbwo.passive, bbwo.playback)
bbwo.eh <- cbind(bbwo.eh[,1:2], bbwo.eh[,4], bbwo.eh[,3], bbwo.eh[,7], bbwo.eh[,5:6],
bbwo.eh[,8:10])
names(bbwo.eh)[3:5] <- c("type", "x1", "x2")

# extract burn severity covariate - % canopy cover mortality (cc)
# see Miller, J. D., E. E. Knapp, C. H. Key, C. N. Skinner, C. J. Isbell, R. M. Creasy, and J. W.
Sherlock.  2009.
# Calibration and validation of the relative differenced Normalized Burn Ratio (RdNBR) to three
measures of fire
# severity in the Sierra Nevada and Klamath Mountains, California, USA.  Remote Sensing of
Environment 113:645-656.

# first need to convert utms to lat-longs for the point covariate data
veg <- sqlFetch(bbwo09, "tbl_Veg_data", colnames = F, rownames=F)
bbwo.locs10 <- veg[veg$UTM_zone == 10, 14:15] # 2 different utm zones so have to split and
do separately.
bbwo.locs11 <- veg[veg$UTM_zone == 11, 14:15]
bbwo.CRS10 <- CRS("+proj=utm +zone=10 +datum=WGS84") # assign coordinate reference
system to point data
bbwo.CRS11 <- CRS("+proj=utm +zone=11 +datum=WGS84")
bbwo.cov10 <- SpatialPointsDataFrame(bbwo.locs10, veg[veg$UTM_zone == 10,], proj4string
= bbwo.CRS10) #convert to spatial points data frame
bbwo.cov11 <- SpatialPointsDataFrame(bbwo.locs11, veg[veg$UTM_zone == 11,], proj4string
= bbwo.CRS11)
```

```
# read in one of the % canopy cover change files to extract coordinate system / projection
r <- raster("M:/BBWO2009/2000azusa_b_cc.img")
cc.CRS <- projection(r)
rm(r)
bbwo.cov10 <- spTransform(bbwo.cov10, CRS = CRS(cc.CRS))    # transform the point utm
coordinates to coordiate system of the can cover change rasters
bbwo.cov11 <- spTransform(bbwo.cov11, CRS = CRS(cc.CRS))
bbwo.covs <- rbind(bbwo.cov10, bbwo.cov11)

# extract point data from forest service canopy cover change files
geopath <- "M:/BBWO2009"
files <- list.files(path = geopath, pattern = "_cc.img$") # create list of files the '$' on the end
makes sure only grabs files with that ending
cc.val <- matrix(NA, nrow = nrow(as.data.frame(bbwo.covs)), ncol = length(files))
for (i in 1:length(files)) {
    cc.raster <- raster(paste(geopath, "/", files[i], sep = ""), values = F)
    cc.raster <- aggregate(cc.raster, fact = 3, fun = mean, na.rm = T)  # I decided that aggregation
at the 90-m scale (averaging) was preferable than just using the values at the 30-m grid
resolution
    #, filename = paste(geopath, "/lr_", files[i], sep = ""), filetype='raster', overwrite = T)
    cc.val[,i] <- xyValues(cc.raster, bbwo.covs, method = "bilinear")   #bilinear method
interpolates average of 4 nearest cells
    }
maxcc <- function(x) {options(warn=-1); ifelse(max(x, na.rm=T) != -Inf, max(x, na.rm=T),
NA)}
cc <- apply(cc.val, 1, maxcc)
bbwo.covs <- cbind(data.frame(bbwo.covs), cc) # join the cc change data back with the veg table
names(bbwo.covs)[2:3] <- c("fire", "point")

# get fire covariates
fires <- sqlFetch(bbwo09, "tlu_Fire_names", colnames = F, rownames=F)
fires <- cbind(fires[,2], fires[,7:9])
names(fires)[1] <- "fire"
fires$fire <- as.character(fires$fire)
fires$fire[fires[,1] == "Mcnally"] <-"McNally" # McNally spelled as Mcnally in the fire data -
need to change to be consistent
fires$fire <- as.factor(fires$fire)
bbwo.eh.covs <- merge(bbwo.eh, bbwo.covs)
bbwo.eh.covs <- merge(bbwo.eh.covs, fires)
bbwo.eh.covs$detec <- ifelse(bbwo.eh.covs$x1 > 0 | bbwo.eh.covs$x2 > 0, 1, 0)
bbwo.eh.covs$detec <- as.factor(bbwo.eh.covs$detec)

#####################################################################################
# get habitat classifications from the California Department of Forestry and Fire Protection's
# Multi-source Land Cover Data (v02_2).  Downloaded on 12/22/09 from:
# http://frap.cdf.ca.gov/data/frapgisdata/download.asp?spatialdist=1&rec=fveg02_2
```

```
# There must be a better way to do this!!!

caveg <- raster("M:/BBWO2009/fveg02_2g/fveg02_2g/w001001.adf", values = F)
caveg.CRS <- projection(caveg)
bbwo.eh.covs.CRS <- CRS(cc.CRS)
bbwo.eh.covs.locs <- bbwo.eh.covs[, 65:66]
bbwo.eh.covs <- SpatialPointsDataFrame(bbwo.eh.covs.locs, bbwo.eh.covs, proj4string =
bbwo.eh.covs.CRS)
bbwo.eh.covs <- spTransform(bbwo.eh.covs, CRS = CRS(caveg.CRS))
vals <- xyValues(caveg, bbwo.eh.covs)

library(RArcInfo)
infodir <- "M:/BBWO2009/fveg02_2g/info"
# get names of all tables in the info directory
tablenames <- get.tablenames(infodir)
# read the vat table for a grid
tabledata <- get.tabledata(infodir, "fveg02_2g.vat")
tabledata <- as.data.frame(tabledata)
names(tabledata) <- c("VALUE", "COUNT", "WHRNUM", "WHRNAME", "WHRTYPE",
"WHRSIZE", "WHRDENSITY", "WHRDEN_NUM", "WHR10NUM",
   "WHR10NAME", "WHR13NUM", "WHR13NAME", "LIFE_NUM", "LIFE_FORM",
"SOURCE_NUM", "SOURCE_NAME")

bbwo.eh.covs <- cbind(data.frame(bbwo.eh.covs), vals) # join the cc change data back with the
veg table
bbwo.eh.covs <- merge(bbwo.eh.covs, tabledata, by.x = "vals", by.y = "VALUE", all.x = T)  #
11 of these points from Gondola are in NV and so have NA values fromt caveg data. Mud also
has 1 NA value.

# some comparison of our classification and theirs:
compare.veg <- bbwo.eh.covs[!is.na(bbwo.eh.covs$WHRTYPE),]
compare.veg <- compare.veg[!is.na(compare.veg$CWHR_code),]
compare.veg$veg <- ifelse(as.character(compare.veg$CWHR_code) ==
as.character(compare.veg$WHRTYPE), 1, 0)
summary(as.factor(compare.veg$veg))

# of 880 points, whr classification was the same for just 300 plots.  Their classification was finer
scale though, and included alot more
# categories, including 'barren', grassland, etc.
# Rather than trying to make sense out of this, and based on plots (see next section) of the data
that did not suggest any clear habitat type
# or elevation pattern with respect to where bbwos were detected, we (Rodney and Jim) decided
to use a pre-fire canopy cover covariate instead.

#create fa covariate
```

```
fa <- 2009 - bbwo.eh.covs$Year_burned
fa <- (fa-mean(fa))/sd(fa)

#create snag covariate
snag <- (bbwo.eh.covs$Snags_basal_count -
mean(bbwo.eh.covs$Snags_basal_count))/sd(bbwo.eh.covs$Snags_basal_count)

#create lat covariate
bbwo.lat.long <- cbind(bbwo.eh.covs$Easting.1.1.1, bbwo.eh.covs$Northing.1.1.1)
bbwo.lat.long <- as.matrix(bbwo.lat.long)
bbwo.lat.long <- SpatialPoints(bbwo.lat.long, proj4string = CRS(caveg.CRS))
bbwo.lat.long <- spTransform(bbwo.lat.long,CRS = CRS("+proj=longlat +datum=NAD83"))
bbwo.coords.df <- as.data.frame(bbwo.lat.long)
lat <- (bbwo.coords.df$coords.x2 -
mean(bbwo.coords.df$coords.x2))/sd(bbwo.coords.df$coords.x2)

# create canopy change covariate
bbwo.eh.covs$cc[is.na(bbwo.eh.covs$cc)] <- 0      # just 1 record with NA - a low severity site I
set to '0' rather than define prior.
cc <- bbwo.eh.covs$cc
cc <- (cc - mean(cc))/sd(cc)

#create index for fires
fire <- as.vector(bbwo.eh.covs[,"fire"])
nfire <- length(unique(fire))
fire1 <- rep(NA, nfire)
for (i in 1:nfire){
  fire1[fire == unique(fire)[i]] <- i
}

#create elevation residuals covariate
tmp <- lm(bbwo.eh.covs$Map_elev ~ bbwo.coords.df$coords.x2)
elev.resids <- data.frame(residuals(tmp))
elev.res <- (elev.resids - mean(elev.resids))/sd(elev.resids)
elev.res <- unlist(elev.res)

#create lt covariate - this used in earlier analysis as covariate for logit(p) - not included in report
#lt <- bbwo.eh.covs$Live_trees_basal_count
#lt <- lt - mean(lt)
#lt <- (lt-mean(lt))/sqrt(var(lt))

#create matix with effort indicator - first interval = 3 minutes (= 1), remaining intervals = 2
minutes (= 0)
ef <- matrix(data = NA, ncol = 5, nrow = npoint)
ef[,1] <- 1
ef[,2] <- 0
```

```
ef[,3:5] <- ef[,2]

#create matrix with survey type indicator(passive = 0; broadcast = 1)
itype <- matrix(data = NA, ncol = 5, nrow = npoint)
itype[,1:2] <- 0
itype[,3:5] <- 1

#write winbugs model to file ####################################################
modelFilename = 'bbwotest3.txt'
cat('
model {

#prior for random fire effect
  for (j in 1:nfire){
    b1[j] ~ dnorm(0, fire.tau)
    }

# prior for occupancy
  psi0 ~ dunif(0,1)
  lpsi0 <- log(psi0/(1-psi0))

# prior for random fire effect variance
fire.tau ~ dgamma(0.001, 0.001)
fire.sd <- pow(fire.tau, -0.5)

#priors for regression coefficients
a1 ~ dunif(-10,10)
a2 ~ dunif(-10,10)
#a3 ~ dnorm(0,0.001)
b2 ~ dnorm(0,0.001)
b3 ~ dnorm(0,0.001)
b4 ~ dnorm(0,0.001)
b5 ~ dnorm(0,0.001)
b6 ~ dnorm(0,0.001)

# prior for p
p0 ~ dunif(0,1)
lp0 <- log(p0/(1-p0))

for (i in 1:npoint){
# observation model
for (j in 1:J){
logit(p[i,j]) <- lp0 + a1*ef[i,j] + a2*itype[i,j] # + a3*lt[i]
muy[i,j] <- z[i]*p[i,j]
y[i,j] ~ dbern(muy[i,j])
}
```

```
# state model
z[i] ~ dbern(psi[i])              # state model
logit(psi[i]) <- lpsi0 + b1[fire1[i]] + b2*fa[i] + b3*snag[i] + b4*lat[i] + b5*cc[i]  + b6*elev.res[i]
}
}
', fill=TRUE, file=modelFilename)

# Run WinBUGS
######################################################################

# data needed for WinBUGS
data <- list ("y", "J", "npoint", "fire1", "nfire", "itype", "fa", "snag", "lat", "cc", "ef", "elev.res")

# initial values for WinBUGS
zst<-rbinom(npoint,1,0.5)
beta.st <- rnorm(1,0,1)
fire.sd.st <-runif(1,0,5)
pst <- runif(1,.05,.5)
psist <- runif(1, .05, .5)

inits <- function(){
list (z  = zst, a1 = runif(1, -1, 1), a2 = runif(1, -1, 1), psi0 = psist, b1 = rnorm(nfire,0,1), b2 =
beta.st, b3 = beta.st, b4 = beta.st, b5 = beta.st, b6 = beta.st, fire.tau = runif(1,.3,.6))
}

#parameters to trace
parameters <- c("p0", "lp0", "a1", "a2", "b1", "b2", "b3", "b4", "b5", "b6", "psi0", "lpsi0",
"fire.sd")    # "a3",      "b3",

#call WinBUGS, store results in 'out'
out <- bugs(data, inits, parameters, "bbwotest3.txt", n.thin=2, n.chains=2, n.burnin=10000,
n.iter=30000, bugs.directory = "c:/Program Files (x86)/WinBUGS14/", debug=F)

#retrieve predicted psi for each point - this used to calculate predicted overal and fire-level
occupancy probabilities and credible intervals
parameters <- c("psi[1:400]")
out2 <- bugs(data, inits, parameters, "bbwotest3.txt", n.thin=2, n.chains=2, n.burnin=10000,
n.iter=30000, bugs.directory = "c:/Program Files (x86)/WinBUGS14/", debug=F)
parameters <- c("psi[401:899]")
out3 <- bugs(data, inits, parameters, "bbwotest3.txt", n.thin=2, n.chains=2, n.burnin=10000,
n.iter=30000, bugs.directory = "c:/Program Files (x86)/WinBUGS14/", debug=F)

#Summaries and figures##############################################################

#Note that Figs. 1, 2, 4-7, 17 created by Rodney or Bob
```

```
#Fig. 8 created by me (JSaracco) in Excel (saved as "detections2009byCWHR.xls" in
"C:/Work/BBWO")
# Note also, that figs not created in order - reflects earlier iterations...

# predicted mean and 95% credible intervals for station-level occupancy probability across the
entire survey (Reported in Results: Occupancy modeling)
pred.psi <- cbind(as.data.frame(out4$sims.list$psi), as.data.frame(out5$sims.list$psi))
mean.psi <- apply(pred.psi, 1, mean) #calculate site mean across simulations
mean.mean.psi <- mean(mean.psi)
psi.mn.025 <- quantile(mean.psi, prob = 0.025)
psi.mn.975 <- quantile(mean.psi, prob = 0.975)

# calculate predicted mean and 95% credible intervals for station-level occupancy probability for
individual fires (Reported in Table 3)
site.psi <- matrix(data = NA, ncol = 3, nrow = npoint)
site.psi <- data.frame(site.psi)
names(site.psi) <- c("psi.mn", "psi.025", "psi.975")

for (i in 1:ncol(pred.psi)){
site.psi$psi.mn[i] <- mean(pred.psi[,i])
site.psi$psi.025[i] <- quantile(pred.psi[,i], prob = 0.025)
site.psi$psi.975[i] <- quantile(pred.psi[,i], prob = 0.975)
}

bbwo.eh.covs.pred <- data.frame(cbind(bbwo.eh.covs, site.psi))

site.pred.psi <- aggregate(bbwo.eh.covs.pred$psi.mn, list(bbwo.eh.covs.pred$fire), mean)
site.pred.psi025 <- aggregate(bbwo.eh.covs.pred$psi.025, list(bbwo.eh.covs.pred$fire), mean)
site.pred.psi975 <- aggregate(bbwo.eh.covs.pred$psi.975, list(bbwo.eh.covs.pred$fire), mean)
site.psi.sum <-  cbind(data.frame(site.pred.psi, site.pred.psi025, site.pred.psi975))
site.psi.sum <- cbind(site.psi.sum[,1:2], site.psi.sum[,4], site.psi.sum[,6])
names(site.psi.sum) <- c("fire", "psi_mn", "psi_025", "psi_975")
write.table(site.psi.sum, "site_psi_sum.txt", sep = ",", col.names = T, row.names = F)

#calculate interval specific and type specific p's and overall p (Reported in Results: Detection
probability)
# p0 was tracked in the out3 result so just reported mean and 95% credible interval from
out$summary
# 3 min interval
p3min <- inv.logit(out$sims.list$lp0 + out$sims.list$a1)
p3min.mn <- mean(p3min)
p3min.025 <- quantile(p3min, prob = 0.025)
p3min.975 <- quantile(p3min, prob = 0.975)
# overall passive detec
p.pa <- 1 - (1-out$sims.list$p0)*(1-p3min)
p.pa.mn <- mean(p.pa)
```

```
p.pa.025 <- quantile(p.pa, prob = 0.025)
p.pa.975 <- quantile(p.pa, prob = 0.975)

# playback detection prob
p.br <- inv.logit(out$sims.list$lp0 + out$sims.list$a2)
p.br.mn <- mean(p.br)
p.br.025 <- quantile(p.br, prob = 0.025)
p.br.975 <- quantile(p.br, prob = 0.975)
# overall playback detec
p.br.tot <- 1 - (1-p.br)^3
p.br.tot.mn <- mean(p.br.tot)
p.br.tot.025 <- quantile(p.br.tot, prob = 0.025)
p.br.tot.975 <- quantile(p.br.tot, prob = 0.975)

poverall <- 1 - (1 - p.pa)*(1 - p.br.tot)
poverall.mn <- mean(poverall)
poverall.025 <- quantile(poverall, prob = 0.025)
poverall.975 <- quantile(poverall, prob = 0.975)

# some summary info
#average covariates at fire level
firecovs <- cbind(as.data.frame(fire1), as.data.frame(2009 - bbwo.eh.covs$Year_burned),
as.data.frame(bbwo.eh.covs$Snags_basal_count), as.data.frame(bbwo.coords.df$coords.x2),
as.data.frame(bbwo.eh.covs$cc))
names(firecovs) <- c("fire1", "fa", "snag", "lat", "cc")
firecovs.mn  <- aggregate(firecovs, by = list(fire1), FUN = mean)
fire.names <- cbind(as.data.frame(fire1), as.data.frame(bbwo.eh.covs$fire))
fire.names <- unique(fire.names)
firecovs.mn <- merge(fire.names, firecovs.mn)

# Make bean plots reported in Results: Exploratory Analyses
detec <- data.frame(detec = bbwo.eh.covs$detec)
fa <- data.frame(2009 - bbwo.eh.covs$Year_burned)
snag <- data.frame(bbwo.eh.covs$Snags_basal_count)
plot1 <- cbind(snag, fa, detec)
names(plot1) <- c("snag", "fa", "detec")
plot1$fa.detec <- interaction(plot1$fa, plot1$detec)
tmp <- aggregate(plot1$snag, list(plot1$fa), mean)
names(tmp) <- c("fa", "fa.mean")
tmp <- merge(tmp, c("0", "1"))
tmp <- tmp[order(tmp$fa.mean),]
tmp$fa.detec <- interaction(tmp$fa, tmp$y)
fa.detec.levels <- as.vector(tmp$fa.detec)
plot1$fa.detec <- factor(plot1$fa.detec, levels = fa.detec.levels)

############################
```

```
elev.resid.plot <- cbind(elev.resids, detec)
elev.resid.plot$Det <- ifelse(elev.resid.plot$detec == 0, "Non-detection", "Detection")

############## Figure 9
elev <- bbwo.eh.covs$Map_elev
cwhr <- data.frame(cwhr = bbwo.eh.covs$CWHR_code)
cwhr.gis <- data.frame(cwhr.gis = bbwo.eh.covs$WHRTYPE)
detec <- data.frame(detec = bbwo.eh.covs$detec)
cc <- data.frame(cc = bbwo.eh.covs$cc)
snag <- bbwo.eh.covs$Snags_basal_count
plot1 <- cbind(cc, snag, elev, cwhr, cwhr.gis, detec)
plot1$cwhr.detec <- interaction(plot1$cwhr, plot1$detec)
tmp <- aggregate(plot1$elev, list(plot1$cwhr), mean)
names(tmp) <- c("cwhr", "cwhr.mean")
tmp <- merge(tmp, c("0", "1"))
tmp <- tmp[order(tmp$cwhr.mean),]
tmp$cwhr.detec <- interaction(tmp$cwhr, tmp$y)
cwhr.detec.levels <- as.vector(tmp$cwhr.detec)
plot1$cwhr.detec <- factor(plot1$cwhr.detec, levels = cwhr.detec.levels)

png(filename = "hab_elevbean.png", width = 6.5, height = 4, units = "in", res = 600)
yaxp = c(1000, 10000, 9)    # use this to set # intervals - 9
ylim = c(750, 3000)
#par(fig=c(0.05, 0.95, 0.05, 0.95))          # set figure position fig = c(left, right, bottom, top)
par(mai = c(1.25,1.25,0.1,0.1))         # set margins in proportions of total mai = c(bottom, left,
top, right)
beanplot(elev*0.3048 ~ cwhr.detec, data = plot1, ll = .11, border = NA, cex = 1, cex.axis = 1, las
= 2, ylim = ylim,  pin = c(5,5), mar = c(5, 35, 4, 2) + 0.1,
  col = list(c("black", "white", "black"), c("gray", "white", "gray")), side = "both")
title( xlab = "CWHR code", ylab = "Elevation (m)", cex.lab = 1.2, line = 4)
legend("topleft", fill = c("black", "grey"), bty = "n", legend = c("Non-detection", "Detection"),
cex = 1)
dev.off()

############canopy closure - I looked at post 2001 fires (data product dated 01/2002) only as
well as all fires. Plot looked the same so used all fires for report.
tmp <- bbwo.eh.covs[bbwo.eh.covs$Year_burned >=2002,]
detec <- data.frame(detec = bbwo.eh$detec)
canclos <- data.frame(canclos = tmp$canclos.vals)
plot2 <- cbind(canclos, detec)

#beanplot(canclos ~ detec, data = plot2, ylab = "Canopy closure (%)", cex.axis = 1.5, xlab =
"Detection code", cex.lab = 1.5,
#  log = "", ll = .06, border = NA, col = list(c("black", "white", "black")))
#legend("topleft", bty = "n", legend = c("0 = Non-detection", "1 = Detection"))
```

```
###elevation bean plot Figrue 10
png(filename = "elevbean.png", width = 5, height = 4, units = "in", res = 600)
beanplot(bbwo.eh.covs$Map_elev*0.3048 ~ elev.resid.plot$Det, ll = 0.01, ylab = "Elevation
(m)", cex.lab = 1.2, cex.axis = 1)
dev.off()

#latitude elevation correlation (Fig. 11)
png(filename = "lat_elev_corr.png", width = 6.5, height = 4.75, units = "in", res = 600) # open
plotting window and set resolution
plot(bbwo.eh.covs$Map_elev*0.3048 ~ firecovs$lat, xlab = "Latitude", ylab = "Elevation (m)",
cex.axis = 1, cex.lab = 1.2)
text(41,2700, "r = -0.681; P < 0.0001", cex = 1)
dev.off()

# examine distributions of latitudes for detections and non-detections - this inserted in Fig. 12,
which was created in ArcGIS/Photoshop by J. Saracco
windows(width = 6, height = 6, xpinch = 600, ypinch = 600) # open plotting window and set
resolution
par(fig=c(0.1, 0.9, 0.1, 0.9))          # set figure position fig = c(left, right, bottom, top)
par(mai = c(0.1,0.2,0.1,0.1))         # set margins in proportions of total mai = c(bottom, left, top,
right)
beanplot(bbwo.coords.df$coords.x2 ~ elev.resid.plot$Det, ll = 0.1, cex.axis = 2.5)
title(ylab = "Latitude", line = 5, cex.lab = 2.5)

# Fig. 13
# examine residual distributions for detections and non-detections from regression of elevation
on latitude
png(filename = "elevresid_bean.png", width = 5.5, height = 4.75, units = "in", res = 600) # open
plotting window and set resolution
beanplot(elev.resid.plot[,1]*0.3048 ~ elev.resid.plot[,3], ylab = "Residuals (elevation ~
latitude)", ll = 0.01)
dev.off()

#############multipanel beanplot (Fig. 14)
windows(width = 6, height = 6, xpinch = 600, ypinch = 600) # open plotting window and set
resolution  - the resolution stuff doesn't seem to work with the windows plotting
function...hmmmmm
par(mfrow = c(2,2), mai = c(0.15, 0.15, 0.05, 0.05))
beanplot(bbwo.eh.covs$cc ~ elev.resid.plot$Det, ll = 0.01, ylab = "Change in % canopy cover",
cex.lab = 1.5, cex.axis = 1.5)
beanplot(bbwo.eh.covs$Snags_basal_count*0.2295687*10 ~ elev.resid.plot$Det, ll = 0.01, ylab
= quote("Snag basal area " ~ ("m"^2 / "ha")), cex.lab = 1.5, cex.axis = 1.5, cutmin = 0)
beanplot(bbwo.eh.covs$canclos.vals ~ elev.resid.plot$Det, ll = 0.01, ylab = "Pre-fire % canopy
cover", cex.lab = 1.5, cex.axis = 1.5, cutmin = 0)
beanplot(2009 - bbwo.eh.covs$Year_burned ~ elev.resid.plot$Det, ll = 0.01, ylab = "Fire age
(years)", cex.lab = 1.5, cex.axis = 1.5, cutmin = 1, cutmax = 10)
```

```
# prediction plots (Figure 15)
png(filename = "prediction_plots.png", width = 6.5, height = 7.5, units = "in", res = 600) # open
plotting window and set resolution
par(mfrow = c(3,2))
par(mai = c(.6,.6,0.2,0.2))
par(cex.lab = 1.25)
x <- firecovs$fa
curve(inv.logit(b0 + mean(out$sims.list$b2)*((x - mean(x))/sd(x))),from = min(x), to = max(x),
las = 1, ylim = c(0, 0.6), xlab = "Fire age (years)", ylab = expression(paste("Occupancy
probability ( ", psi, ")")))
x= firecovs$snag
curve(inv.logit(b0 + mean(out$sims.list$b3)*((x*0.2295687*10 -
mean(x*0.2295687*10))/sd(x*0.2295687*10))), from = min(x*0.2295687*10), to =
max(x*0.2295687*10), las = 1,       # constants convert ft/acre x10 to m/ha
ylim = c(0, 0.6), xlab = quote("Snag basal area" ~ ("m"^2/"ha")), ylab =
expression(paste("Occupancy probability ( ", psi, ")")))
x= firecovs$lat
curve(inv.logit(b0 + mean(out$sims.list$b4)*((x - mean(x))/sd(x))), from = min(x), to = max(x),
las = 1,
ylim = c(0, 0.6), xlab = "Latitude", ylab = expression(paste("Occupancy probability ( ", psi,
")")))
x= firecovs$cc
curve(inv.logit(b0 + mean(out$sims.list$b5)*((x - mean(x))/sd(x))), from = min(x), to = max(x),
las = 1,
ylim = c(0, 0.6), xlab = "Change in % canopy cover", ylab = expression(paste("Occupancy
probability ( ", psi, ")")))
x= elev.resid.plot[,1]
curve(inv.logit(b0 + mean(out$sims.list$b6)*((x*0.3048 - mean(x*0.3048))/sd(x*0.3048))),
from = min(x), to = max(x), las = 1,
ylim = c(0, 0.6), xlab = "Residuals (elevation ~ latitude)", ylab = expression(paste("Occupancy
probability ( ", psi, ")")))
dev.off()

# Figure 16  bean plot
snagplot <- read.table("snag_yrcat_detec.txt", sep = ",", header = T) #snag_yrcat_detec.txt
created in JMP by J Saracco
snagplot$Snags_basal_count <- snagplot$Snags_basal_count*0.2295687*10    #scale snag
variable to m^2/ha
snagplot$yrcat2.detec <- interaction(snagplot$yrcat2, snagplot$detec)
tmp <- aggregate(snagplot$Snags_basal_count, list(snagplot$yrcat2), mean)
names(tmp) <- c("yrcat2", "yrcat2.mean")
tmp <- merge(tmp, c("0", "1"))
tmp <- tmp[order(tmp$yrcat2),]
tmp$yrcat2.detec <- interaction(tmp$yrcat2, tmp$y)
yrcat2.detec.levels <- as.vector(tmp$yrcat2.detec)
```

```
snagplot$yrcat2.detec <- factor(snagplot$yrcat2.detec, levels = yrcat2.detec.levels)

png(filename = "snag.png", width = 5.5, height = 5, units = "in", res = 600) # open plotting
window and set resolution
beanplot(Snags_basal_count ~ yrcat2.detec, data = snagplot, ylim = c(0, 120), ll = .01, border =
NA, cex = 1, cex.axis = 1, cex.lab = 1, las = 1, cutmin = 0, lwd = 1.5,
xlab = "Fire age (years since burned)", ylab = quote("Snag basal area " ~ ("m"^2 / "ha")),
  col = list(c("black", "white", "black"), c("gray", "white", "gray")), side = "both")
legend("topleft", fill = c("black", "grey"), bty = "n", legend = c("Non-detection", "Detection"),
cex = 1)
dev.off()
```