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Sierra Nevada Bird Observatory

**Assessing Home Range Size and Habitat Needs
of Black-backed Woodpeckers in California**

Report for the 2011 and 2012 Field Seasons

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Summary

The Black-backed Woodpecker is a designated Management Indicator Species (MIS) for snags in burned forest across ten national forest units of the Pacific Southwest Region of the USDA Forest Service (USDA Forest Service 2007), and at this writing is also a candidate species for listing under the California Endangered Species Act. Effective management of recently burned forest in California that also meets the conservation needs of the Black-backed Woodpecker requires better information on the resource requirements that support Black-backed Woodpecker occupancy and reproduction in California forests. In particular, Black-backed Woodpecker home range size has never been empirically estimated in California ecosystems, and only limited information is available on foraging habitat selection by the species in California forests. Our objective was to develop information on Black-backed Woodpecker home range size and foraging ecology in recent fire areas that could aid in better incorporating Black-backed Woodpecker habitat needs into the management of recently burned forest. Our specific goals were:

- Estimate size of Black-backed Woodpecker home ranges in burned forest stands of California.
- Describe snag density and abundance, and other habitat elements, within home ranges of Black-backed Woodpeckers.
- Describe foraging habitat selection, and assess how habitat at observed foraging locations (e.g., foraging substrate, stand-level snag density, etc.) differs from available habitat.

In 2011 and 2012 we radio-tagged 22 Black-backed Woodpeckers on the Peterson and Sugarloaf fires (3 and 2 years post-fire, respectively) on Lassen National Forest and the Wheeler (alternately called ‘Antelope Complex’) Fire (5 years post-fire) on Plumas National Forest. We conducted 284 ‘bouts’ of radio-tracking marked birds, collecting foraging observations at 3308 distinct locations. Monte Carlo sampling projections revealed that we amassed sufficient radio-tracking data to estimate home range sizes for 14 of the radio-tracked birds. Our ability to radio-track the remaining eight birds was curtailed prematurely by the birds shedding their transmitter

(with or without the tail feather we had attached it to) before we had collected sufficient data. We collected on-the-ground habitat data at 2,535 observed foraging locations and 1,808 systematically arrayed 'background' points within the birds' home ranges.

Home range estimation

We used two different analytical techniques to estimate and compare home ranges and utilization distributions of the woodpeckers we tracked: Minimum Convex Polygons (MCP) and Brownian bridge kernel estimation (Kernel). MCP home ranges were calculated for comparison to other studies and yielded the largest estimates of home ranges (95% mean home range size = 185 ha). Brownian bridge kernel estimates account for movement patterns and may provide more meaningful estimates of home range size. We used the Brownian bridge kernel method to estimate sizes of entire ranges (95% mean home range size = 97 ha) as well as core ranges (50% mean home range size = 16 ha). Home range estimates were independent of the total number of relocation points used for each individual. Independent of estimation method there was wide variation in home range sizes, with three birds exhibiting home ranges 2-3 times greater than the mean. Interestingly, two of these birds with comparatively much larger home ranges occupied and foraged in large areas of unburned forest. We observed these birds foraging on dead and ailing trees in unburned forest stands well over 3 km outside the perimeter of the fire area in which they were nesting.

These estimates of home range size can aid in estimating the size of local (e.g., for a single fire area) and regional (e.g., for all of California) breeding populations.

Home range characteristics

Mean snag basal area of individual Black-backed Woodpecker home ranges varied between 3.4 and 39 m²/ha (mean = 23 m²/ha) while mean live tree basal area varied between 1.8 and 34 m²/ha (mean = 13 m²/ha). Within home ranges, total basal area estimates varied by home range estimator but reached a maximum of 3,995 m² of snag basal area and a minimum of 435 m² of snag basal area (both using the 95% Kernel estimator). We found and quantified a strong

negative relationship between average snag basal area density and home range size, and a positive relationship between average live tree basal area density and home range size.

These quantitative relationships between home range characteristics and home range size can aid in estimating the size of local (e.g., for a single fire area) and regional (e.g., for all of California) breeding populations, and also provide forest managers with information on the area of post-fire forest and the quantity of snags required to support Black-backed Woodpecker occupancy and reproduction – critical information for making post-fire forest management compatible with Black-backed Woodpecker conservation.

Foraging habitat selection

Comparisons of foraging habitat at observed versus available locations revealed significant selection for specific resources at 3 different scales: foraging substrate, 10-m radius stand, and 50-m radius stand. In general, we found that the woodpeckers selected snags that were: larger, more highly charred, more heavily colonized by wood-boring beetle larvae, and showing fewer signs of decomposition than the available snags. Yellow Pine snags were preferred, and Black Oak snags were avoided. At the 10-m stand scale, woodpeckers selected stands for foraging that – in decreasing order of importance to the probability of an area being used for foraging – contained higher densities of: large snags (>60 cm dbh), medium snags (31-60 cm dbh), small snags (10-30 cm dbh), live trees, and logs. The presence of stumps (i.e., snags or trees that were cut pre- or post-fire) had no significant effect on the probability of an area being used for foraging, although this result does not account for the effect of the corresponding reduction in the number of snags or live trees in the stand. At the 50-m scale, we looked at the factors that correlated with kernel-based utilization distributions (i.e., usage probability). At this scale, woodpeckers more heavily used portions of their home range that were closer to their nest tree, where pre-fire canopy cover had been higher, and where fire had burned the forest more severely. Within home ranges, woodpeckers did not forage or nest in areas where salvage logging or other post-fire snag removal treatments had occurred, although they frequently used immediately adjacent stands that had not been salvage-logged.

In addition to assessing the factors that made some trees more likely to serve as foraging substrate than others, we also assessed factors that correlated with the length of time birds spent foraging on individual trees, which likely correlates with foraging success in those trees. Of many factors explored, the size of the tree, whether the tree was alive or dead, the amount of bark retained on the tree, and the number of wood-borer holes in the lowest 1 m of the bole contributed to the explanation of foraging duration. Of these significant effects, the size of the tree was the most consistently important across individual birds, with birds foraging longer on bigger snags.

These results on foraging habitat selection and foraging duration can help forest managers select for retention after fire the stands and individual snags that are most valuable for supporting Black-backed Woodpecker foraging.

Nest site characteristics

Over the course of two field seasons we identified 21 Black-backed Woodpecker nests, allowing an analysis of nest site characteristics. Of 13 variables at three spatial scales (tree-level, 10-m plot, 50-m plot), 7 variables had significant relationships to nest location. Nests were more likely to be placed in medium-sized snags (mean = 33 cm DBH) that were tall for their trunk diameter, and were extensively scorched. In areas surrounding nests, the number of snags (of all size classes) within 10 m and the total basal area of snags within 50 m were positively related to nest-site location.

These results can help forest managers select for retention after fire the forest stands in which Black-backed Woodpeckers are more likely to nest.

Breeding phenology and nest success

We found nests and monitored nesting attempts of 21 pairs of Black-backed Woodpeckers. Estimated dates for the initiation of incubation ranged from April 28 to June 26. Observed and estimated fledging dates of nestlings ranged from June 4 to July 25. The latest-starting nest we

observed failed for unknown reasons during the nestling phase, but had it succeeded, we estimate that the nestlings would have fledged around August 2.

Of 21 nests in which we are certain eggs were laid, 16 (76%) were confirmed or believed to fledge at least one young, and five failed to fledge any young. Causes of nest failure were unknown in 3 cases. In the 4th case, the nest cavity was clearly ripped open by a bear, as evidence by claw marks on the bark around the newly exposed nest. In the 5th case, observers had reason to suspect the nest was predated by chipmunks, but could not be certain.

These results provide the information needed for avoiding the scheduling of potentially nest-disturbing activities when nests are likely to be active, or even establishing dates for limited operating periods (LOPs), should they be deemed necessary for curtailing some activities during the nesting season.

Population age structure

We used plumage characteristics to determine the age class of 22 Black-backed Woodpeckers that we captured for radio-tagging, and thereby characterize the age structure of the populations at our study sites, which were 2-5 years post-fire at the time of the study. The majority of the adult birds were after-third-year individuals (three years old or greater). In the future we hope to compare these results with the age structure of populations occupying fire areas 1 year after fire. Adult birds caught during the first breeding season after fire are presumably colonizers, who emigrated from elsewhere. If such populations are comprised of predominantly second-year (1-year-old) birds, this will indicate that new fires are colonized by young birds dispersing from their natal areas. Alternately, if the population age structure is similar to that of the older fires assessed in this study (i.e., comprised mainly of older birds), it will indicate that colonizing birds are frequently adult birds that have presumably already attempted to nest elsewhere in previous years.

Either way, this information provides a key puzzle piece in understanding dispersal dynamics and population demography in this species, information that may ultimately be important for landscape-level conservation planning and habitat management for the species.

Disease

When one of our marked birds died near the end of the 2011 field season after we had tracked it for ten weeks, we recovered the carcass and had a necropsy performed. The necropsy revealed that the likely cause of death was infection by *Procyrnea* nematodes, which have been known to cause substantial die-offs in other bird species, including woodpeckers.

This finding, which we have already published in Journal of Zoo and Wildlife Medicine (see Appendix 1), is, to our knowledge, the first information ever published on disease in Black-backed Woodpecker, and is important for assessing population-level threats to the species.

Extreme agonistic behavior among Black-backed Woodpeckers

In 2012 when a second of our focal birds died, we again collected the carcass for necropsy. The necropsy and circumstances of the mortality lead us to conclude that we observed the first ever documented case of an adult woodpecker killing a conspecific adult. Lethal agonistic behavior has not been previously documented in woodpeckers and is therefore likely quite rare. We hypothesize that the association of Black-backed Woodpeckers with a limited resource (stands of recently killed conifers) that fluctuates unpredictably from year to year may severely limit breeding opportunities when local habitat quality for Black-backed Woodpeckers inevitably degrades, usually rapidly, in the years after a fire. In future studies, systematic observations of intraspecific interactions could test whether agonistic behavior among Black-backed Woodpeckers is indeed more intense than among other woodpecker species that are not burned-forest habitat specialists and that instead rely more heavily on habitats that do not fluctuate greatly in extent and quality from year to year.

This finding adds to general knowledge about Black-backed Woodpecker behavior and how it may be shaped by the species' strong association with recently burned forest.

Genetic population structure

Genetic population structure of Black-backed Woodpeckers across their range has been studied and reported elsewhere, but California birds' insularity or relatedness to other populations has never been evaluated. We collected feathers from 21 Black-backed Woodpeckers and sent them to the Conservation Genetics Laboratory at the U.S. Forest Service Rocky Mountain Research Station. DNA was successfully extracted and analyzed from 20 of the samples (see Appendix 2). Work is now underway in collaboration with personnel at the Conservation Genetics Laboratory to assess the results of the genetic analysis in the context of the species' larger population structure, and especially to assess the degree of connectivity with the Oregon population.

Information on population connectivity with Black-backed Woodpeckers in Oregon, when complete, will allow a more informed assessment of the vulnerability of the species in California.

Identification of possible prey species

In 2011 we trapped for wood-boring and bark beetles to assess qualitatively which potential prey species were present in the study areas during the field season. Using pheromone-baited Lindgren funnel traps placed in burned stands that our marked woodpeckers were actively using, we captured and then identified adult beetles at the Peterson fire on Lassen National Forest. The larger-sized wood-boring beetles we captured included two species of *Monochamus* and two species of *Acanthocinus* (long-horned beetles), and one species of metallic wood-boring beetle, *Chalcophora angulicolis*. We also captured large adult Elaterid beetles, *Alaus melanops*. These beetles predate upon larvae of wood-boring beetles, and their own larvae can be found under the bark of pine and fir trees, representing another potential large prey item for Black-backed Woodpeckers. We captured smaller *Scolytidae* bark beetles that we were able to identify to the genera *Dendroctonus* and *Ips*. We also captured bark beetle predator species, including *Enoclerus spegeus* and *Temnoscheila chlorodia*.

Although these results are preliminary, we hope to use them as a springboard for a more intensive study of Black-backed Woodpecker prey species in the future.

Conclusions

Our work on this study during the past two years has substantially advanced our understanding of Black-backed Woodpecker ecology in burned forests of California, and provides information that can directly inform management of post-fire forests. In particular, our home range estimates can aid in the estimation of Black-backed Woodpecker population sizes in burned forests, and help managers assess the likely effects of different post-fire management actions on the number of home ranges a post-fire forest may support. Our finding that home ranges across our study areas varied in size so greatly – by as much as an order of magnitude – and that the local density of snags largely explains this variation in home range size, provides a quantitative relationship (between snag availability and home range size) that allows for nuanced predictions about the effects of specific forest management actions on Black-backed Woodpeckers. Our characterization of the individual snags, trees, and stands that support Black-backed Woodpecker foraging and nesting can form the basis of quantitative targets for managers interested in selecting for retention the habitat elements and habitat patches that are most valuable to Black-backed Woodpeckers.

Introduction

The Black-backed Woodpecker is a designated Management Indicator Species (MIS) for snags in burned forest across the ten national forest units of the Pacific Southwest Region of the USDA Forest Service (USDA Forest Service 2007), and at this writing is also a candidate species for listing under the California Endangered Species Act. Annual Black-backed Woodpecker surveys initiated as part of the Forest Service's MIS monitoring program (Siegel et al. 2008, 2010, 2011, 2012) use broadcast surveys and passive point counts to assess occupancy at survey stations throughout portions of randomly selected fire areas across ten National Forest units of the Sierra Nevada region. Selected fire areas are 1-10 years post-fire, and comprise at least 50 ha of montane forest burned at moderate and/or high severity.

This MIS monitoring program for Black-backed Woodpecker addresses many monitoring needs for the species, including:

- Annual estimates of the total area and proportion of recently burned forest that is occupied by Black-backed Woodpeckers (Siegel et al. 2010, 2011, 2012).
- Assessment of multi-year trends in occupied area and proportion of available habitat occupied (Siegel et al. 2011, 2012).
- Analysis of habitat conditions (such as years since fire, fire severity, size of fire area, prefire habitat composition and structure, and post-fire snag density) that correlate with occupancy (Saracco et al. 2011, Siegel et al. 2012) and even post-hoc assessments of the effects of forest management activities on occupancy (Siegel et al. 2011).

Information from the program has directly informed conservation planning for the species (Bond et al. 2012).

However, effective management of recently burned forest in California that also meets the conservation needs of Black-backed Woodpecker requires additional information that the MIS monitoring alone will not provide. One component of this information is space use; knowledge of home range size is needed for estimating population size and predicting the effects of different management scenarios for burned forest stands on local Black-backed Woodpecker populations.

Black-backed Woodpecker home range size has never been empirically estimated in California. Elsewhere in the species range, the limited available information indicates that Black-backed Woodpeckers have relatively large home ranges, typically over 100 ha. However, size appears to vary with habitat type and time since fire. Average home-range size of 2 males in 6-year-old post-fire forests, and 2 males in 8-year-old post-fire forests in Idaho was 322 ha (range 123.5–573.4 ha) using 95 percent minimum convex polygon, and 207 ha (range 115.6–420.9 ha) using fixed-kernel estimates (Dudley and Saab 2007). While sample sizes were small, home ranges were substantially larger 8 years than 6 years after fire, suggesting that woodpeckers forage over larger areas as the beetle population decreases over time. Goggans et al. (1988) reported median minimum convex polygon home-range size for 3 individual woodpeckers was 124 ha (range 72–328 ha) in beetle-killed forests of Oregon; larger home ranges had smaller proportions of unlogged and mature habitats, suggesting a need to range farther in areas of lower-quality habitats, although sample size was small. Minimum convex polygon home-range sizes of 7 Black-backed Woodpeckers in unburned boreal forests of eastern Canada averaged 151.5 ± 18.8 ha (range 100.4–256.4 ha), with a home-range size of 358.8 ha for a female whose breeding attempt failed (Tremblay et al. 2009). Because none of these habitats elsewhere in the species' range is clearly analogous to most occupied burned areas in the Sierra Nevada, and because even the available values vary substantially, information on home range size in the Sierra Nevada is needed for predicting the effects of different forest management scenarios on local and regional Black-backed Woodpecker populations.

Additionally, informed habitat management would benefit greatly from better information on habitat characteristics that Black-backed Woodpeckers select within California's recently burned forest stands. Like information on home range size, most information on Black-backed Woodpecker habitat selection and foraging ecology comes from regions outside California (but

see also Hanson and North [2008] and Saracco et al. [2011]), where forest structure, composition and other conditions may differ markedly. More detailed information on habitat selection and foraging ecology in California ecosystems is needed to inform post-fire forest management strategies (e.g., density, composition, and spatial configuration of snags retained on the landscape) that support Black-backed Woodpecker foraging and reproduction while still meeting other resource management goals.

We developed this study to provide more detailed home range information for Black-backed Woodpecker conservation and burned-forest management. Our primary objectives in this project included:

- Estimate size of Black-backed Woodpecker home ranges in burned forest stands of California.
- Describe snag density and abundance, and other habitat elements, within home ranges of Black-backed Woodpeckers.
- Describe foraging habitat selection, and assess how habitat at observed foraging locations (e.g., foraging substrate, stand-level snag density, etc.) differs from available habitat.

Additional project objectives, which did not guide the design of the project but which we pursued to the degree that they did not interfere with the primary objectives, included:

- Describe nest site selection (nest tree species, local snag density, etc.) and compare with available habitat.
- Collect DNA samples to facilitate assessing the degree of genetic differentiation of Black-backed Woodpeckers in California from populations elsewhere across the species' range. Pierson et al. (2010) used DNA analysis to identify at least three genetically distinct groups of Black-backed Woodpeckers: a large, continuous population throughout the northern boreal forest to the Rocky Mountains; a second small, isolated population in the Black Hills of South Dakota; and a third population in the Cascade region of Oregon. However, no birds from California were included in the analysis, so the degree of genetic isolation or connectivity between birds in Oregon and California is unknown. We

collected feather samples from Black-backed Woodpeckers that we captured for radio-tagging, to facilitate this analysis.

- Identify potential prey species at study sites. Black-backed Woodpeckers are known to forage primarily on wood-boring and to a lesser degree, bark beetles. Adult wood-boring beetles detect burning or recently burned forest habitat by sensing smoke (e.g., the Cerambycid *Monochamus*) or heat (e.g., the Buprestid *Melanophila*), and lay their eggs in the recently killed trees (Hart 1998). Larvae of these wood-boring beetles are found in the bark, phloem, and xylem of standing dead trees, although they spend most of their time in the deeper xylem (Powell 2000). Black-backed Woodpeckers are better able to extract wood-boring insect larvae from deeper in the trees than other members of the *Picidae* due to their highly specialized anatomical adaptations (Dixon and Saab 2000). Wood-boring beetle larvae remain inside the wood for one to three years (Linsley 1961), providing a relatively long-term high-quality food source for Black-backed Woodpeckers. As a starting point for understanding Black-backed Woodpecker trophic relationships, we sought to assess which wood-boring and bark beetle species occurred at our study sites.

Methods

Study area

During the 2011 and 2012 breeding seasons, we studied Black-backed Woodpeckers occupying areas burned by the Peterson, Sugarloaf, and Wheeler (the latter alternately referred to as ‘Antelope Complex’) fires on Lassen and Plumas National Forests (Figure 1) in the northern Sierra Nevada mountains of California.

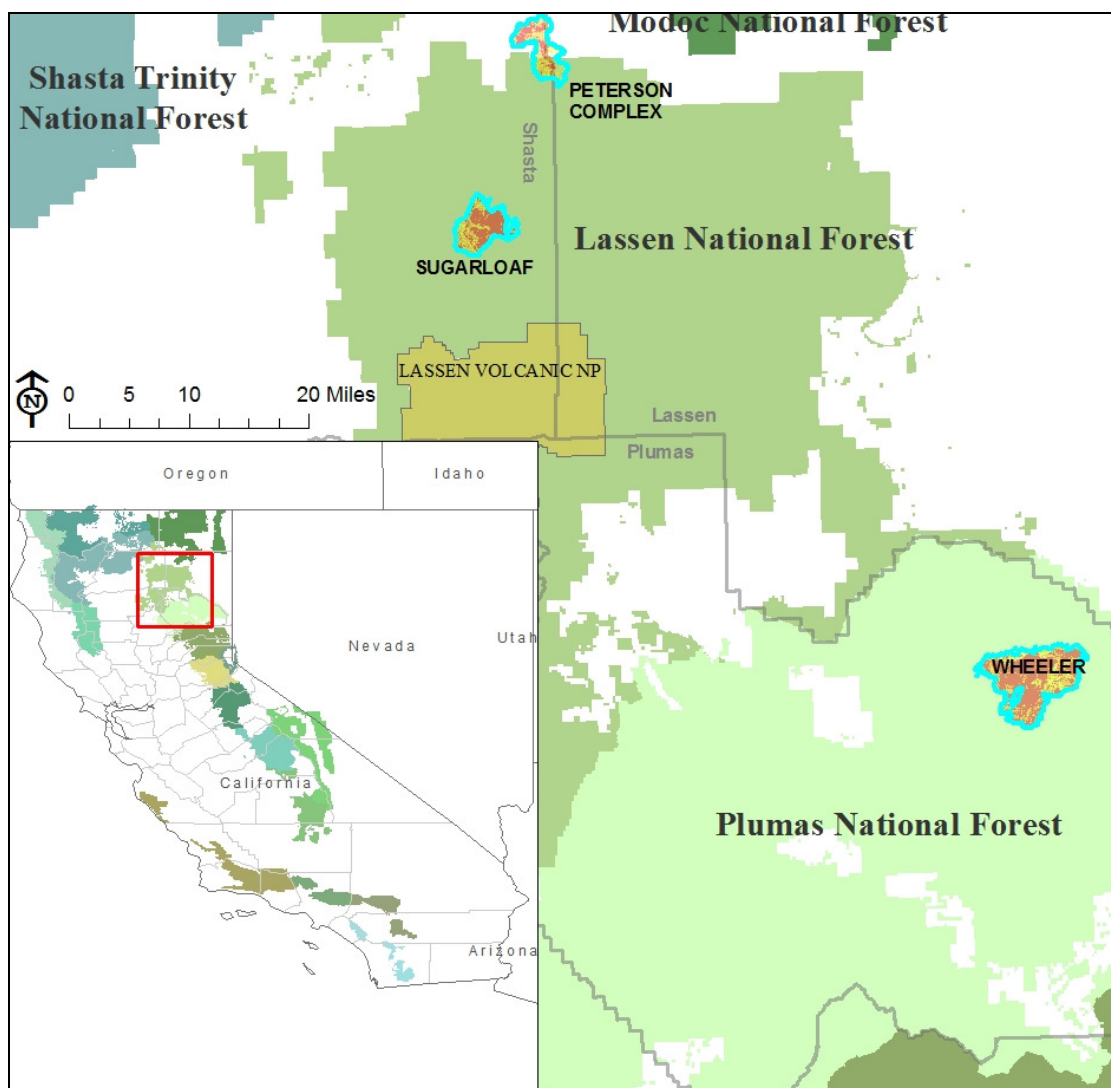


Figure 1. Location of Peterson, Sugarloaf and Wheeler fires (outlined in blue) in Lassen and Plumas National Forests. Within the three fire areas, red shading indicates high-severity fire, orange shading indicates medium-severity fire, and yellow-shading indicates low-severity fire.

We selected these fires from among all the recent fires on the ten National Forests of the greater Sierra Nevada planning area, based on the following factors:

- Prior knowledge of high densities of Black-backed Woodpeckers based on past MIS surveys (Siegel et al. 2011, 2012).
- Adequate road access to facilitate radio-tracking.
- Feasibility of late-spring access – we wanted to avoid sites where late-lingering snowpack would impede vehicle access to the site and/or foot-travel at the site.
- Free of ongoing active forest management that would restrict or interfere with our activities.
- Relatively gentle terrain, conducive to radio-tracking and other off-trail work.

The three study areas ranged from 2-5 years post-fire at the time of study (Table 1).

Table 1. Study areas where we studied Black-backed Woodpeckers in 2011 and 2012.

| Fire name | National Forest | Year of fire | Year studied | Years post-fire at time of study |
|-----------|-----------------|--------------|--------------|----------------------------------|
| Peterson | Lassen | 2008 | 2011 | 3 |
| Sugarloaf | Lassen | 2009 | 2011 | 2 |
| Wheeler | Plumas | 2007 | 2012 | 5 |

The Peterson fire burned in 2008, affecting 1161 ha of mostly Eastside Pine forest (Mayer and Laudenslayer 1988, California Department of Fish and Game 2005) on Forest Service land. Of 1161 ha within the fire perimeter, Forest Service mapping efforts based on Landsat Thematic Mapper data before and after the fire classified 9.8% as high-severity, 35.0% as mid-severity, 33.7% as low-severity, and 21.5% as unchanged. Subsequent to the fire (but before our study) approximately 100 ha of forest – mostly in high-severity areas – were salvage-logged in 2010 (USDA Forest Service Forest Activity Tracking System [FACTS] database, <http://www.fs.fed.us/r5/rsl/clearinghouse/gis-downloads.html>). Additionally, wood-cutting by the public in order to collect firewood from fire-killed forest stands was pervasive along roads throughout portions of the fire area. Most of the unharvested burned area was thus burned at low- or mid-severity (Figure 2). The burned area extends from 4140 - 5051 ft above sea level.



Figure 2. Representative views of the Peterson fire on Lassen National Forest. Note the prevalence of live trees, relative to the more severely burned forest stands pictured in Figure 3 (Sugarloaf Fire) and Figure 4 (Wheeler Fire).

The Sugarloaf fire burned in 2009, affecting 3129 ha of mostly Sierra Mixed Conifer forest (Mayer and Laudenslayer 1988, California Department of Fish and Game 2005) on Forest Service land. Of 3124 ha within the fire perimeter, Forest Service mapping efforts based on Landsat Thematic Mapper data before and after the fire classified 53.2% as high-severity, 27.8% as mid-severity, 16.5% as low-severity, and 2.5% as unchanged. A small amount of post-fire snag removal occurred prior to our study, but it was entirely outside the portion of the fire area in which we conducted our work. Unlike the Peterson fire, the Sugarloaf fire included large areas of unharvested high-severity burn, with relatively smaller areas of mid- and low-severity burn (Figure 3). The burned area extends from 3680 - 6552 ft above sea level. The study area includes patchy but extensive lava fields that are nearly devoid of trees or other vegetation.



Figure 3. Representative views of the Sugarloaf fire on Lassen National Forest.

The Wheeler Fire burned in 2007, affecting 9265 ha of mostly Sierra Mixed Conifer forest (California Department of Fish and Game 2005) on Forest Service land. Forest Service mapping efforts based on Landsat Thematic Mapper data before and after the fire classified 52.6% of the area inside the fire perimeter as high-severity, 28.3% as mid-severity, 13.4% as low-severity, and 5.7% as unchanged. No post-fire logging occurred on Forest Service land within our study area, but a few private inholdings within and adjacent to the study area were clear-cut after the fire, and post-fire wood-cutting for firewood by the public was pervasive along roads throughout much of the study area on Forest Service land. Much of the study area encompassed large, continuous stands of medium- or high-severity burned forest (Figure 4). The burned area extends from 4650 - 7015 ft above sea level.



Figure 4. Representative views of the Wheeler fire on Plumas National Forest. Note the highly variable understory structure.

Data collection

Finding and catching birds. In late April of 2011 (Peterson and Sugarloaf fires) and 2012 (Wheeler Fire) we began searching for Black-backed Woodpeckers, using a combination of broadcast surveys (loosely following the survey methods described in Saracco et al. 2011) and passive observation. Once we located birds, we attempted to catch them in mist nets (Figure 5) using more broadcasts and a wooden carving of a Black-backed Woodpecker that served as a lure. We caught the majority of our focal birds this way, but when we were unable to catch some individuals in this manner (generally because they tended to remain too high in the trees to be caught in mist nets when agitated by the lure and broadcast vocalizations), or when nests of unmarked birds were discovered later in the breeding season, we instead caught birds with hoop nets as they exited their nest cavities (Figure 5). Other researchers (Jennifer Pierson, personal

communication) report that Black-backed Woodpeckers may abandon their nests if caught while exiting nest cavities during the incubation phase or before nestlings turn 4 days old; we therefore closely monitored nesting activity and did not attempt to catch birds with this method until at least 5 days after eggs hatched. Hatching dates and/or age of nestlings were inferred from parental behavior and auditory detection of nestlings.



Figure 5. Black-backed Woodpeckers were captured with mist nets (left) or in a hoop net as they exited their nest (right).

After we caught and radio-tagged a bird, we deliberately avoided catching its mate, both to minimize disturbance of nesting efforts, and also to avoid pseudoreplication in our foraging data. However there were two instances in which birds shed their transmitters shortly after being marked, and we responded by then catching and marking their respective mates.

Attaching radio-transmitters. Various methods for attaching transmitters to woodpecker-sized birds have been described (e.g., Raim 1978, Rappole and Tipton 1991, J. Tremblay *personal communication*). We attached Model BD-2 radio-transmitters supplied by Holohil Systems, Ltd. to the dorsal surface of one of the inner rectrices. Transmitters were custom-modified by the manufacturer with a hole drilled into the large end, through which we could feed monofilament. Transmitters, including batteries, weighted ca. 2.5g. We used ethyl cyanoacrylate (available commercially as ‘Superglue’) to glue transmitters to a feather shaft and then additionally attached them with two loops of monofilament tied around the feather shaft (Figure 6).



Figure 6. Attaching a radio-transmitter to a woodpecker's tail feather using (left) ethyl cyanoacrylate and (right) monofilament.

When we caught woodpeckers, in addition to attaching transmitters we also:

- banded the birds with uniquely numbered aluminum leg bands supplied by the USGS Bird Banding Laboratory.
- measured wing length and collected other morphometric data.
- made a preliminary assessment of the bird's age, based on plumage and evidence of past molts (Pyle 1997).
- collected photographs of open wings for after-the-fact determination of bird age.
- collected feather samples for genetic analysis.

In some cases the birds spontaneously molted an adequate number of body feathers during processing that no further feather collection was necessary; when this did not happen, we collected additional feathers by taking a small 'pinch' of feathers from the back of the bird – generally yielding 3-5 small feathers. Feathers collected from each bird were stored in a labeled and sealed paper envelope. Later in the field season some of the birds shed the tail feather on which we mounted the transmitter – with the functioning transmitter still attached. In these instances we collected the shed tail feather and added it to feather samples we collected during in-the-hand processing. After the field season, all feather samples were shipped to Dr. Michael Schwartz, Conservation Genetics Team Leader at the U.S. Forest Service Rocky Mountain Research Station, for DNA extraction and analysis.

In-the-hand processing generally lasted about 15 minutes (range 11-20 minutes) after which all birds were released in apparently good condition. When we caught birds exiting their nests, we released them onto their nest trees or even into their nest cavities when possible, in an attempt to minimize the likelihood of nest abandonment relating to capturing birds at their nests.

Monitoring nesting attempts of focal birds. We located Black-backed Woodpecker nests by following unmarked or radio-tagged birds to their nests, or by cueing in to the sounds of nest excavation or begging nestlings. Once we discovered a nest, we attempted to visit it at least every four days to observe parental behavior and/or listen for hatchlings. We were generally unable to observe nest contents directly, but we were nevertheless able to construct a timeline for each nesting attempt, based on direct observations of parental behavior and nestlings (when they were mature enough to be audible from ground level or to peer out of the cavity entrance), and published information on the expected duration of each nesting interval. For the 2012 field season we obtained a borescope with a flexible probe for looking into nest cavities, but most of the nests were too high to use this technique without climbing the nest tree – which we chose not to do out of safety concerns and a desire to minimize disturbance to nesting efforts. Following Ehrlich et al. (1988), when our direct observations were equivocal we assumed that egg laying lasted 5 days, incubation lasted 13 days, and the nestling period (hatching to fledging) lasted 25 days.

Radio-tracking and marking foraging locations. Once birds were marked with radio-transmitters emitting signals at unique frequencies, we attempted to track them approximately every second day, although intended tracking bouts were sometimes missed due to inclement weather or other logistic reasons. Alternately, when the crew had time, we sometimes tracked birds daily. Each pair of crew members usually had time to find and track two birds per day (including the substantial time needed to describe foraging substrate and habitat at observed foraging points – see below), so for each individual bird we strove to alternate whether it was the first (generally tracked during mid-morning) or second (generally tracked during early afternoon) bird tracked in a day, in case activity patterns varied substantially with time of day.

We used radio receivers and Model RA-7 antennas supplied by Telonics Telemetry Consultants and AVM Instruments Company, Ltd. to locate and track marked birds (Figure 7). Radio-tracking generally required a team of two people working together. The team would return to the home range of a marked bird and use a receiver and antenna to find a signal and use the homing method (Mech 1983, White and Garrott 1990) to approach and find the bird. Sometimes this process was rapid, but because the birds often moved too quickly to be followed on foot over large distances, it sometimes required as long as 2 hours to visually locate a bird prior to initiating the collection of foraging observations. Black-backed Woodpeckers were very unwary of human observers, consistently allowing trackers to approach within 3-4 m without obviously altering their behavior, as has been reported from the boreal forest (Tremblay et al. 2009).



Figure 7. Using a receiver and antenna to assess the direction of a transmitter signal.

Once a bird was visually located, the team would follow it for at least one hour of continuous tracking, or until at least 20 foraging locations were marked. One member of the team – the ‘tracker’ – would use the receiver, antenna, and binoculars to find and follow the bird, and a stopwatch to measure the time the bird spent on each tree. The other person – the ‘scribe’ – would carry a GPS unit, clipboard with data sheet, and at least 20 pre-numbered vinyl pin flags. Upon sighting the bird alight on a tree and begin foraging (defined as touching its bill to the

tree), the tracker would start the stopwatch and time the period from the initiation of foraging until the bird left the tree. The tracker would also call out which of four height ranges (<1 m above ground, 1-3 m, 3-10 m, >10 m) on the tree the bird foraged within, and which foraging methods it used (peck, flake, excavate, glean). The scribe would record the tracker's observations and the elapsed time (also called out by the tracker), collect a GPS waypoint, and plant a pin flag at the base of the tree (generally waiting until the bird departed, unless it was foraging high enough on the tree not to be flushed by the observer). When the bird departed from the tree, the team would follow it, and record the next foraging event in a similar manner.

Describing foraging substrate and habitat at foraging locations. After completing each bout of tracking a focal bird, the tracking team used their GPS waypoints to return to each pin flag and collect information on the foraging substrate as well as habitat data within a 10-m and a 50-m radius plot centered on the tree.

For the foraging substrate, the data collected included:

- Identification of substrate as live tree, snag, log, or stump
- Height (length for logs)
- Whether any needles were present
- How much bark was retained
- Diameter at breast height (dbh; max width for logs)
- Broken or intact top
- Percent retained live foliage (live trees only)
- Percent trunk scorched
- Number of wood-boring beetle holes <1 m above ground
- Number of woodpecker excavations <1m above ground

For the 10-m plot, the data collected included:

- Aspect
- Linear extent of logs >10 cm thick

- Number of live trees > 10 cm dbh
- Number of cut stumps
- Number of snags in each of three size classes (10-30 cm, 31-60 cm, >60 cm dbh)

For the 50-m plot, the data collected included:

- dominant fire severity (none, low, medium, or high)
- apparent pre-fire CWHR habitat type
- basal area of snags and live trees (assessed with a 'Cruiser's Crutch')

Describing available habitat at systematic points across each bird's home range. Near the end of the field season we used the radio-tracking data to construct preliminary minimum convex polygons (MCPs) describing 100% of each marked bird's observed home range. Within each home range we defined a systematic grid of points 100 m apart, and then conducted vegetation survey at each of these points, to describe 'available' habitat within each bird's home range (Figure 8). As some birds foraged outside of preliminary MCPs during subsequent tracking efforts near the end of the respective field seasons, background points did not fully cover entire MCPs for all birds, particularly 2 birds at the Peterson fire and 1 bird at the Sugarloaf fire. To effectively cover several very large home ranges at the Peterson fire, the spacing of the background grid was expanded to 275 m between adjacent sampling points. A total of 1,808 background grid points was sampled.

At each of the systematic grid points we conducted a vegetation assessment similar to what we did at the observed foraging locations. For information on available foraging substrate, we collected our foraging substrate data (see *Describing foraging substrate and habitat at foraging locations*, above) at the nearest snag and live tree within 50 m of each systematic point. 10-m plot data and 50-m plot data were collected identically to what we did at the observed foraging locations, but rather than collecting these data at every grid point as we did for the foraging substrate information, these data were only collected at alternating grid points.

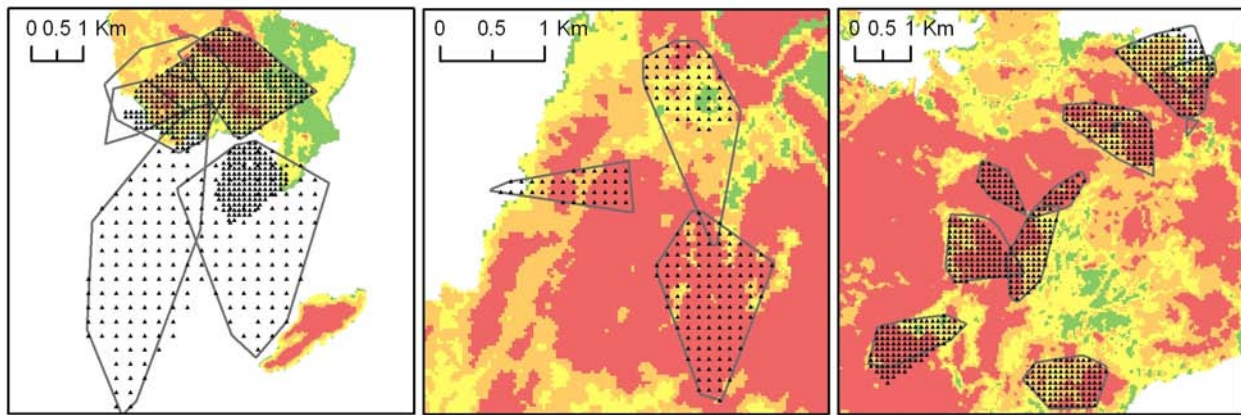


Figure 8. Spatial coverage of background sampling points (triangles) in relation to individual bird MCPs (gray outlines) and fire burn severity for Peterson (left), Sugarloaf (middle), and Wheeler (right) fires. Burn severity classes are unchanged (green), low (yellow), medium (orange), and high (red), with areas outside the fire perimeter in white.

Insect sampling. During the 2011 field season only, we trapped wood-boring and bark beetles from 12 May through 20 July 2011 to assess qualitatively which potential prey species were present in the study areas (Figure 9). We used Lindgren funnel traps with a conical drain screen, and baited them with a-pinene UHR-75% and Ipsenol bubble pheromonal lures (Synergy Semiochemicals Corp., Burnaby, British Columbia, Canada). Traps were placed in burned stands known to be used for foraging by our sample of radio-marked Black-backed Woodpeckers. Initially we placed 2 traps in the Sugarloaf fire area (1 in a high-severity and 1 in a mixed-severity patch) and 3 traps in the Peterson fire area (1 in a high-severity, 1 in a mixed-severity, and 1 in a low-severity patch). These traps were set once and then checked and emptied once per week. After 28 June we placed all 5 traps in new locations in the Peterson fire area (2 in a high-severity and 3 in a mixed-severity patch) because we were concentrating most of our Black-backed Woodpecker tracking efforts there. These traps were set each morning and then emptied and taken down each afternoon to avoid incidentally catching of non-target taxa.

Wood-boring and bark beetles were identified to genus and, when possible, to species using online sources (www.bugguide.net) and Linsley and Chemsak (1984). We did not quantify number of beetles captured by genus or species because often the insects were not intact due to the presence of numerous predatory insects in the traps. Predators of wood-boring and bark beetles also were identified to genus and species to the extent possible. We captured many species of *Coleoptera*, but only identified and present here representatives of the major groups.



Figure 9. Beetle trap in a high-severity patch of the Peterson fire.

Necropsy. Late in the 2011 field season, after nearly ten weeks of being radio-tracked and having successfully raised and fledged its young, one of our marked birds was found dead at the base of a tree, with no obvious sign of trauma. We collected the carcass, froze it, and then shipped it to the California Animal Health and Food Safety Laboratory System at Davis, California, where a necropsy was performed. During the 2012 field season, another one of our focal birds, which had shed its transmitter a few days prior, was found dead inside its nest cavity. This carcass was also sent to the California Animal Health and Food Safety Laboratory for necropsy. Details of the necropsy methodology are provided in Siegel et al. (2012), which is reproduced in Appendix 1.

Data analysis

Data preparation. Data collected from radio-tracking can be divided into three classes: 1) GPS points taken from sightings of known birds prior to tagging and radio-tracking; 2) GPS points taken during radio-tracking where foraging trees were later measured; and 3) GPS points taken during radio-tracking where foraging trees were not measured (primarily late in the field season when vegetation measurements were limited by crew availability). For the calculation of home range sizes, only GPS points collected during radio tracking (regardless of whether foraging trees were measured) were used. Movement-based kernel estimation requires GPS locations to be ordered temporally with approximate time intervals between points. These data were collected during sampling in 2012, but in 2011, exact elapsed time between GPS points was not recorded. Instead, start times and end times for observed foraging bouts (which could include a few to

dozens of observed foraging locations) were recorded in 2011. To estimate time intervals between successively used foraging locations in 2011, the differences in bout start and end times were divided by the number of foraging locations recorded within each bout.

All data analyses were conducted in R (R Development Core Team 2011) and made use of the home range estimation packages AdehabitatHR and AdehabitatLT (Calenge 2006). Subsequent spatial manipulations and area estimations used ArcGIS (ESRI 2011), and the R packages PBSmapping (Schnute et al. 2010), raster (Hijmans and van Etten 2011), and sp (Bivand et al. 2008). Analyses of home range characteristics involving Generalized Linear Mixed Models (GLMM) with both normal and binomial distributions were done using the package lme4 (Bates and Maechler 2011).

Home range estimators. Home range can be estimated using various methods depending on assumptions, data type, and data quality. Classically, home range has been estimated by simply circumscribing all tracked points, which results in the Minimum Convex Polygon (MCP; Mohr 1947). If this is done around all points, it yields the 100th percentile MCP, but often the 5% most extreme points are excluded, resulting in the 95th percentile MCP.

The joining of home range and use led to the conceptualization of a home range as consisting of an area with varying degrees of usage, and that within the home range there may be patches that are more heavily used and less heavily used. This usage pattern is termed the Utilization Distribution (UD; van Winkle 1975) and can be modeled as a bivariate probability density distribution. This logic led to the development of the “classic” kernel method of home range estimation which uses the density of observed locations to model the UD (Worton 1989). How “tight” or “fuzzy” the UD is around observed locations depends on one or more kernel smoothing parameters.

It should be noted that all methods include assumptions and biases that sometimes lead to wildly different “home range” estimates, often depending on different inherent ideas of what a “home range” actually is. As kernel-based estimates have been shown to consistently minimize Type I and Type II errors versus other home range estimation methods, including the MCP method

(Cumming and Corn  lis 2012), we prioritize this metric for presentation and results in this report. However, our overall goal is to present results using multiple methods so as to maximize comparability to other studies of home range size in Black-backed Woodpeckers, thus MCP estimates are also presented.

The first home range estimation method we used was the basic MCP with percentiles calculated at 10%, 50%, 95%, and 100%. The 100th percentile represents the area bounded by a polygon drawn exactly around all points. The 10th percentile would be the area of the smallest potential polygon that could be drawn around 10% of the points.

The second home range estimator we used, Brownian bridge kernel estimation, accounts for temporal autocorrelation in the woodpecker radio-tracking data and explicitly uses both the path taken between consecutive relocations as well as the amount of time between observations at successive foraging points to estimate a Utilization Distribution (Bullard 1999, Horne et al. 2007). Unlike classic (fixed) kernel methods, the Brownian bridge method assumes that the area between consecutive relocations is part of the ‘home range’ and that the degree with which this in-between area is used is related to the amount of time spent traveling between two fixes (relative to the speed of the animal). Thus, parameterization of Brownian bridge kernel home ranges requires the specification of two variables: *sig1*, which relates to the speed of the animal and defines the width of Brownian bridges; and *sig2*, which relates to the imprecision of the relocations and defines the width of kernels around known locations. Brownian bridge kernel estimation works best when the time between consecutive locations is relatively constant, thus lumping ‘bouts’ (i.e., series of radio-tracking) collected across multiple days or weeks into a single continuous movement trajectory invalidates model assumptions. To avoid this problem, kernel-based home ranges were modeled for individual observation bouts (consisting of 1 to 60 foraging relocations; median = 10), and then all bout-specific home ranges for a single bird were averaged to create a composite utilization distribution for an entire bird’s home range. The parameter *sig1* can be empirically estimated using data for a single bout (Horne et al. 2007), but given that *sig1* has meaning as a bird-specific rather than bout-specific property, we averaged empirical estimates of *sig1* across all bouts for a single bird and used this single mean *sig1* value for home range estimation with all bouts of an individual. The parameter *sig2* was set to 5

(meters) for all birds, consistent with the approximate uncertainty of field-based GPS units used in this study. Kernel home range areas were calculated for multiple percentiles. Consistent with previous studies, we utilize the 95th percentile to represent the full home range, and the 50th percentile to represent the ‘core’ home range (Anich et al. 2012).

Results

We captured and radio-tagged 10 Black-backed Woodpeckers during the 2011 breeding season, and 12 Black-backed Woodpeckers during the 2012 field season, for a total of 22 birds marked. Getting the transmitters to adhere well to tail feathers proved to be a process of trial and error; the first two transmitters we attached in 2011 both were shed within two weeks of application. After these two unsuccessful attempts, we improved our methods sufficiently that none of the remaining 20 transmitters we attached was dislodged from the tail feather to which it was attached. In several cases, however, even though the transmitter held fast to the feather, the woodpecker shed its entire feather, thereby ending our tracking efforts prematurely. Nevertheless, we were still able to accomplish substantial radio-tracking: 284 bouts comprising 3308 foraging events at 2943 unique foraging locations. Data on foraging substrate and local stand conditions were collected at 2535 of these foraging locations. In addition, on-the-ground habitat data were collected at 1808 “background” grid points within MCP boundaries.

Breeding phenology and nest success

We were able to monitor nesting attempts of 21 pairs of Black-backed Woodpeckers (Figure 10), where nesting attempts are defined as nesting efforts during which we are certain eggs were laid. In numerous cases we observed birds excavating more than one cavity and/or abandoning nest cavities during excavation, before the cavities were deep enough to be used. In a few cases nests in which excavation may have been completed were also abandoned, but if we were unable to confirm egg laying we did not consider it a failed nesting attempt. We were rarely able to see into nest cavities, making exact dates for the onset of incubation, hatching, and sometimes even fledging, difficult to collect. However, we were able to estimate the dates with a reasonable degree of accuracy by observing changes in behavior of parents and the behavior and appearance of chicks when they were old enough to beg for food at the nest cavity entrance. Estimated dates for the initiation of incubation ranged from April 28 to June 26 (Figure 10). Observed and estimated fledging dates of nestlings ranged from June 4 to July 25 (Figure 10). The latest-

starting nest we observed failed for unknown reasons during the nestling phase, but had it succeeded, we estimate that the nestlings would have fledged August 2 (Figure 10).

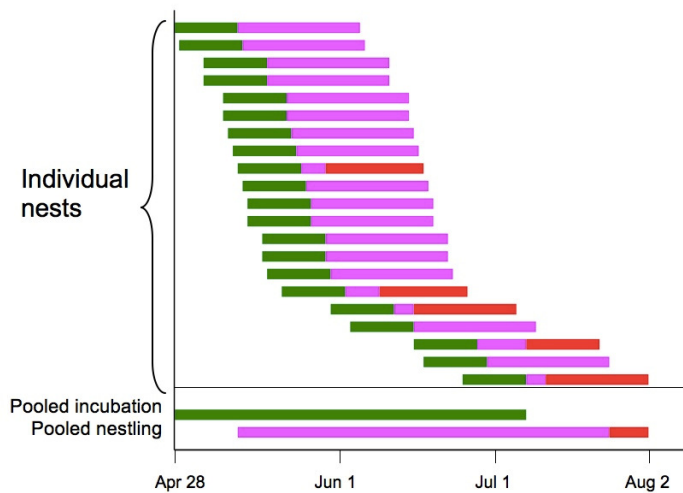


Figure 10. Nesting phenology of 21 Black-backed Woodpecker nests in the Peterson, Sugarloaf, and Wheeler fire areas during the 2011 and 2012 breeding seasons. Green bars indicate the incubation stage, pink bars indicate the nestling stage, and red bars indicate the expected remainder of the nestling period for nests that failed during the nestling stage.

Of the 21 nests in which we are certain eggs were laid, 16 (76%) were confirmed or believed to fledge at least one young, and five failed to fledge any young. These results are based on a naive nest success rate that did not consider exposure period or length of time the nest was observed (Shaffer 2004). All 5 observed nest failures occurred during the first half of the nestling phase (Figure 10). Causes of nest failure were unknown in 3 cases. In the 4th case, the nest cavity was clearly ripped open by a bear (Figure 11), as evidenced by claw marks on the bark around the exposed nest. In the last case, observers returned to the nest after not having visited it for several days and observed chipmunks entering and leaving the cavity, with no sign of Black-backed Woodpeckers in the area, suggesting the young nestlings may have been predated by chipmunks. A bear apparently attempted to predate an additional nest, again as evidenced by stripped bark and obvious bear claw marks (Figure 11) but the bear apparently was unable to completely expose the nest, and the nestlings eventually fledged.



Figure 11. The nest of woodpecker SP090W at the Wheeler Fire was predated by a bear, which exposed the nest cavity and left telltale claw marks on the surrounding bark (left). A bear also attempted to predate the nest of woodpecker HU555S at the Sugarloaf Fire, again as evidenced by stripped bark and obvious bear claw marks (right), but the bear apparently was unable to completely expose the nest, and the nestlings eventually fledged.

Home range estimation

Of 20 birds with radio tracking data (two birds shed their transmitters before we could collect any tracking data), 14 were males and 6 were females. All 20 birds attempted to nest during the study. Six birds (5 males and 1 female) were radio-tagged within the Peterson fire (Figures 12, 13), three birds (all males) were radio-tagged within the Sugarloaf fire (Figure 14), and 12 birds (7 males and 5 females) were radio-tagged within the Wheeler Fire (Figure 15).

At all three fires, nests of all marked birds were found to be within fire perimeters. Home ranges were also consistently within fire perimeter boundaries with two notable exceptions: TU222P and HB777P at the Peterson fire foraged widely and extensively outside of the fire perimeter in stands of unburned forest and at farther distances away from their nests than any of the other birds. A third bird at the Peterson fire, RO888P, also foraged heavily outside of the fire perimeter, although this bird did not travel quite so extensively away from his nest.

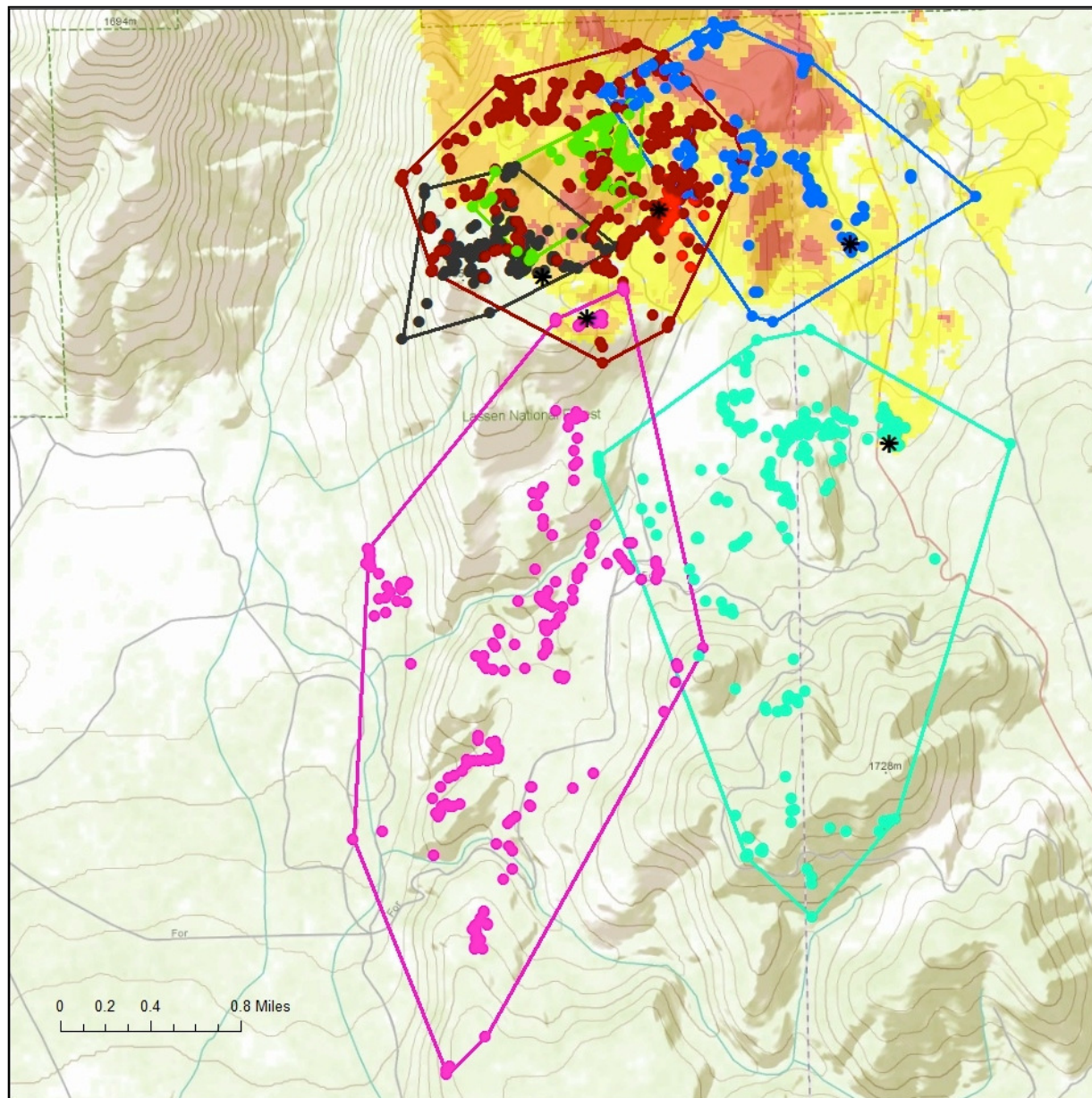


Figure 12. Observed foraging locations (points), nests (asterisks) and 100% MCP boundaries for seven individual Black-backed Woodpeckers (each represented with a unique color) radio-tracked at the Peterson fire. Burn severity is shown from low (yellow) to high (red). Bright red points indicate tracking locations of the mate of the bird indicated with brown points, whose transmitter was shed after only a few days.

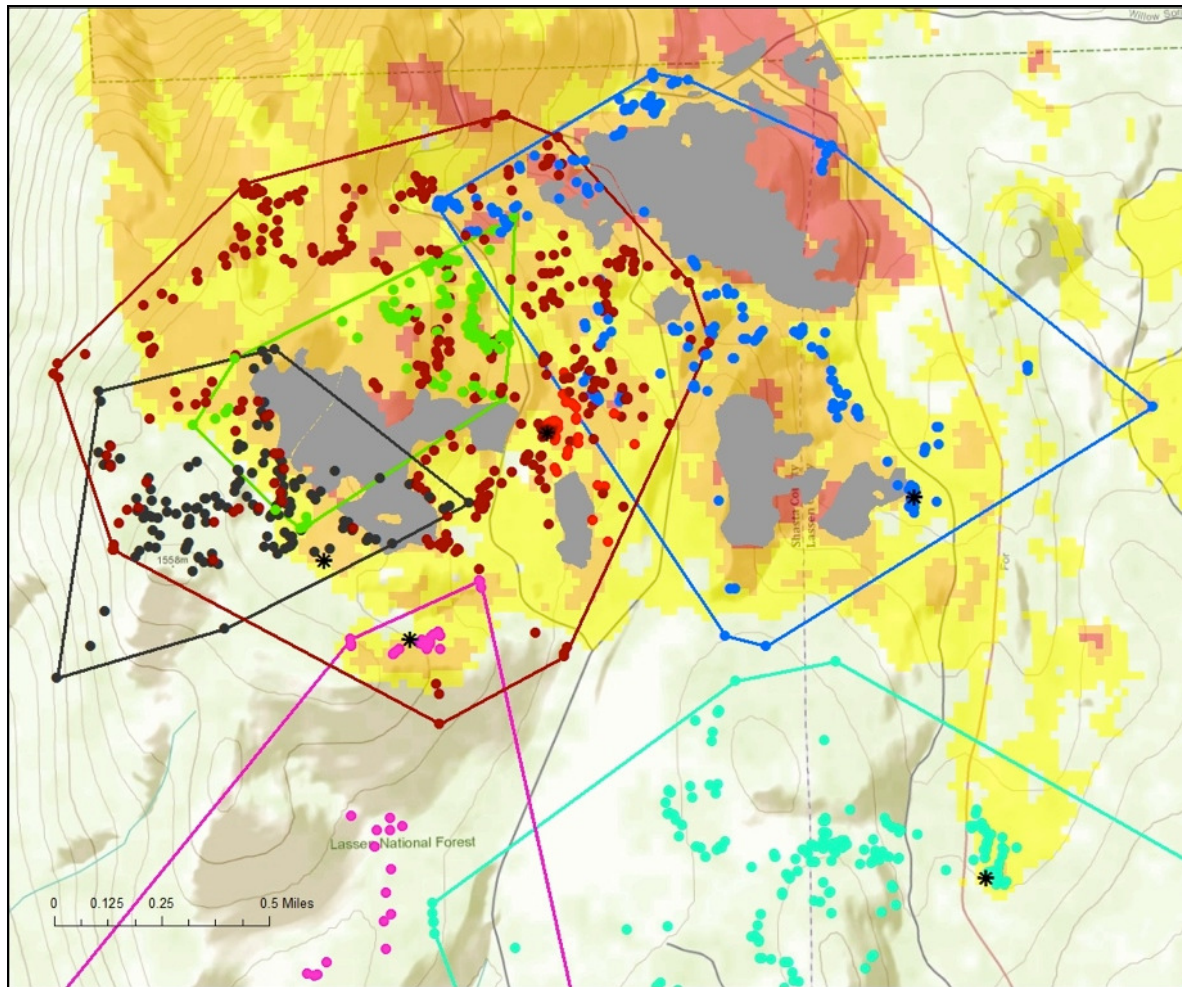


Figure 13. Close-up of Peterson fire, with observed foraging locations and MCP boundaries of Black-backed Woodpeckers. Symbology is consistent with Figure 12, with the addition of areas of post-fire snag harvest indicated by gray shading. Note the general absence of foraging locations within the post-fire harvest areas.

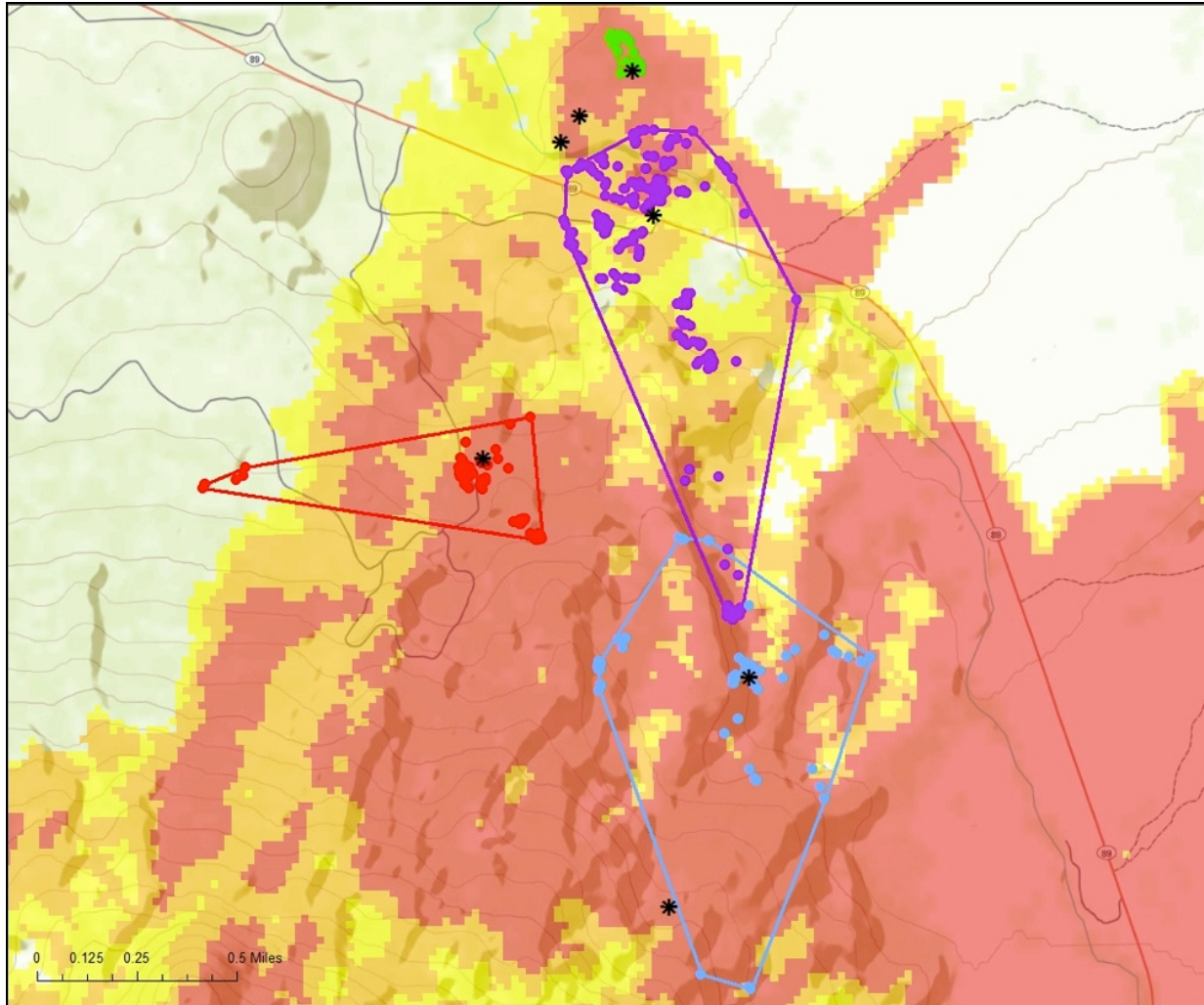
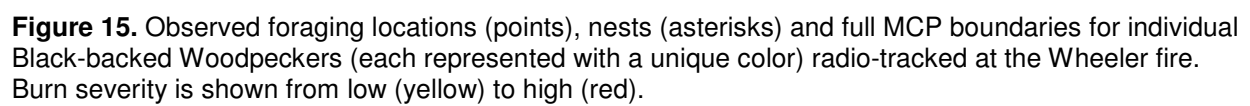


Figure 14. Observed foraging locations (points), nests (asterisks) and full MCP boundaries for individual Black-backed Woodpeckers (each represented with a unique color) radio-tracked at the Sugarloaf fire. Burn severity is shown from low (yellow) to high (red).



Prior to formal home range size estimation it was necessary to limit analysis to only those individual birds for which we had collected enough relocation data. The number of radio-tracked relocations per bird ranged from 7 (CA131W) to 366 (CH112P) with a median of 175. To adequately compare home range sizes across individuals, we desired to *a priori* exclude birds with insufficient numbers of relocations. This was done through a Monte Carlo simulation: for each bird, increasing numbers of relocation points, n , were drawn at random (with replacement) and used to build an MCP resulting in an area estimate. The simulation started with drawing only 5 points and continued until all the available points were drawn for each bird. At each n , the process was repeated 500 times, to calculate an incremental mean and 95% credible interval of MCP area (Figure 16). Based on the results of this sample size analysis, we excluded six birds in Figure 16 (CA131W, CG169W, FF666S, HU555S, KK700W, and PU111W [note that the suffix letter indicates the fire study site, with W=Wheeler, S=Sugarloaf, and P=Peterson]) from formal home range size analysis due to a lack of convergence of means and error. Our resulting group of 14 birds each had more than 100 relocation points.

Home ranges were modeled using both the MCP and Brownian bridge kernel method, which provided estimation of home range sizes at varying percentiles (Figures 17-18). When interpreting home range maps it is important to note that kernel estimation methods include all pixels within the extent of analysis as part of total UD volume at the 100th percentile. As a result, the 100th percentile includes the full map area for each bird, so 99th percentiles are presented instead of 100th percentiles for kernel estimates.

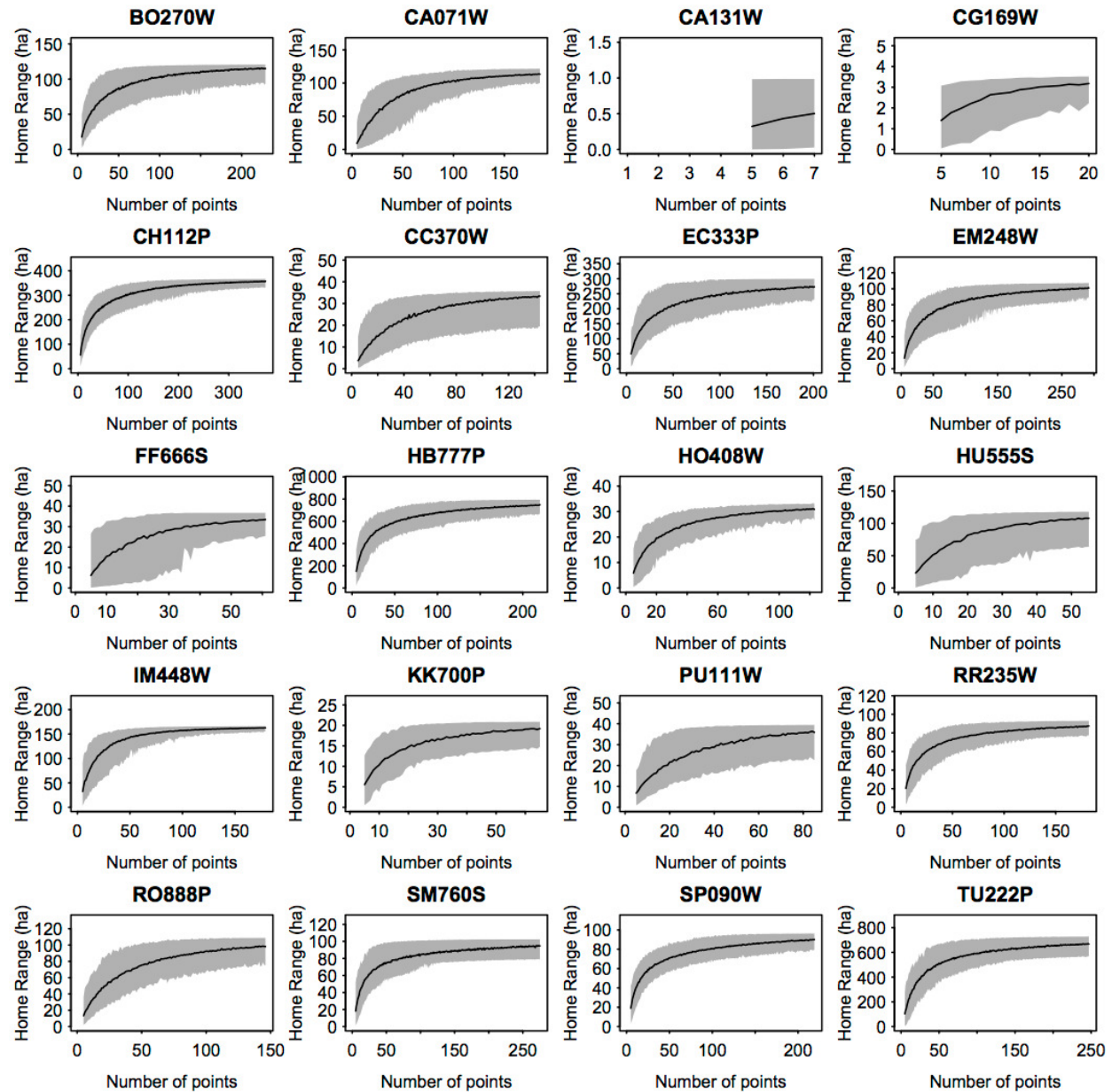


Figure 16. Mean (black line) and 95% credible interval (gray) of MCP home range size for increasing random draws of n relocation points for each radio-tracked Black-backed Woodpecker. Plots were assessed for evidence of home range convergence as n increased. For each individual bird's data plot, the suffix letter in the code above the plot indicates the fire study site, with W=Wheeler, S=Sugarloaf, and P=Peterson.

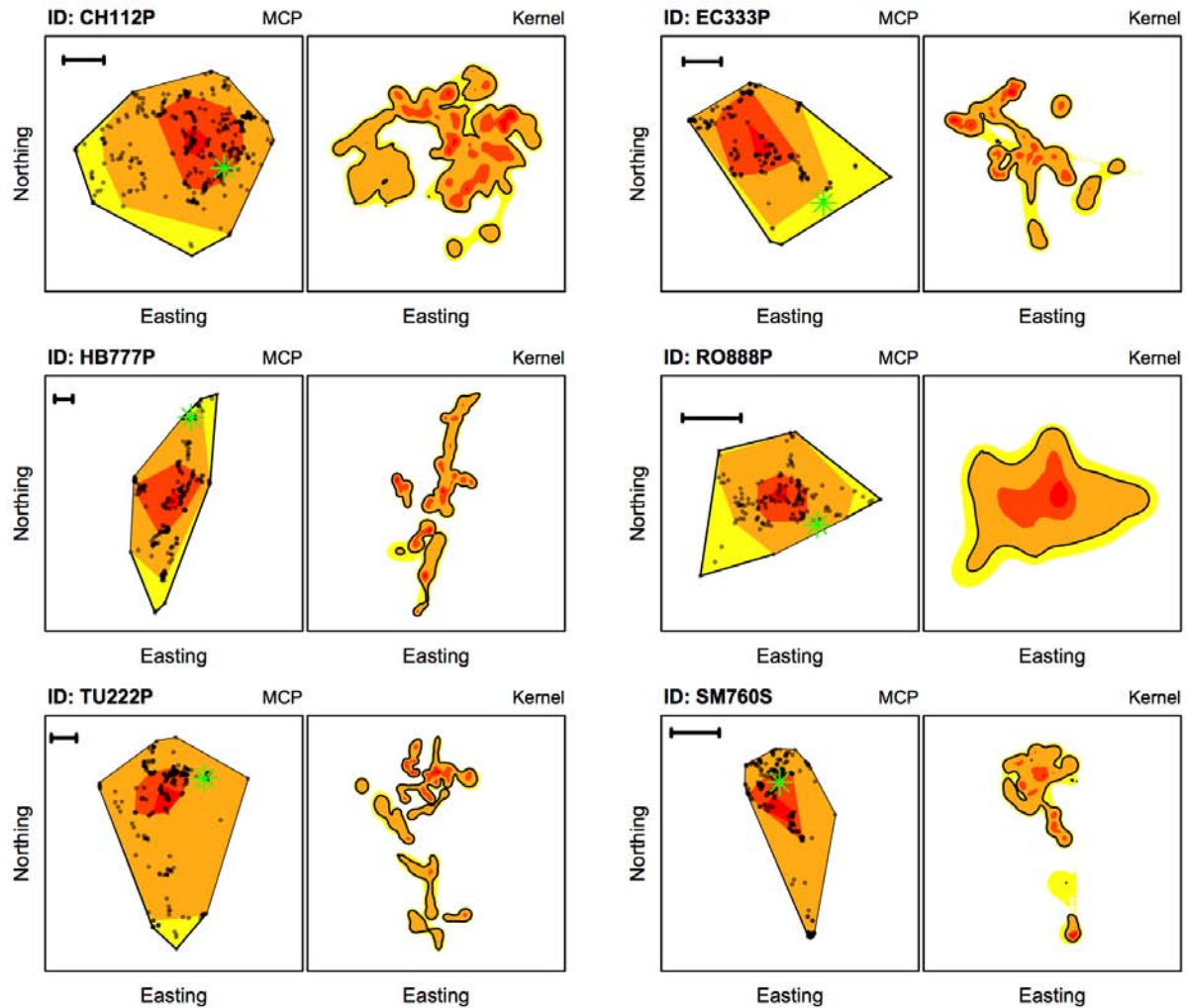


Figure 17. Maps of home range size for robustly-tracked birds at the Peterson and Sugarloaf fires as estimated by MCP and Brownian bridge kernels. Color scale increases from large percentile home range to small percentile home range, specifically from 100th or 99th (yellow), through 95th (orange), 50th (light red), and 10th (dark red). Black outlines are drawn around recommended home range percentiles: 100% for MCP and 95% for kernel. MCP panels additionally show relocation points (circles) and the nest sites (green asterisks). Scales bars represent 500 m increments. For each ID code, the suffix letter indicates the fire study site, with W=Wheeler, S=Sugarloaf, and P=Peterson.

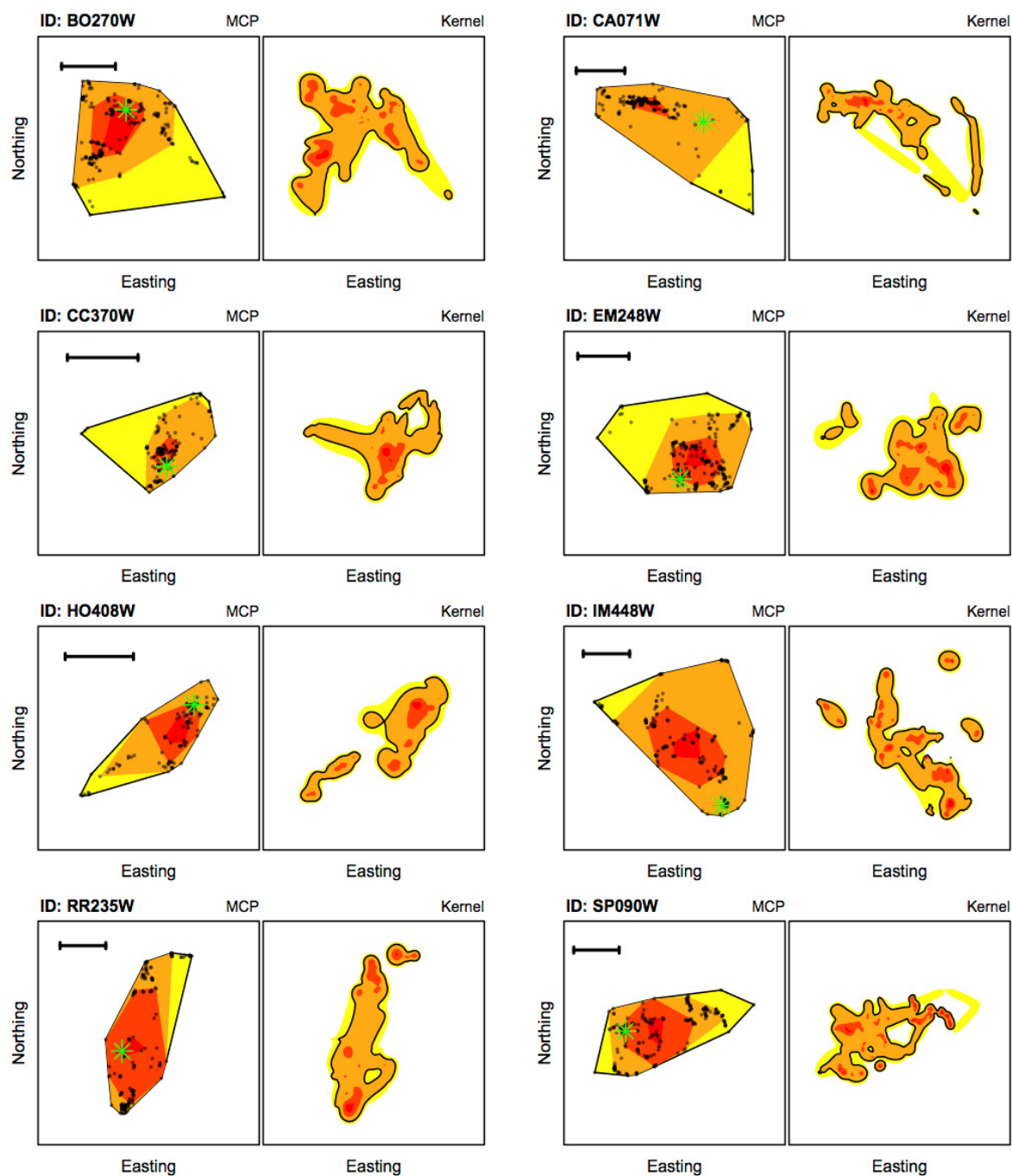


Figure 18. Maps of home range size for robustly-tracked birds at the Wheeler fire as estimated by two methods. Color ramp and symbology are the same as Figure 17.

Using both estimators (MCP and Brownian bridge kernel), home range size was calculated across a range of percentiles for each of the 14 robustly-tracked Black-backed Woodpeckers (Table 2). As expected, MCPs gave larger estimates of home range size (100% HR range 33 – 796 ha) while kernels gave more conservative home range sizes (95% HR range 24 – 313 ha), particularly at the upper end. Independent of estimation method, there was a wide range in home range sizes, with three birds (CH112P, HB777P, and TU222P) exhibiting home ranges 2-3 times greater than the overall mean and approximately an order of magnitude greater than the smallest home ranges we estimated. Home range estimates were not significantly related to the total number of relocation points used for each individual ($\rho = 0.46$, $p = 0.10$), although the correlation was marginal.

Table 2. Home range size estimates (ha) for each of 14 Black-backed Woodpeckers based on two estimation methods.

| Fire | Bird ID | MCP Area (ha) ^a | | | | Kernel Area (ha) ^a | | | | n ^b |
|----------------------------|---------|----------------------------|------------|--------------|--------------|-------------------------------|------------|-------------|--------------|----------------|
| | | 10% | 50% | 95% | 100% | 10% | 50% | 95% | 99% | |
| Peterson | CH112P | 7 | 87 | 301 | 367 | 3 | 42 | 215 | 292 | 366 |
| Peterson | EC333P | 7 | 76 | 204 | 300 | 1 | 18 | 106 | 163 | 197 |
| Peterson | HB777P | 14 | 210 | 638 | 796 | 4 | 55 | 313 | 457 | 219 |
| Peterson | RO888P | 2 | 15 | 79 | 109 | 3 | 23 | 103 | 147 | 145 |
| Peterson | TU222P | 19 | 73 | 690 | 729 | 2 | 21 | 179 | 272 | 238 |
| Sugarloaf | SM760S | 5 | 22 | 102 | 102 | 0.3 | 6 | 41 | 67 | 262 |
| Wheeler | BO270W | 8 | 21 | 68 | 121 | 1 | 11 | 66 | 97 | 228 |
| Wheeler | CA071W | 1 | 4 | 92 | 122 | 0.2 | 4 | 44 | 81 | 185 |
| Wheeler | CC370W | 0.1 | 2 | 19 | 36 | 0.3 | 3 | 24 | 35 | 144 |
| Wheeler | EM248W | 3 | 18 | 61 | 107 | 1 | 11 | 57 | 85 | 261 |
| Wheeler | HO408W | 2 | 10 | 28 | 33 | 0.3 | 4 | 24 | 36 | 123 |
| Wheeler | IM448W | 6 | 44 | 156 | 167 | 1 | 11 | 67 | 94 | 169 |
| Wheeler | RR235W | 3 | 57 | 81 | 93 | 1 | 10 | 68 | 92 | 181 |
| Wheeler | SP090W | 4 | 38 | 71 | 96 | 1 | 9 | 57 | 88 | 213 |
| Peterson mean (SD) | | 10 (6) | 92 (64) | 382 (241) | 460 (262) | 3 (1) | 32 (14) | 183 (78) | 266 (111) | 233 (73) |
| Wheeler mean (SD) | | 3 (2) | 24 (19) | 72 (40) | 97 (42) | 0.5 (0.2) | 8 (3) | 51 (17) | 76 (24) | 188 (42) |
| All birds mean (SD) | | 6 (5) | 48 (52) | 185 (208) | 227 (236) | 1.2 (1.1) | 16 (15) | 97 (80) | 143 (115) | 209 (60) |

^aShaded percentiles indicate the preferred percentile for home range size used for comparison to other studies (see *Methods: Home Range Estimators*).

^bThe total number of relocation points per individual bird.

The percentage of overlap between the home range of each bird and the home ranges of all other radio-tracked birds was estimated separately for each estimation method, as the two methods have different spatial extents (Figures 17-18). Consequently, home range overlap was estimated for 100th percentile MCPs, and 95th and 50th percentile kernels. The 50th percentile kernel was used to represent the core home range for each bird. As percentage overlap depends on the number of birds sampled, home ranges for all radio-tracked birds were used to estimate overlap, although overlap for only the “robustly-tracked” birds are shown in Table 3. Additionally, there were a small number of known Black-backed Woodpeckers in the study area that were not radio-tracked, so overlap estimates are minimums.

Table 3. Minimum percentage overlap in home range between each individual Black-backed Woodpecker and all other radio-tracked individuals.

| Bird ID | Fire | Kernel 50% | Kernel 95% | MCP 100% |
|-------------------------|-------------|-------------------|-------------------|-----------------|
| CH112P | Peterson | 5% | 43% | 60% |
| EC333P | Peterson | 9% | 26% | 22% |
| HB777P | Peterson | 0% | 6% | 12% |
| RO888P | Peterson | 0% | 45% | 81% |
| TU222P | Peterson | 0% | 1% | 6% |
| SM760S | Sugarloaf | 0% | 5% | 3% |
| BO270W | Wheeler | 0% | 1% | 7% |
| CA071W | Wheeler | 0% | 0% | 0% |
| CC370W | Wheeler | 5% | 29% | 89% |
| EM248W | Wheeler | 0% | 0% | 0% |
| HO408W | Wheeler | 9% | 17% | 18% |
| IM448W | Wheeler | 2% | 11% | 19% |
| RR235W | Wheeler | 3% | 6% | 15% |
| SP090W | Wheeler | 0% | 0% | 0% |
| All birds median | | 0% | 6% | 13% |

Minimum percentage overlap for each bird varied considerably (Table 3), but estimates were highly dependent on metric and percentile. Core home ranges did not overlap with other tracked birds by more than 10%, with most birds showing no core range overlap. Full home ranges showed much more variability, from no overlap (EMP248W and SP090W), to almost entire overlap (RO888P and CH1112P). CH1112P overlapped with four birds in total (although CH1112P was a female and all birds with home ranges overlapping hers were males). As a whole, birds overlapped with a median of only 1 other individual bird. The difference between

kernel and MCP overlap estimates is at least partly due to kernel methods being able to detect concavities in bordering home ranges where it appears that neighboring birds may cede territory in non-convex ways (e.g., where CH112P meets EC333P, see Figures 13, 17).

Home range characteristics

Through analysis of habitat characteristics within Black-backed Woodpecker home ranges, we sought to estimate the total basal area of snags and live trees within the home ranges of each bird. Basal area estimates (converted to m^2/ha) were made for stands surrounding foraging snags and live trees identified during radio-tracking and along the grid of 1808 background points. These data provided the foundations for interpolating a constant surface of snag and live tree basal area within each of the three fire areas. Using the Spatial Analyst extension of ArcGIS 9.3 (ESRI 2011) continuous basal area surfaces were interpolated using the Inverse Distance Weighting method parameterized with the nearest 10 points and a maximum distance of 500 m to create a 50 x 50 m resolution surface (Figures 19-21).

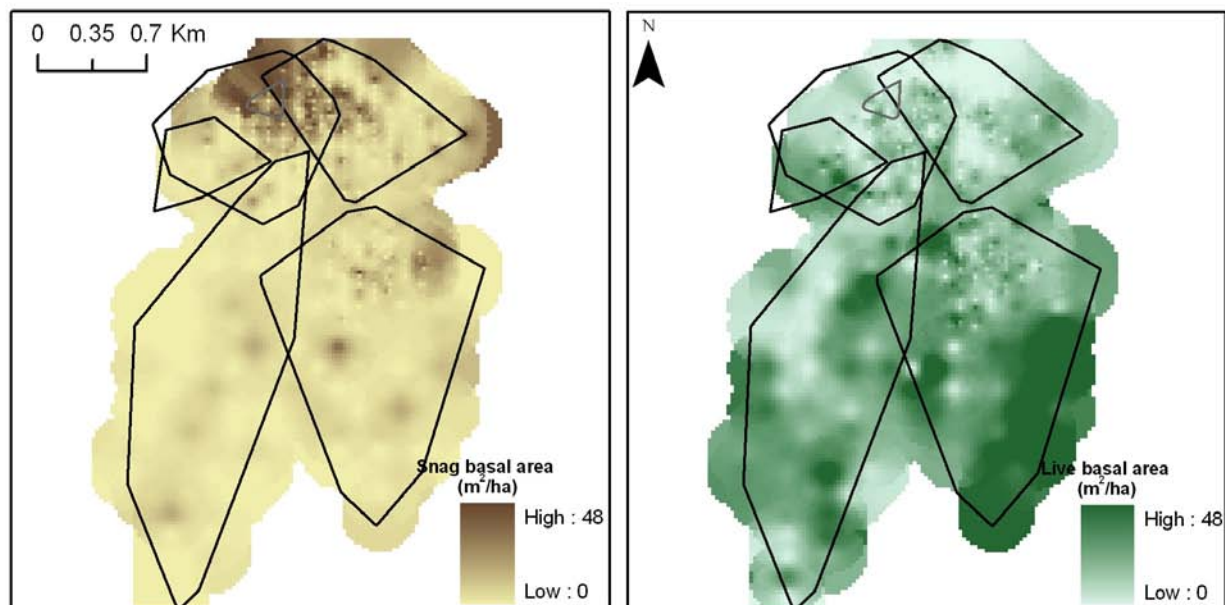


Figure 19. Interpolated basal area surfaces for snags (left) and live trees (right) for the Peterson fire. MCPs of robustly tracked Black-backed Woodpecker home range are outlined in black; home ranges considered incomplete due to insufficient sample sizes are outlined in gray.

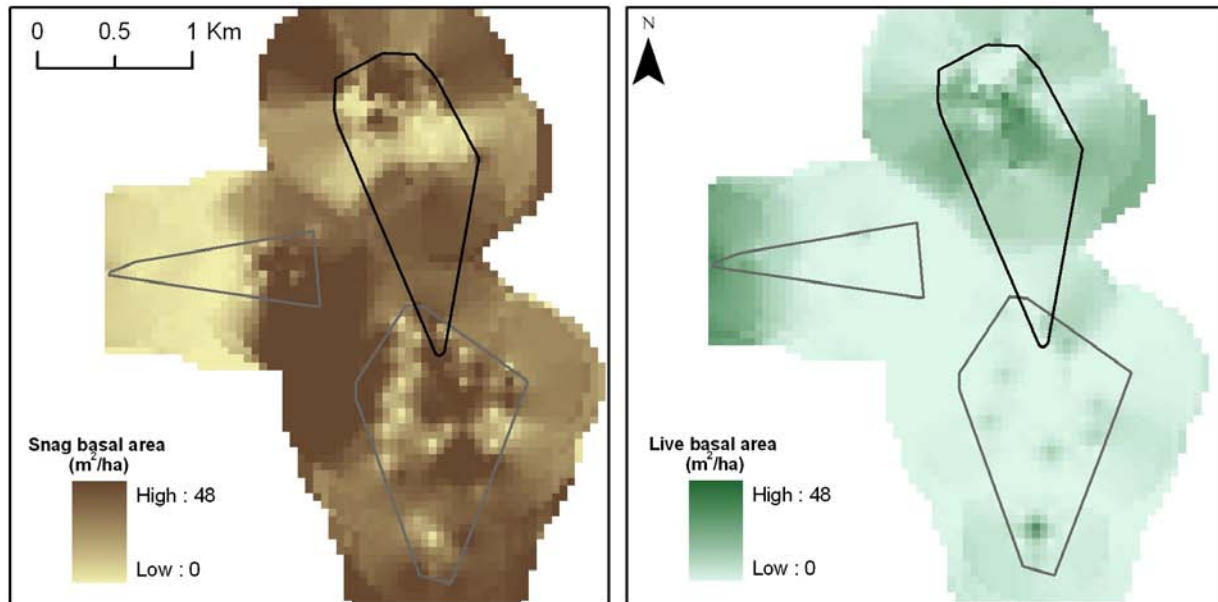


Figure 20. Interpolated basal area surfaces for snags (left) and live trees (right) for the Sugarloaf fire. MCPs of robustly tracked Black-backed Woodpecker home range are outlined in black; home ranges considered incomplete due to insufficient sample sizes are outlined in gray.

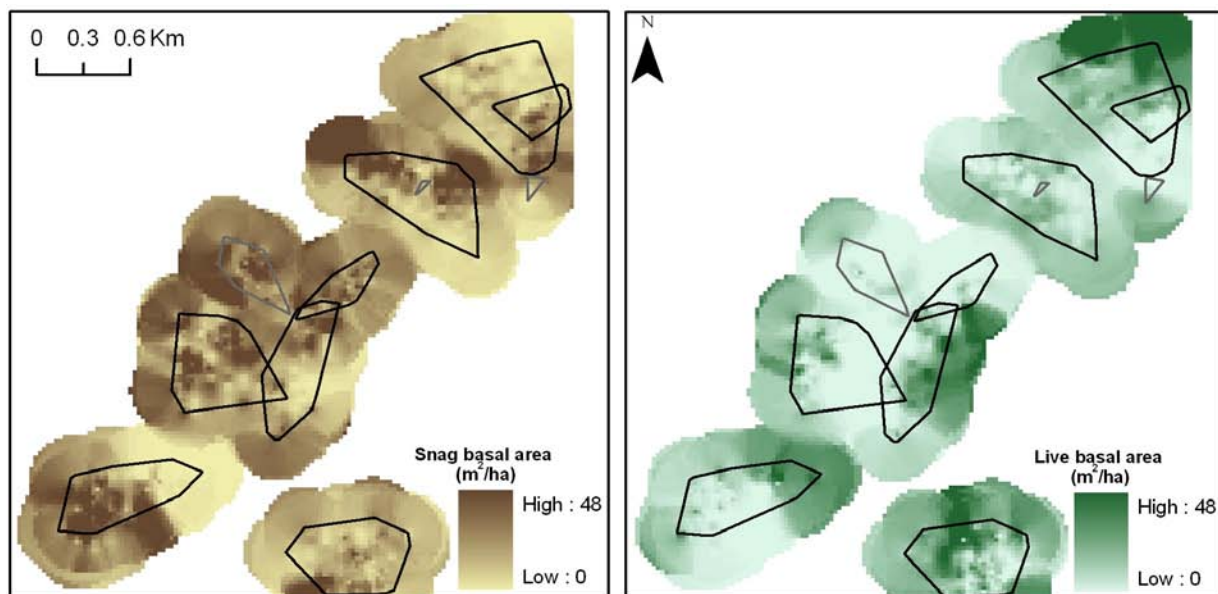


Figure 21. Interpolated basal area surfaces for snags (left) and live trees (right) for the Wheeler fire. MCPs of robustly tracked Black-backed Woodpecker home range are outlined in black; home ranges considered incomplete due to insufficient sample sizes are outlined in gray.

Table 4. Total basal area of snags and live trees within home ranges of Black-backed Woodpeckers, using the Minimum Convex Polygon (MCP) and Brownian bridge kernel estimation (Kernel) methods to delineate home ranges. A few home ranges extended slightly beyond the interpolated surfaces, though the total area outside the interpolated surface was never more than 6% of the overall home range. In such instances, total basal area was calculated as the sum of the total basal area of the interpolated surface within the home range with an estimate of basal area outside the interpolation. This estimate was the product of the mean basal area density within the home range times the number of hectares within the home range not covered by the interpolated surface.

| Fire | Bird ID | MCP 100% | | Kernel 95% | | Kernel 50% | | Avg Ratio Snag:Live ^a |
|-------------|---------|-------------------------|------------------------------|-------------------------|------------------------------|-------------------------|------------------------------|-------------------------------------|
| | | Snag basal area (m2) | Live tree basal area (m2) | Snag basal area (m2) | Live tree basal area (m2) | Snag basal area (m2) | Live tree basal area (m2) | |
| Peterson | CH112P | 5548 | 5468 | 3955 | 2978 | 1000 | 604 | 1.3 |
| Peterson | EC333P | 4012 | 3733 | 2313 | 1278 | 532 | 168 | 2.0 |
| Peterson | HB777P | 2076 | 20,088 | 1057 | 8880 | 216 | 1498 | 0.1 |
| Peterson | RO888P | 494 | 2453 | 435 | 2415 | 70 | 605 | 0.2 |
| Peterson | TU222P | 3534 | 27,964 | 990 | 6027 | 195 | 563 | 0.2 |
| Sugarloaf | SM760S | 2970 | 1409 | 1331 | 566 | 221 | 65 | 2.6 |
| Wheeler | BO270W | 3223 | 820 | 2094 | 620 | 422 | 122 | 3.6 |
| Wheeler | CA071W | 2861 | 1308 | 1317 | 383 | 175 | 15 | 5.7 |
| Wheeler | CC370W | 625 | 491 | 491 | 261 | 114 | 0 | 1.3 ^b |
| Wheeler | EM248W | 1753 | 2781 | 1131 | 1058 | 254 | 161 | 1.1 |
| Wheeler | HO408W | 955 | 167 | 676 | 157 | 115 | 22 | 5.1 |
| Wheeler | IM448W | 2255 | 3114 | 1173 | 1060 | 264 | 157 | 1.2 |
| Wheeler | RR235W | 1844 | 1577 | 1368 | 876 | 277 | 106 | 1.8 |
| Wheeler | SP090W | 2609 | 1310 | 2003 | 456 | 314 | 85 | 3.4 |
| Mean | | 2483 | 5192 | 1452 | 1930 | 298 | 298 | 2.1 |
| Min | | 625 | 167 | 435 | 157 | 70 | 0 | 0.1 |
| Max | | 5548 | 27,964 | 3955 | 8880 | 1000 | 1498 | 5.7 |

^a The average (across the three home range metrics) ratio of total mean snag basal area to live tree basal area. Numbers greater than 1 indicate relatively more snags than live trees within the home range.

^b Only Kernel 95% and MCP 100% were averaged due to an approximately 0 denominator for Kernel 50%.

Interpolated surfaces were subsequently used to estimate the total basal area and mean basal area density within the home range of each bird. As interpolated surfaces did not fully cover the full home ranges of every bird (Figure 19), estimation of total basal area consisted of an exact component (calculation of total basal area within the portion of the range covered by basal area surfaces) and an estimated component (extrapolation of total basal area within the portion of the range not covered by basal area surfaces). This estimation was only needed for three birds in the Peterson fire (CH112P, RO888P, TU222P). Mean snag basal areas of individual 95% kernel home ranges varied between 3.4 and 35.1 m²/ha (median = 21.5 m²/ha) while mean live tree basal areas varied between 1.8 and 33.7 m²/ha (median = 10.2 m²/ha). With the exception of three Peterson Fire birds (HB777P, RO888P, TU222P), all birds had mean snag basal areas above 17 m²/ha and mean live tree basal areas below 20 m²/ha. Within home ranges, total basal area estimates varied by home range estimator and percentile (Table 4) but 95% kernel home ranges had a maximum of 3,955 m² of snags (CH112P) and a minimum of 435 m² of snags (RO888P).

As total basal area is likely to be proportional to the area within a home range, other metrics were used to explore the relative density of snags versus live trees within home ranges. The average ratio of total snag basal area to total live tree basal area was greater than 1 (indicating relatively more snags than live trees) for 11 of the 14 birds (Table 4). This ratio reached a maximum of 5.7:1 for CA071W, which occupied a particularly high-severity portion of the Wheeler fire. The three birds with ratios less than one (HB777P, RO888P, TU222P) were the same three birds in the Peterson fire which foraged extensively outside the fire perimeter and two of which had substantially larger home ranges than other tracked birds (Table 2).

Also of interest was the relationship between average basal area density of snags and live trees within a home range and total home range size (Figure 22). We found there to be a strong negative relationship between average snag basal area density and home range size (GLM repeated for each HR estimator), and a positive relationship between average live tree basal area density and home range size.

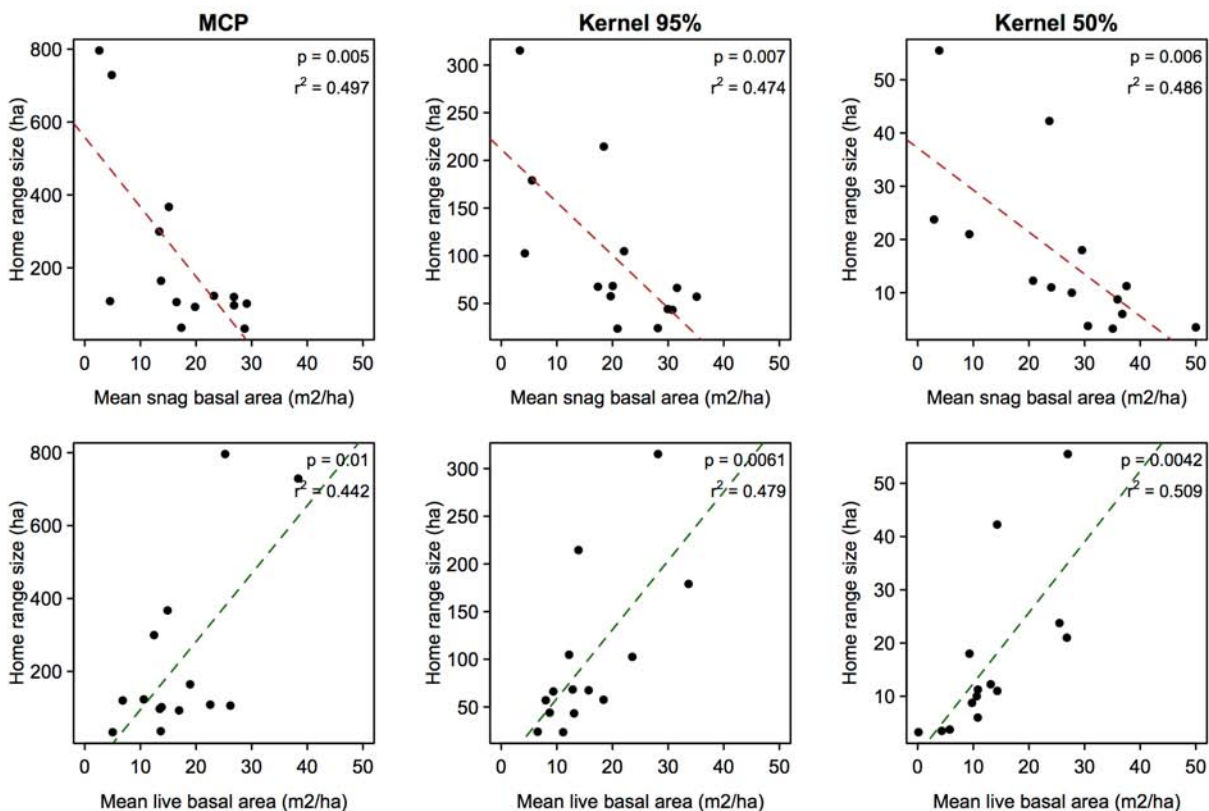


Figure 22. Relationship between snag (top) and live (bottom) mean basal area and home range size for each of three home range estimations for 14 birds. P-values and r^2 from linear regressions are presented within each plot.

Foraging habitat selection

We assessed foraging habitat usage at three spatial scales: 50-m grid cells of overall forest structure; detailed 10-m vegetation plots; and individual foraging trees. For the 50-m analysis, 95th percentile kernel UD with 50-m resolution were clipped to the extent of each individual bird's MCP, resulting in a defined surface within each home range composed of areas of use (high percentile) and relative disuse (low percentile). Usage percentiles were then related statistically to several background habitat layers for each individual bird: (1) burn severity, as measured by change in percent canopy cover based on the satellite-derived, relativized difference normalized burn ratio score (Miller et al. 2009) summarized at 90-m² resolution by averaging 30-m² coverages provided by the USDA Forest Service (J. D. Miller, pers. comm.); (2) pre-fire % tree canopy cover calculated by averaging midpoints of mean % tree cover within 100-m buffers around survey points, as derived from California Multi-source Land Cover Data (100-m

resolution; http://frap.cdf.ca.gov/data/frapgisdata/download.asp?rec=fveg02_2); (3) whether a grid cell was within the defined fire perimeter; (4) status of post-fire snag removal at survey sites, derived by the presence within each grid cell of accomplished post-fire snag removal operations (codes 4113, 4114, 4230 and 4231, verified by J. Sherlock, USDA Forest Service, in the Forest Activity Tracking System [FACTS] database, <http://www.fs.fed.us/r5/rsi/clearinghouse/gis-download.shtml>), and (5) the distance from the center of a grid cell to the nest tree. All continuous variables were standardized to a mean of 0 and standard deviation of 1 prior to analysis. Relationships between used areas and unused areas were assessed individually for each bird as well as pooled together in a GLMM with individual bird as a random effect.

Results of the 50-m grid-based analysis of habitat use indicate that while there is individual-to-individual heterogeneity, when analyzed altogether in a group model, there are strong relationships defining broad patterns of intra-home range habitat usage (Table 5). Increasing burn severity was related to increased usage in the group model and was significant for eight individuals. No birds showed significant declines in usage with increased burn severity. Interestingly, pre-fire canopy cover was significantly related to usage for many individual birds but showed differing directions of the relationship. Four birds showed increased usage in areas of greater pre-fire canopy cover, and seven birds showed increased usage in areas of less pre-fire canopy cover. In the group model, usage was positively related to greater pre-fire canopy cover, although the effect size was very small (Table 5). The variability in this result is likely related to differences in how burn severity and forest type interact with pre-fire canopy cover to produce different post-fire forest structures. Distance from nest was also strongly related to usage, with higher usage being significantly closer to nest trees for 10 birds. Only one bird (EC333P) showed significantly higher usage farther away from the nest tree. Of the final two categorical variables, only snag removal showed strong consistent responses across both individuals and the group model. Usage was negatively related to the portions of home ranges where post-fire snag removal had occurred for 6 birds and in the group model. Fire perimeter could not be evaluated for seven birds as those birds foraged entirely within (or, in the case of TU222P, outside) the fire perimeter. In the group model, usage was higher within fire perimeters. Comparing the two

variables, the effect size of snag removal was three times larger than fire perimeter, indicating a proportionately larger effect of snag removal on intra-range foraging usage.

Table 5. Linear model results for analysis of general patterns of area usage versus non-usage within home ranges for all robustly tracked birds, calculated individually and grouped for all birds. Parameter values in bold indicate parameters with Wald scores having P-values < 0.05. 'NA' values indicate that the model could not be tested for that variable (i.e., all sampling points were within the fire perimeter).

| Fire | Bird ID | Intercept | Dist. to nest | Pre-fire canopy cover | Burn severity | Inside snag removal area | Inside fire perimeter |
|--------------------|---------|--------------|---------------|-----------------------|---------------|--------------------------|-----------------------|
| Peterson | CH112P | -0.31 | -0.18 | 0.16 | -0.01 | -0.74 | 0.48 |
| Peterson | EC333P | -0.22 | 0.21 | -0.02 | 0.21 | -0.82 | 0.36 |
| Peterson | HB777P | 0.01 | -0.19 | -0.11 | 0.00 | -0.54 | -0.01 |
| Peterson | RO888P | 0.15 | -0.43 | 0.08 | -0.03 | -0.12 | -0.31 |
| Peterson | TU222P | 0.00 | -0.26 | 0.21 | 0.11 | 0.14 | NA |
| Sugarloaf | SM760S | 0.04 | -0.39 | -0.15 | 0.19 | -0.47 | NA |
| Wheeler | BO270W | 0.08 | -0.41 | -0.12 | -0.02 | -0.33 | NA |
| Wheeler | CA071W | -0.04 | -0.01 | 0.47 | 0.15 | 0.09 | NA |
| Wheeler | CC370W | 0.35 | -0.73 | -0.38 | 0.31 | -0.24 | -0.37 |
| Wheeler | EM248W | -0.17 | -0.32 | -0.17 | 0.32 | 0.06 | 0.15 |
| Wheeler | HO408W | 0.05 | -0.20 | 0.02 | 0.24 | -0.27 | NA |
| Wheeler | IM448W | -0.01 | 0.00 | -0.03 | 0.08 | -0.34 | 0.10 |
| Wheeler | RR235W | -0.04 | -0.05 | -0.19 | 0.15 | 0.20 | NA |
| Wheeler | SP090W | -0.05 | -0.45 | -0.15 | -0.10 | 0.21 | NA |
| Group Model (GLMM) | | -0.16 | -0.18 | 0.02 | 0.11 | -0.25 | 0.09 |

The second analysis of intra-home range usage was conducted at the scale of 10-m radius vegetation plots. These plots were taken at individual woodpecker foraging locations observed during radio-tracking and at background grid points (see *Methods: Data Collection*). We tested for a relationship between the vegetation characteristics of the 10-m radius areas around snags and trees used by Black-backed Woodpeckers for foraging and background points within each individual bird's home range. These characteristics were: (1) the total length (m) of logs >10 cm thick present; (2) the number of live trees > 10 cm dbh present; (3) the number of tree stumps present (indicating tree removal, either post-fire or pre-fire); and (4-6) the number of snags within each of three size classes (10-30 cm dbh, 31-60 cm dbh, and >60 cm dbh). This analysis was only conducted on 12 of the 14 birds with home range estimates, because 10-m plot

vegetation data were not collected at foraging locations of individual birds HB777P and RO888P. Birds were tested individually using logistic regression (1 = vegetation at foraging location; 0 = vegetation at background point), and collectively using a binomially-distributed GLMM.

Table 6. Means (and 95% quantiles) of 10-m plot characteristics of plots where Black-backed Woodpeckers foraged versus background plots, for 12 birds.

| Variable | Foraged plots | Background plots | P-value ^a | n ^b |
|------------------------------|----------------|------------------|----------------------|----------------|
| Log count (>10 cm) | 18.96 (0 - 58) | 8.72 (0 - 42.93) | <0.001 | 2279, 1204 |
| Live tree count (>10 cm) | 4.33 (0 - 22) | 4.05 (0 - 21) | 0.015 | 2269, 1205 |
| Stump count | 1.16 (0 - 12) | 1.72 (0 - 17.9) | 0.069 | 2287, 1205 |
| Small snag count (10-30 cm) | 10.24 (0 - 35) | 3.07 (0 - 19) | <0.001 | 2286, 1204 |
| Medium snag count (31-60 cm) | 2.44 (0 - 8) | 0.56 (0 - 5) | <0.001 | 2282, 1205 |
| Large snag count (>60 cm) | 0.2 (0 - 2) | 0.03 (0 - 0) | <0.001 | 2282, 1204 |

^a P-values are the result of Mann-Whitney U tests for differences in two distributions.

^b Samples sizes for foraged plots followed by background plots.

All individual variables showed strong and significantly different mean values between foraged plots and background plots, when pooled across all 12 birds (Table 6). These significant differences were additionally supported in our multivariate analysis (Table 7). While not all individuals showed significant relationships for every variable, effect signs for significant individual effects were mostly consistent across individuals and the group model, indicating that nearly all birds were responding to available habitat in approximately the same way. In observed significant effects, there appeared a fundamental background relationship between the probability of foraging and the overall density of woody material, whether live trees, logs, or snags. This is evidenced by the results of the group model, where all vegetation-based variables (excluding stumps) show positive effects. However, the strength of the effect size (indicated by the parameter value) varied among vegetation types (Figure 23). In the group model, ordered in decreasing importance to the probability of an area being used for foraging, were: large snags, medium snags, small snags, live trees, and logs. Comparing effect sizes can lead to interesting insights: the addition of a single live tree increases the odds of foraging by 8%, while the addition of a single small (<30 cm) snag increases the odds of foraging by 11%, and the addition of a medium or large snag increases the odds of foraging by 46 and 81%, respectively (Figure 23).

Table 7. Logistic model results for analysis of 10-m plot area around trees used for foraging versus systematically arrayed 10-m plots within the home range. Results are shown for each tracked bird individually and for the group model (GLMM) using individuals as a random effect. Response variable was whether or not an individual was observed foraging within a 10-m plot area within its home range. Parameter values in bold indicate parameters with Wald scores holding P-values < 0.05.

| Bird ID | Intercept | Logs >10 cm | Live trees >10 cm | Stumps | Snags 10- 30 cm | Snags 31- 60 cm | Snags >60 cm |
|----------------|--------------|----------------|----------------------|--------------|--------------------|--------------------|-----------------|
| CH112P | -2.44 | 0.04 | 0.11 | -0.41 | 0.11 | 0.40 | 2.69 |
| EC333P | -2.59 | 0.03 | 0.05 | -0.14 | 0.13 | 0.75 | -0.59 |
| TU222P | -2.24 | 0.02 | 0.07 | -0.03 | 0.18 | 1.18 | 1.53 |
| SM760S | -1.11 | -0.02 | 0.20 | -0.18 | 0.14 | 0.26 | 2.41 |
| BO270W | -0.65 | 0.01 | 0.28 | -0.14 | 0.12 | 0.31 | 0.64 |
| CA071W | -1.60 | 0.03 | 0.16 | 0.07 | 0.03 | 0.44 | 0.63 |
| CC370W | -2.18 | 0.03 | 0.12 | 0.27 | 0.19 | 0.82 | 16.94 |
| EM248W | 0.07 | -0.01 | -0.03 | 0.29 | 0.15 | 0.75 | -0.21 |
| HO408W | 0.46 | 0.04 | 0.01 | -0.10 | 0.00 | 0.12 | 0.07 |
| IM448W | -2.24 | -0.01 | 0.16 | -0.04 | 0.25 | 0.77 | 2.06 |
| RR235W | -1.22 | 0.01 | 0.06 | 0.08 | 0.19 | 0.60 | 14.72 |
| SP090W | 0.40 | 0.00 | 0.06 | 0.03 | 0.02 | 0.19 | 0.27 |
| Group Model | -1.14 | 0.01 | 0.08 | 0.01 | 0.11 | 0.46 | 0.81 |

In the analysis of the 10-m plots areas (Table 7), stumps had a significant negative effect on foraging probability for two individuals and a significant positive effect for two individuals. In the group model the effect was not significant.

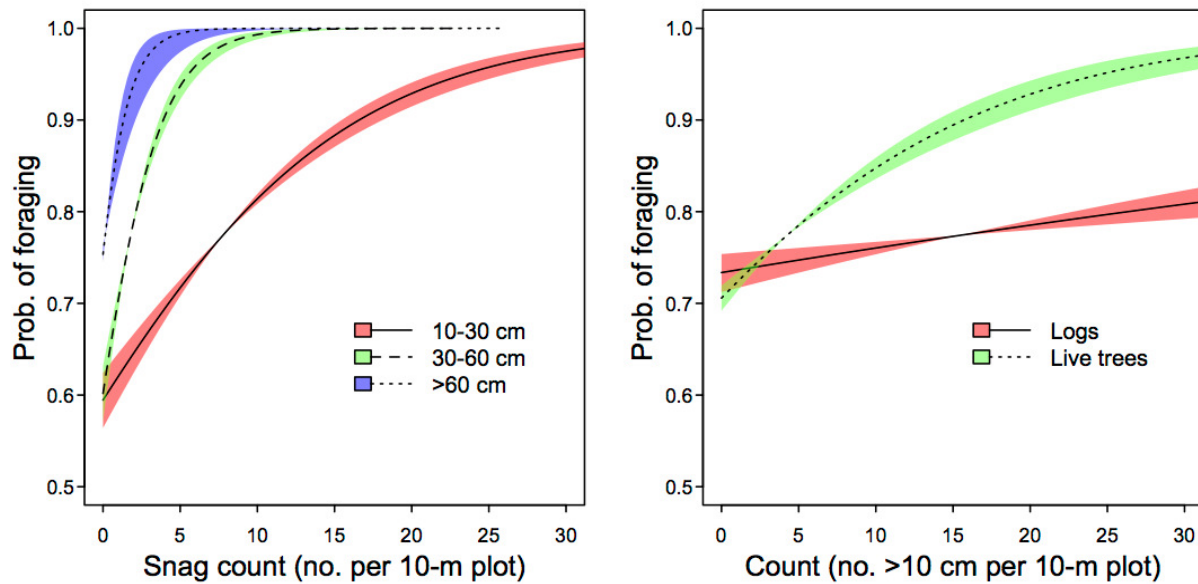


Figure 23. Relationship between 10-m plot vegetation variables and the probability of Black-backed Woodpecker foraging in a plot. All relationships are derived from a group model (GLMM) analysis on all individuals combined. Colored plot widths indicate 95% confidence intervals.

The final analysis of foraging habitat selection assessed the characteristics of individual snags and trees that were used for foraging versus the nearest snags and trees to background “non-use” grid plots (see *Methods: Data Collection*). Based on preliminary data exploration, we specifically tested 9 potential response variables relating to tree foraging usage: (1) whether or not the tree was a snag (compared to live trees or, rarely, logs or stumps); (2) tree DBH; (3) the number of wood-boring beetle holes in the bottom 1 m of the bole, log-transformed; (4) whether the tree had less than 50% of its bark intact; (5) whether the crown of the tree was intact; (6) whether the percent of tree scorching was greater than 90%; (7) whether the tree was a California Black Oak (*Quercus kelloggii*); (8) whether the tree was in the Yellow Pine assemblage (*Pinus ponderosa* or *P. jeffreyi*); and (9) distance from tree to nesting location. Foraging tree usage characteristics were tested for each individual woodpecker and for all woodpeckers in a group model with a binomial-distributed GLMM.

Table 8. Means (and 95% quantiles) of variables describing the trees where Black-backed Woodpeckers foraged versus background available trees.

| Variable | Foraged trees | Background trees | P-value ^a | n ^b |
|----------------------------|-----------------|-------------------|----------------------|----------------|
| % of snags | 80 | 50 | <0.001 | 2288, 3072 |
| DBH (cm) | 36.17 (12 - 80) | 27.13 (1 - 73.45) | <0.001 | 2270, 2903 |
| Tree height (m) | 13.74 (2 - 32) | 10.63 (1.5 - 31) | <0.001 | 2269, 2887 |
| No. Borer Holes | 7.19 (0 - 41) | 3.48 (0 - 24) | <0.001 | 2270, 2906 |
| % with <50% bark remaining | 1 | 5 | <0.001 | 2288, 3072 |
| % with >90% scorching | 42 | 14 | <0.001 | 2288, 3072 |
| % of black oaks | 0 | 8 | <0.001 | 2288, 3072 |
| % of yellow pines | 57 | 53 | 0.013 | 2288, 3072 |
| Distance from nest (m) | 536 (20 - 1743) | 720 (106 - 1810) | <0.001 | 2288, 3072 |

^a P-values are the result of Fisher's Exact Tests (for proportions) or Mann-Whitney U tests (for 2 distributions).

^b Samples sizes for foraged trees followed by background trees.

Results of the analysis of foraging tree characteristics showed significant relationships for all variables individually (Table 8), with 8 of 9 variables significant in the multivariable model (Table 9). Based on the group model, we found the following results. Black-backed Woodpeckers were more likely to forage on snags than live trees and foraging probability was positively related to the size of the tree (Figure 24). Foraging was also more likely if the tree had greater numbers of wood boring beetle holes and was closer to the nest tree. Foraging probability was further positively related to two indicators of snag condition: trees with more bark intact, and trees that were more extensively scorched. This indicates that Black-backed Woodpeckers select trees subject to high burn severity but which have not yet substantially decomposed. Whether tree crowns were intact was positively related for some individuals (notably, all birds within the Peterson fire), but this factor was not significant in the group model. Finally, we found tree species matters, as Black-backed Woodpeckers preferentially selected *P. ponderosa* and *P. jeffreyi* over other tree species including other conifer species, and actively avoided *Q. kelloggii* where it occurred.

Table 9. Logistic model results testing the probability of a snag or tree being used for foraging within the home range of Black-backed Woodpeckers. Results are shown for individuals and for all birds (grouped).

| Bird ID ^a | Interc. | Snag: yes | DBH | Log ₁₀ Borer holes | Bark: <50% | Crown: intact | Scorch: >90% | Black Oak: yes | Yellow Pine: yes | Distance from nest |
|----------------------|--------------|--------------|-------------|-------------------------------------|---------------|------------------|-----------------|----------------------|------------------------|--------------------------|
| BO270W | 0.39 | 0.48 | 0.38 | 0.53 | -0.74 | -0.47 | 0.35 | NA | -1.88 | -1.19 |
| CA071W | 0.75 | 0.82 | 0.79 | 0.31 | -2.47 | -2.25 | 0.39 | NA | -0.12 | 1.51 |
| CC370W | -1.15 | 0.56 | 1.19 | 0.24 | 13.23 | 0.29 | 0.93 | NA | -0.48 | -0.97 |
| CH112P | -9.49 | 2.59 | 0.97 | 0.17 | -1.23 | 2.97 | -1.07 | NA | 4.32 | -1.15 |
| EC333P | -8.19 | 2.60 | 1.11 | 0.63 | -1.70 | 3.44 | 0.26 | -1.39 | 2.11 | 0.40 |
| EM248W | -1.87 | 1.45 | 0.50 | 0.90 | -1.53 | -0.96 | 0.44 | NA | 1.73 | -0.82 |
| HO408W | 0.73 | -0.60 | -0.21 | 0.54 | -0.32 | 0.10 | 1.35 | NA | -0.75 | -0.54 |
| IM448W | -1.71 | 0.41 | 0.69 | 0.36 | -0.89 | 0.97 | 1.56 | NA | -1.04 | -0.05 |
| RR235W | -0.42 | 1.49 | 0.98 | 0.32 | -2.98 | 0.22 | 1.08 | NA | -1.75 | 0.20 |
| SM760S | -3.79 | 1.85 | 0.32 | 0.42 | 0.68 | 2.90 | 0.27 | -0.53 | 1.54 | 0.12 |
| SP090W | -0.78 | 0.02 | 0.56 | 0.88 | -2.84 | 0.19 | 1.14 | 1.60 | 0.62 | -0.10 |
| TU222P | -6.50 | 1.33 | 0.30 | 0.17 | -1.67 | 1.72 | 0.60 | 1.82 | 3.93 | -0.78 |
| All birds | -1.25 | 1.29 | 0.59 | 0.41 | -2.21 | -0.12 | 0.80 | -2.19 | 0.32 | -0.17 |

^a Results are shown for each tracked bird individually and for all birds combined ('All') using individuals as a random effect. Parameter values in bold indicate parameters with Wald scores having P-values < 0.05. 'NA' values indicate that the model could not be tested for that variable (e.g. there were no black oaks sampled within the home range). As foraging habitat information was not sampled for two individuals (RO888P and HB777P), results are only shown for 12 of the 14 individuals that were radio-tracked. For each ID code, the suffix letter indicates the fire study site, with W=Wheeler, S=Sugarloaf, and P=Peterson.

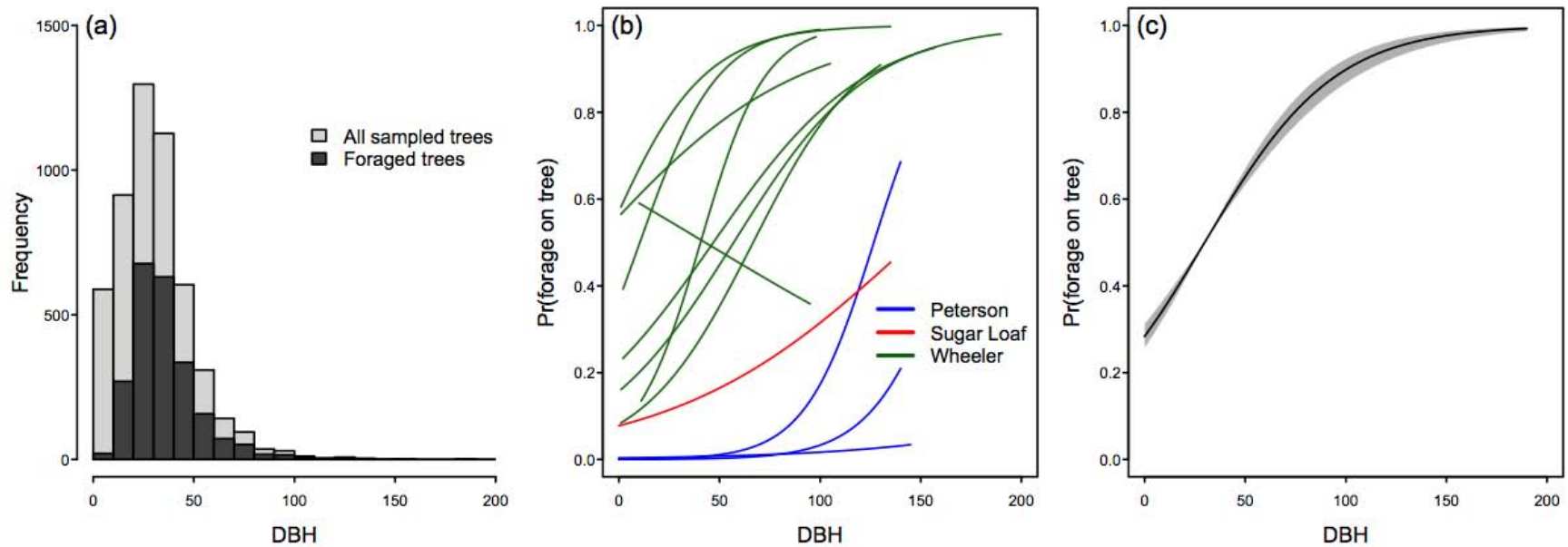


Figure 24. Relationship between snag size (DBH, expressed in cm) and the probability of use for foraging. Compared to all sampled trees within home ranges, foraged trees were larger on average (a), which resulted in generally positive and significant relationships between DBH and foraging probability in individual bird models (b). The only bird that did not follow this pattern was HO408W, which had a negative but not significant relationship. The group model (GLMM) analysis on all combined individuals showed increased probability of foraging with DBH, including a leveling-off near 100 cm DBH (c).

While there was some individuality evident across birds, individuals only showed sign-switching (i.e., a positive relationship for some individuals and a negative relationship for others) for parameter effects for the two tree species variables (i.e., yellow pine and black oak) and for distance from nest. TU222P showed a positive response to black oak, which is interesting considering this individual bird foraged almost exclusively in non-burned areas. The effect was slight, however, as only 5% of foraged-upon trees for TU222P were black oaks. In comparison, three birds within the Wheeler fire showed negative responses to yellow pine, even though the overall relationship was significantly positive. This discrepancy may have to do with the availability of different habitats and conditions across the three fires areas.

Duration of foraging on individual trees

Data were collected on the amount of time each bird spent foraging on individual trees. As specific characteristics were collected on each foraging tree, this provided an opportunity to explore the traits of individual trees that may influence the amount of foraging time, which is likely positively correlated with successfully obtaining food. This analysis was conducted on all 8 birds of the Wheeler fire and the 4 birds from the Peterson and Sugarloaf fires that had foraging habitat data, and explored the same tree traits as the tree-selection analysis (see *Results: Foraging habitat selection and usage*).

Of the ten variables tested for relationships with foraging duration, only tree size (DBH) showed consistent significant relationships in both multiple birds and the group model (Table 10). In this case, over half of the birds showed positive significant relationships with DBH (Figure 25). The group model also indicated that foraging duration was greater on snags (versus live trees or other substrates), on trees with more wood-borer holes (a potential signal of food availability), on trees with greater than 50% bark retention, and on firs.

Table 10. Model results testing the effect of 10 variables on duration spent foraging on individual trees by Black-backed Woodpeckers. Results are presented for individual birds (GLM) and for all birds combined in a group model (GLMM).

| Bird ID ^a | Inter- cept | Is Snag: Yes | DBH | Log Borer holes | Bark: <50% | Crown: Intact | Scorch: >50% | Fir: Yes | Yellow Pine: Yes | Has Needles: Yes | Dist. from nest |
|----------------------|----------------|--------------------|-------------|-----------------------|---------------|------------------|-----------------|--------------|------------------------|------------------------|-----------------------|
| BO270W | 3.41 | 0.18 | 0.13 | 0.12 | -0.23 | 0.09 | 0.16 | 0.96 | NA | 0.28 | 0.25 |
| CA071W | 4.33 | 0.35 | 0.21 | 0.13 | NA | -0.43 | -0.04 | -0.11 | 0.56 | 0.19 | 0.11 |
| CC370W | 3.06 | 0.68 | 0.00 | -0.10 | -1.05 | 0.42 | -0.50 | -0.08 | NA | -0.27 | -0.76 |
| CH112P | 3.32 | 0.43 | 0.36 | 0.16 | NA | NA | -0.79 | NA | 0.85 | -0.51 | -0.09 |
| EC333P | 3.24 | 0.20 | 0.35 | 0.10 | -0.97 | 0.73 | 0.54 | -0.71 | -0.30 | -0.24 | 0.05 |
| EM248W | 3.46 | 0.51 | 0.22 | 0.06 | -0.75 | 0.53 | -0.24 | -1.20 | NA | 0.01 | 0.12 |
| HO408W | 5.22 | -0.24 | 0.06 | 0.01 | 0.53 | -0.55 | -0.27 | 0.11 | NA | -0.44 | 0.23 |
| IM448W | 4.55 | 0.51 | 0.24 | 0.06 | -0.99 | -0.75 | 0.14 | -0.30 | NA | 0.36 | 0.01 |
| RR235W | 2.97 | 0.59 | 0.25 | 0.10 | -1.48 | -0.24 | -0.19 | 1.12 | 0.88 | 0.27 | 0.10 |
| SM760S | 2.84 | 0.17 | 0.01 | 0.17 | -1.38 | 0.82 | -0.34 | 0.06 | 0.30 | 0.01 | 0.13 |
| SP090W | 3.69 | 0.46 | 0.26 | -0.04 | NA | -0.39 | -0.19 | 0.17 | -0.17 | 0.50 | -0.16 |
| TU222P | 2.43 | 0.34 | 0.43 | 0.12 | -1.16 | 0.68 | -0.72 | NA | 0.74 | 0.10 | 0.10 |
| All birds | 3.62 | 0.42 | 0.23 | 0.06 | -0.54 | -0.07 | -0.08 | 0.39 | 0.18 | 0.06 | 0.06 |

^a Results are shown for each tracked bird individually and for all birds combined ('All birds') using individuals as a random effect. Parameter values in bold indicate parameters with Wald scores holding P-values < 0.05. 'NA' values indicate that the model could not be tested for that variable (e.g., there were no yellow pines sampled within the home range). The response parameter, foraging duration, was log-transformed prior to analysis.

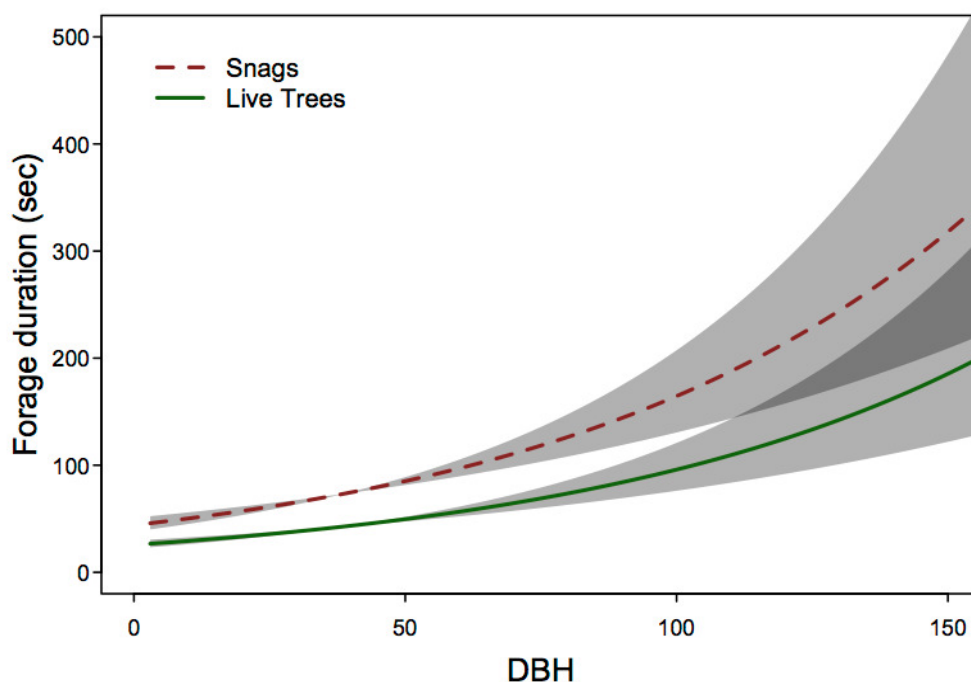


Figure 25. Relationship between tree size (DBH, expressed in cm), tree condition (live tree or snag) and foraging duration, based on data from 12 birds analyzed in a group model within a GLMM.

Foraging in unburned forest

Over the course of telemetry operations in 2011, we observed that a few birds consistently spent large portions of their time foraging outside burned areas, while the majority of birds foraged almost exclusively within burned forest (Table 11). Seven of the 14 robustly radio-tracked birds foraged outside burn perimeters at some point during tracking, although only three birds (RO888P, HB777P, and TU222P), all in the Peterson fire, did so extensively. Of these, both HB777P and TU222P were observed foraging almost exclusively in unburned forest. We further investigated the potential differences between these two foraging strategies by separately examining data from the three birds with more than 25% of observed foraging locations outside of fire perimeters.

Table 11. Extent to which individual Black-backed Woodpeckers foraged outside of burned forest during radio-tracking.

| Fire | Bird ID | n | Percent of foraging locations outside fire |
|-----------|---------|-----|--|
| Wheeler | BO270W | 229 | 0% |
| Wheeler | CA071W | 185 | 0% |
| Wheeler | EM248W | 292 | 0% |
| Wheeler | HO408W | 123 | 0% |
| Wheeler | RR235W | 182 | 0% |
| Sugarloaf | SM760S | 275 | 0% |
| Wheeler | SP090W | 219 | 0% |
| Peterson | EC333P | 201 | 1% |
| Wheeler | CC370W | 144 | 6% |
| Peterson | CH112P | 373 | 7% |
| Wheeler | IM448W | 179 | 12% |
| Peterson | RO888P | 146 | 49% |
| Peterson | HB777P | 220 | 89% |
| Sugarloaf | TU222P | 247 | 93% |

The three unburned-forest birds had noticeably larger home ranges than the burned-forest birds. This comparison was statistically significant (Table 12), and the unburned-forest birds included the two largest MCP areas (Table 2). Unburned-forest birds did not forage on a different proportion of snags versus live trees, take more or less time to forage on each tree, or select foraging trees of different DBHs in comparison with burned-forest birds. However, unburned-

forest birds foraged on trees of significantly greater height and on trees that were significantly less scorched (not surprising since these birds were primarily outside fire areas - the snags on which these birds foraged outside of the burned area were not killed by fire, but rather by other causes). Finally, unburned-forest birds traveled more than twice as far, on average, between consecutive foraging events. While burned-forest birds were able to frequently fly short distances to encounter proximal foraging trees, unburned-forest birds traveled an average of 167 m between foraging trees.

Table 12. Average differences in foraging and home range variables between unburned-forest and burned-forest foraging birds.

| Variable | Unburned-forest Birds | Burned-forest Birds | P-value | n ^a |
|--|-----------------------|---------------------|---------|----------------|
| 95% Kernel home range size (ha) | 198 (107 - 306) | 70 (24 - 188) | 0.043 | 3, 11 |
| 100% MCP home range size (ha) | 545 (140 - 793) | 140 (34 - 350) | 0.088 | 3, 11 |
| % snags | 76 | 80 | 0.180 | 156, 2143 |
| DBH (cm) | 35 (13 - 61) | 36 (12 - 80) | 0.900 | 156, 2125 |
| Tree height (m) | 15.7 (5.9 - 25) | 13.6 (1.9 - 32) | <0.001 | 154, 2126 |
| Proportion with >90% scorching | 0.03 | 0.45 | <0.001 | 156, 2125 |
| Duration of foraging (s) | 131 (6 - 973) | 131 (6 - 654) | 0.347 | 156, 2135 |
| Dist. traveled between foraging events (m) | 167 (3.4 - 787) | 74 (2 - 490) | <0.001 | 546, 2052 |

^a Samples sizes are for unburned-forest birds followed by burned-forest birds.

Nest site characteristics

We discovered a total of 21 Black-backed Woodpecker nests during field work in 2011 and 2012, including nests of all 19 radio-tracked birds, and nests of two additional pairs that were not radio-tracked. To understand the broader characteristics defining nest trees and nest sites, characteristics of all 21 nests were analyzed at three different spatial scales. In order to get a sense of background, or unused trees, within the forest stand chosen for nesting, nest trees – as well as 10- and 50-m radius plots around nest trees – were compared to background grid points that were located within 200 m of nest trees (mean = 8.6 background points per nest tree).

Table 13. Mean (and range) of woodpecker nesting site variables and comparison to nearby background plots, for habitat variables at each of three spatial scales.

| Spatial Scale | Variable | Nest sites | Background Plots^a | P-value^b | n^c |
|----------------------|--------------------------------------|--------------------|-------------------------------------|----------------------------|----------------------|
| Tree | % Snags | 100 | 57 | <0.001 | 21, 361 |
| Tree | DBH | 33 (23 - 53) | 28 (1 - 74) | 0.071 | 21, 361 |
| Tree | Height (m) | 14 (5 - 23) | 11 (2 - 30) | 0.015 | 21, 355 |
| Tree | % Bark retention>90% | 71 | 85 | 0.113 | 21, 361 |
| Tree | % Scorch>90% | 95 | 28 | <0.001 | 21, 361 |
| 10m Plot | Live tree count (>10 cm dbh) | 0.5 (0 - 3.6) | 2.1 (0 - 13.0) | 0.267 | 20, 161 |
| 10m Plot | Small snag count (10-30 cm dbh) | 13.1 (2.0 - 29.5) | 5.1 (0 - 23.0) | <0.001 | 21, 161 |
| 10m Plot | Medium snag count (31-60 cm dbh) | 4.2 (0 - 11.0) | 0.9 (0 - 5.0) | <0.001 | 21, 161 |
| 10m Plot | Large snag count (>61 cm dbh) | 0.4 (0 - 2.5) | 0.2 (0 - 2.0) | 0.020 | 21, 161 |
| 10m Plot | Log count (>10 cm) | 20.9 (1.8 - 46.0) | 10.7 (0 - 45.0) | <0.001 | 21, 161 |
| 10m Plot | Stump count | 0.6 (0 - 6.5) | 1.0 (0 - 9.0) | 0.189 | 21, 161 |
| 50m Plot | Snag basal area (m ² /ha) | 43.1 (18.4 - 85.0) | 14.4 (0 - 55.1) | <0.001 | 21, 160 |
| 50m Plot | Live basal area (m ² /ha) | 3.1 (0 - 13.8) | 8.0 (0 - 53.0) | 0.825 | 21, 160 |

^a Background plots were all background grid points (see *Methods*) within 200 m radius of nest trees.

^b P-values are the result of Fisher's Exact Tests (for frequencies) and Mann-Whitney U-tests (for distributions).

^c Samples sizes are for nest sites followed by background plots.

Based on frequency of selection versus availability, many significant factors in nest site selection are evident (Table 13). All nesting trees were snags, even though live trees were available.

Within forest stands chosen for nesting, selected nest trees were only marginally larger than available trees, but they were of intermediate size, with no nests in trees less than 23 cm DBH or greater than 53 cm DBH. Nest trees were significantly taller than background trees. Nest trees were also severely burned, with 20 of 21 nests occurring in trees with greater than 90% scorching. Nests also occurred in relatively denser stands of trees, as measured by counts of small (10-30 cm), medium (31-60 cm), and large (>61 cm dbh) snags within 10 m, logs within 10 m, and the snag basal area within 50 m.

Population age structure

In capturing birds for radio-telemetry, we were able to determine the age class of each bird, using plumage retention and replacement patterns. Woodpeckers are generally relatively long-lived birds, with longevity records for several North American species (generally those most frequently captured) reaching well beyond ten years (USGS Bird Banding Laboratory,

http://www.pwrc.usgs.gov/bbl/longevity/Longevity_main.cfm). As would be expected in a species with a relatively long lifespan, the majority of the birds captured at these fires (8 of 16 males and 4 of 6 females) were after-third year individuals (Figure 26).

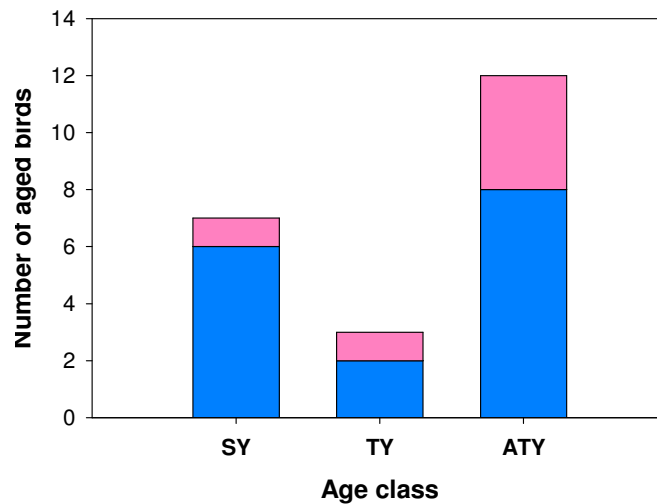


Figure 26. Age classes of adult birds captured at the Peterson (3 years post-fire), Sugarloaf (2 years post-fire) and Wheeler (5 years post-fire) fires at the time of capture in 2011 or 2012 (SY = second year, TY = third-year, ATY = after-third-year). Blue bars indicate male birds; pink bars indicate females.

Disease

Near the end of the 2011 field season, one of our radio-tagged woodpeckers on the Sugarloaf fire (SM760S), was observed behaving lethargically, after being tracked for ten weeks, during which it successfully nested and fledged young. Three days later the bird's radio transmitter led us to its carcass, which was on the ground at the base of a tree, with no obvious sign of trauma.

A necropsy at the California Animal Health and Food Safety Laboratory System at Davis, California, revealed that the bird was severely emaciated and had several nematodes in the gizzard koilin. Aside from the emaciation, significant histopathologic findings were limited to the gizzard where the surface koilin and mucosal glands were markedly disrupted by numerous sections of a nematode parasite embedded within the koilin and underlying distorted and dilated

mucosal gland lumina (Fig. 27). There also were numerous exfoliated epithelial cells and free red blood cells admixed with large bacterial colonies within the koilin (Fig. 27).

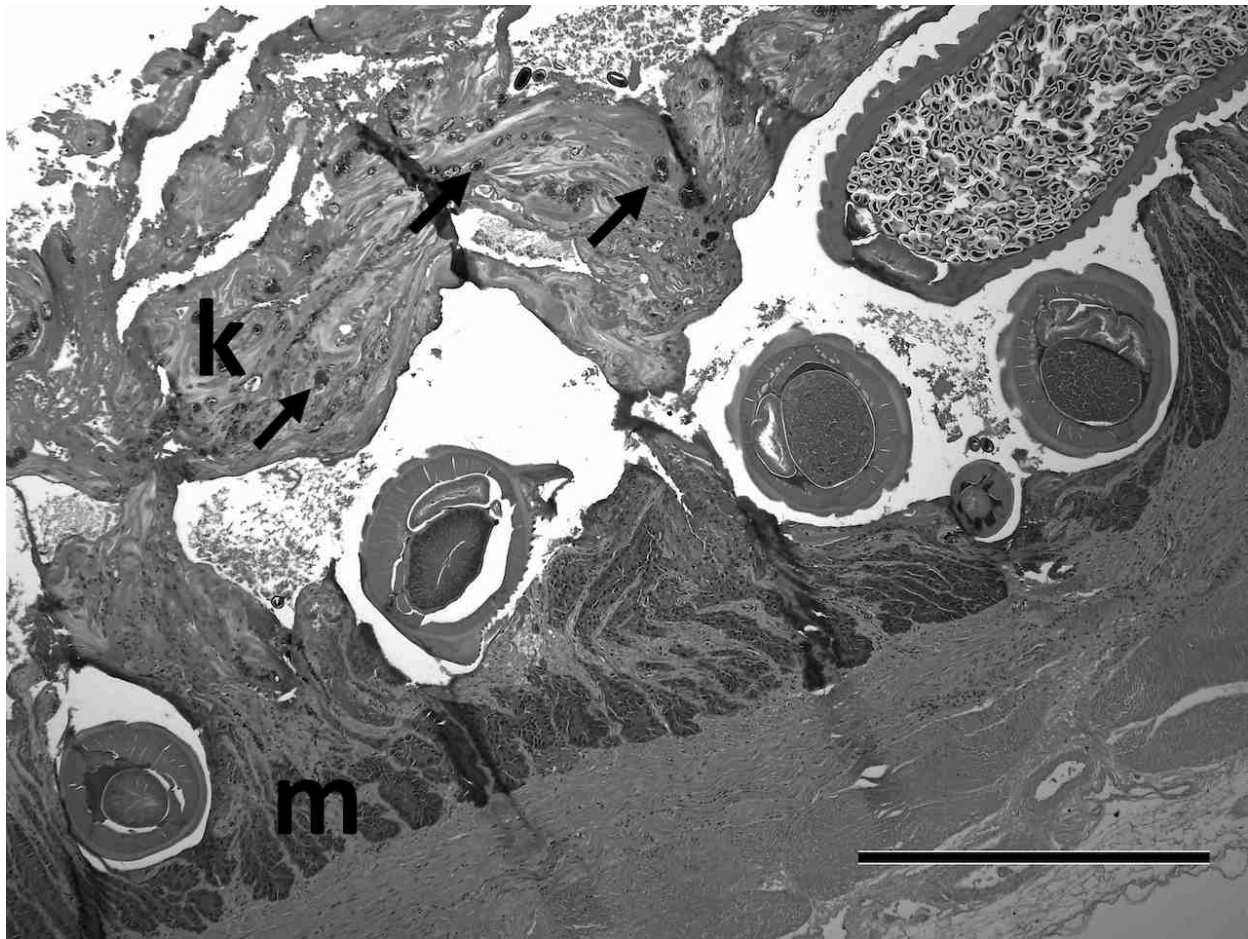


Figure 27. Low magnification photomicrograph demonstrating the high density of nematode cross sections lying within the gizzard koilin (k) or underlying mucosal (m) dilated gland lumen. There is marked splitting of the koilin which contains numerous large bacterial colonies (arrows). Mag bar = 500 microns. Hematoxylin and eosin stain.

Nematodes collected from the gizzard (Fig. 28) were identified as spiruroids of the genus *Procyrnea* (*Spiruroidea: Habronematidae*) based on the following combination of characters: two tri-lobed lips, thick-walled buccal cavity, esophagus divided into muscular and glandular portions, coiled male tail with prominent caudal alae, unequal spicules, presence of a gubernaculum, and vulva in females near midbody (Chabaud 1975). Identification to the species *Procyrnea pileata* (Walton 1928) was based primarily on the shape and size of the spicules in the males and the distance of the vulva from the anterior end in the females; the left spicule ranged in length from 1560 to 1770 μm and the right spicule from 380 to 430 μm (Pinto et al. 1996).

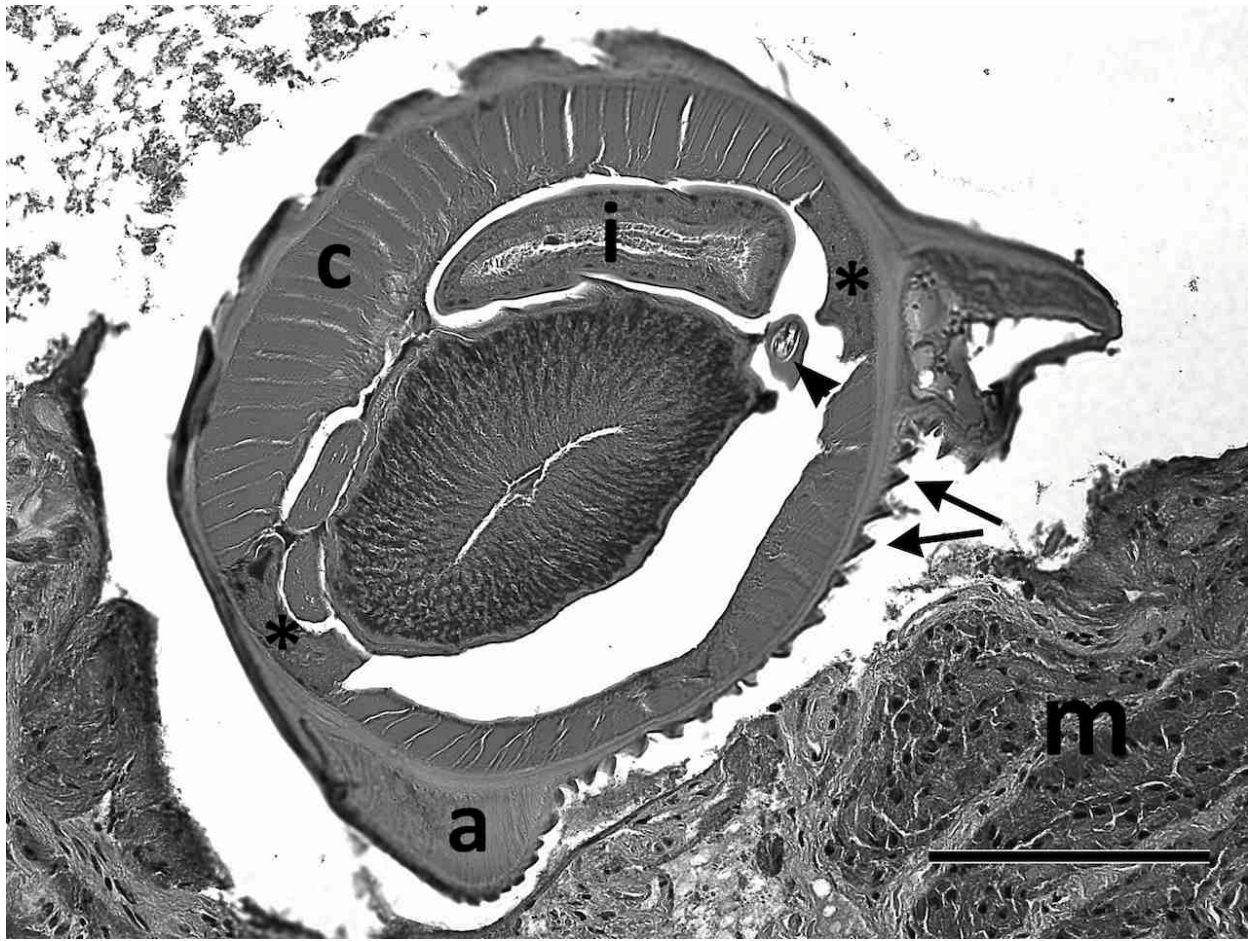


Figure 28. High magnification photomicrograph of a single cross section through the posterior end of a male spirurid nematode. There is a small spicule (arrowhead) within the pseudocoelom. The nematode has coelomyarian musculature (c) with lateral chords (*), numerous ventral ridges (arrows) along one side of the cuticle and two large projecting caudal alae (a). i = intestine. m = mucosa. Mag bar = 100 microns. Hematoxylin and eosin stain.

Evidence for extreme agonistic behavior among Black-backed Woodpeckers

Adult female CG169W was caught and tagged on the Wheeler fire on 24 April 2011. At the time of capture we noted that three Black-backed Woodpeckers – a male and two females – were in the area, and all three responded aggressively to the decoy and broadcast, rather than the more usual pair or lone individual. The marked bird was subsequently radio-tracked on two occasions (25 and 27 April) before she shed her transmitter sometime between 27 April and 1 May and could no longer be tracked. However during the two tracking bouts we followed the bird to her nest cavity, which we then continued to observe after she lost her transmitter. On 1 May we used

a wireless inspection camera with a flexible probe to determine that the nest was empty. Four days later we looked into the nest again, and discovered the formerly radio-tagged female bird (still wearing its leg band) in the nest cavity, but obviously dead. That same day, we observed a male Black-backed Woodpecker excavating a new cavity with a female woodpecker 360 m away from the cavity in which we found the dead bird, on the same hill and within the home range in which the dead bird had been observed. Although we could not be certain, we presumed the male Black-backed Woodpecker was the dead bird's mate because of the close proximity of the new cavity to the previous nest cavity and the timing of the new excavation.

The carcass was extracted from the nest cavity, frozen, and shipped to the California Animal Health & Food Safety Laboratory System at UC Davis. B. Barr performed a necropsy which included gross examination as well as histological, bacteriological, and virological assessments. The primary salient finding was multiple perforating skin wounds 3-6 mm in diameter on the head, with underlying fractures to the dorsal skull. The plates of the skull were depressed down into the brain, traumatizing and exposing it. The parenchyma was fully intact, suggesting that the wounds were created antemortem, as a scavenger would have presumably consumed portions of the exposed tissues. The carcass was highly autolyzed, limiting the value of the histological assessment, but no other significant pathological findings were observed beyond the gross findings. There was a large grub in the gizzard indicating recent foraging, and the breast muscles were relatively large in size suggesting the bird was in good body condition prior to death. The gizzard was unremarkable both grossly and microscopically, with no evidence of parasitic nematodes such as *Procyrnea*, which caused the death of a Black-backed Woodpecker whose carcass we collected in 2011 at the Sugarloaf fire (Siegel et al. 2012 and above in *Results:Disease*).

Genetic population structure

We collected feathers from 21 of the 22 Black-backed Woodpeckers that we captured for radio-tagging, and sent them to the Conservation Genetics Laboratory at the U.S. Forest Service Rocky Mountain Research Station. DNA was successfully extracted and analyzed from 20 of the

samples. Detailed findings, provided by the Conservation Genetics Laboratory, are provided in Appendix 2.

Identification of possible prey species

The early portion of summer 2011 was unusually cold at our study areas, and it is likely for this reason that we caught relatively few beetles in our traps until near the end of our study period, when more typical summer weather conditions finally arrived. The larger-sized wood-boring beetles we captured (Table 14) included two species of *Monochamus* and two species of *Acanthocinus* (long-horned beetles) and one species of metallic wood-boring beetle, *Chalcophora angulicolis*. The adult *Monochamus* and *Acanthocinus* we trapped ranged from 11-22 mm in body length. The adult *Chalcophora* we captured ranged from 25-30 mm in length. We also captured large adult Elaterid beetles, *Alaus melanops*, which ranged between 30-33 mm in length. These beetles predate upon larvae of wood-boring beetles, and their own larvae can be found under the bark of pine and fir trees, representing another potential large prey item for Black-backed Woodpeckers.

We captured smaller *Scolytidae* bark beetles that we were able to identify to the genera *Dendroctonus* and *Ipps* (Table 14). We also captured bark beetle predator species, including *Enoclerus spegeus* and *Temnoscheila chlorodia*.

Table 14. Wood-boring and bark beetle species, and beetle species that prey on them, that we captured at the Peterson and/or Sugarloaf fire area. See Appendix 3 for photographs of specimens.

| Scientific Name | Common Name |
|-------------------------------------|---|
| Wood-boring Beetles | |
| <i>Cerambycidae</i> | Long-horned beetles |
| <i>Monochamus clamator latus</i> | Spotted Pine Sawyer |
| <i>Monochamus obtusus</i> | Flat-faced Longhorned Beetle |
| <i>Acanthocinus princeps</i> | Ponderosa Pine Bark Borer |
| <i>Acanthocinus obliquus</i> | -- |
| <i>Buprestidae</i> | Metallic wood-boring beetles, jewel beetles, flat-headed borers |
| <i>Chalcophora angulicollis</i> | Western Sculpted Pine Borer |
| Wood-boring beetle predators | |
| <i>Elateridae</i> | Click beetles |
| <i>Alaus melanops</i> | Western Eyed Click Beetle |
| Bark beetles | |
| <i>Scolytidae</i> | -- |
| <i>Dendroctonus spp.</i> | -- |
| <i>Ipps spp.</i> | -- |
| Bark beetle predators | |
| <i>Cleridae</i> | Checkered beetles |
| <i>Enoclerus sphegeus</i> | Red-bellied Clerid |
| <i>Trogossitidae</i> | Bark-gnawing beetles |
| <i>Temnoscheila chlorodia</i> | -- |

Photographs of representative larger-sized beetles we captured are presented in Appendix 3.

Discussion

During the 2011 and 2012 breeding seasons we captured and radio-tagged 22 Black-backed Woodpeckers occupying 3 recent fire areas. We were able to radio-track 14 of those birds sufficiently to estimate breeding-season home range size. We completed 284 bouts of radio-tracking, comprising 3,308 distinct foraging locations, and we collected on-the-ground habitat data at 2,535 of the observed foraging locations and 1,808 systematically arrayed ‘background’ points within the birds’ home ranges. Modeling efforts of these data revealed numerous interesting and management-relevant findings about habitat selection and use.

Size and characteristics of home ranges

Black-backed Woodpecker home range estimates from outside California have varied substantially, although much of this variation may be due to different home range estimation methods and conditions during radio tracking, as well as small sample sizes (Table 15). For example, Dudley and Saab (2007) and Goggans et al. (1989) conducted their studies during the post-fledging period when woodpeckers, at least in some portions of their species-wide range, may wander more widely in search of patchy food resources (Tremblay et al. 2009), while Tremblay et al. (2009) studied home range size during the pre-fledging period. Dudley and Saab (2007) is the only study of home ranges besides our own to have looked at Black-backed Woodpeckers within burned forests.

Different home range calculation methods have produced a variety of estimates from three studies conducted elsewhere in the range of Black-backed Woodpecker (Table 15). Kernel-based methods generally yield smaller home range estimates than does the MCP approach, because they emphasize areas of actual use by a focal animal, whereas MCP home ranges sometimes include substantial area that simply lies in between areas of use, but is not in itself used by the focal animal. Brownian bridge kernel estimation further accounts for temporal autocorrelation in observation data and explicitly uses both the path taken between consecutive observations as well as the amount of time between observations at successive observations, to estimate a

Utilization Distribution (Bullard 1999, Horne et al. 2007). Unlike classic (fixed) kernel methods, the Brownian bridge method assumes that the area between consecutive relocations is part of the ‘home range’ and that the degree with which this in-between area is used is related to the amount of time spent traveling between two fixes (relative to the speed of the animal). For all these reasons, we believe the Brownian bridge kernel estimates provide the most meaningful home range descriptors. Nevertheless, we also presented the MCP estimates because they are useful for cross-study comparisons; among the three published studies reporting Black-backed Woodpecker home range size, the only reporting metric common to all is the 100th percentile MCP, which is considered standard, even if its biological meaningfulness has been questioned (Börger et al. 2006).

Table 15. Summary of published studies of Black-backed Woodpecker home range size in comparison to findings presented in this report.

| Study | Home range size (ha) | | | Method | Percentile | n | YSF ^a | Location | Period ^b |
|-----------------------|----------------------|-----|------|--------------|-------------------|----|------------------|------------|---------------------|
| | Min | Max | Mean | | | | | | |
| Goggans et al., 1989 | 72 | 328 | 175 | MCP | 100 th | 3 | - | Oregon | Post-fl. |
| Dudley and Saab, 2007 | 24 | 91 | 45 | Fixed-kernel | 50 th | 4 | 6-8 | Idaho | Post-fl. |
| Dudley and Saab, 2007 | 116 | 421 | 217 | Fixed-kernel | 95 th | 4 | 6-8 | Idaho | Post-fl. |
| Dudley and Saab, 2007 | 124 | 573 | 322 | MCP | 95 th | 4 | 6-8 | Idaho | Post-fl. |
| Dudley and Saab, 2007 | 150 | 766 | 429 | MCP | 100 th | 4 | 6-8 | Idaho | Post-fl. |
| Tremblay et al., 2009 | 100 | 256 | 151 | MCP | 100 th | 8 | - | Quebec | Pre-fl. |
| Current | 33 | 796 | 227 | MCP | 100 th | 14 | 2-3,5 | California | Both |
| Current | 3 | 55 | 16 | Kernel-Br. | 50 th | 14 | 2-3,5 | California | Both |
| Current | 24 | 313 | 97 | Kernel-Br. | 95 th | 14 | 2-3,5 | California | Both |

^aYears since fire, if applicable.

^b‘Pre-fl.’ indicates data were collected prior to nestlings fledging; ‘Post-fl.’ Indicates data were collected after nestlings fledged; ‘Both’ indicates data were collected before and after fledging.

Our Monte Carlo simulations indicated that at least 100 foraging observations were necessary to estimate home range size robustly using our methods (although the required number of observations will also be influenced by the degree of geographic dispersion of the observations), and we met this threshold for 14 of our focal birds. Comparing among 100th percentile MCP estimates, mean home range sizes in the three previous studies vary from 151-429 ha, with the larger number derived from the only study of the three to have looked at home ranges in burned forests.

The number of Black-backed Woodpeckers tracked over 2 years in the present study (14) is one less than the total number of Black-backed Woodpeckers tracked in all previously published studies combined. When comparing our home range size estimates as based on the 100th percentile MCP (which is the only method used consistently across all studies), our mean findings are quite consistent with those of Dudley and Saab (2007). Even by this metric, however, nine of 14 birds in our study had 100% MCPs smaller than the minimum MCP area of 124 ha in Dudley and Saab (2007). This difference is more obvious when comparing the kernel-based home range estimates. Although this study uses a movement-based kernel method which may more accurately describe home ranges than fixed-kernel methods, the two methods should be roughly comparable. Based on kernel estimates, our home ranges were consistently smaller than those reported in Dudley and Saab (2007). This is true for both 95th percentile home ranges and ‘core’ home ranges (50th percentile). In fact, the mean 95th percentile home range of our 14 birds was less than the minimum 95th percentile home range in Dudley and Saab, as measured by kernel methods.

This difference in size could plausibly be due to sampling (the Dudley and Saab study only tracked 4 birds), metrics (if Brownian bridge kernels result in consistently smaller home ranges given the same data), region (ecological differences between Idaho and California), time-since-fire, or characteristics of individual post-fire habitats. Dudley and Saab (2007) suggest, based on limited data, that Black-backed Woodpecker home ranges expand within burned forests over time, as snags fall and decomposing trees gradually decline in foraging quality. Although the three fires with tracked birds in this study span 2, 3, and 5 years post-fire, we were not able to test this hypothesis in an unbiased way. Comparing the Peterson fire (3-years post-fire) to the Wheeler fire (5-years post-fire), birds within the Peterson fire had greater mean home range areas than Wheeler birds (Table 2). This apparent trend was clearly influenced, however, by several factors. For one, several birds in the Peterson fire foraged heavily outside of burned forests (Table 11), and these birds had substantially larger home ranges (Table 12). Perhaps even more important is the difference in habitat characteristics between the two fire areas. It is apparent from our results that the density of severely burned snags is important for foraging (Figure 23), and snag density has a strong relationship to home range size (Figure 22). Inspection of the graphs in Figure 22 hints at a possible threshold value of mean snag basal area at around

20m²/ha, above which home range size does not continue to decrease appreciably, and below which home range size expands rapidly. If confirmed with additional data, such a threshold could provide a useful target for post-fire forest management that is compatible with Black-backed Woodpecker occupancy. In any case, the Wheeler fire, although older than the Peterson fire, has much more extensive severely burned areas, whereas the Peterson fire includes large patches of forest showing little to no fire damage (Figures 13, 15). These differences in burn characteristics and available habitat may far outweigh potential effects of snag aging on home range sizes. To robustly study this process, one would need to monitor home range sizes within the same fire from year to year.

Of our 14 robustly tracked focal birds, four were female and ten were male. It is unknown whether male and female Black-backed Woodpeckers have differently sized foraging home ranges during the breeding season. Dudley and Saab (2007) sampled only male woodpeckers. In the Wheeler fire, the three female birds showed home range estimates that were not significantly different from the five male birds ($P = 0.3$), although the mean size was smaller. Dudley and Saab (2007) noted that their 4 male birds showed no overlap in home ranges, while we noted considerable overlap in some birds, at least using the 100% MCP estimates (Table 3). It is difficult to parse overlap by sex in this study, and certainly some female birds (e.g., CH112P and CC370W) had the highest rates of overlap (with non-mates), yet home range overlap was observed between male birds (e.g., RR235W and BO270W). Thus, we do not have any strong reason to believe that our results or their generality is biased by treating both male and female birds alike.

It should be noted that not all of birds in our study areas were marked and studied (we believe we tracked one member of most, but not all, pairs), so any assessments of home range overlap we can make are minimum estimates only. While we found substantial home range overlap (median = 13%) using the 100% MCP method, more conservative methods yielded incrementally smaller amounts of overlap, with relatively little overlap apparent using 95% kernel estimates (median = 6%), and almost no overlap (median <1%) using the 50% kernel estimates, which may be thought of as representing the birds' "core" home ranges.

Although consistent with other studies, home range sizes of our focal birds varied greatly, exhibiting a strong negative relationship with snag density within the home range (Figure 22). Characteristics of individual home ranges, including snag density, varied widely. Mean snag basal areas of individual 95% kernel home ranges varied between 3.4 and 35.1 m²/ha (median = 21.5 m²/ha) while mean live tree basal areas varied between 1.8 and 33.7 m²/ha (median = 10.2 m²/ha). With the exception of three Peterson fire birds whose home ranges encompassed substantial area outside the fire perimeter, all birds had mean snag basal areas above 17 m²/ha and mean live tree basal areas below 20 m²/ha. The average ratio of total snag basal area to total live tree basal area was greater than 1 (indicating relatively more snags than live trees) for all birds except for the three Peterson fire birds that foraged extensively outside the fire perimeter.

These results describing home range characteristics, and particularly the quantitative relationship average snag basal area and home range size, may be very helpful in predicting the effects of post-fire forest management strategies on local Black-backed Woodpecker populations, and helping land managers design post-fire management plans that retain adequate numbers of snags to support breeding Black-backed Woodpeckers.

Foraging habitat selection

Our comparisons of foraging habitat at observed versus available locations revealed significant selection for specific resources at 3 different spatial scales: foraging substrate, 10-m radius stand, and 50-m radius stand. At the scale of the individual tree or snag used for foraging, the woodpeckers selected snags in preference to live trees, and those snags were: larger, more highly charred, more heavily colonized by wood-boring beetle larvae, and showing fewer signs of decomposition than the available snags (Table 16). Yellow Pine snags were preferred, and Black Oak snags were avoided (Table 16). The same variables that affected foraging probability generally also affected duration of foraging (Table 16), further corroborating that the two independent models that produced these results identified important variables governing habitat selection by the woodpeckers

Table 16. Relationships between tree or snag characteristics and the probability of use for foraging, as well as the duration of foraging (summarized from Tables 9 and 10). 'Positive' or 'negative' indicates the direction of the variable, followed by '*' for statistically significant ($p < 0.05$) effects or 'NS' for non-significant effects.

| Variable | Probability of foraging on a tree or snag | Duration of foraging on a tree or snag |
|--------------------|--|---|
| Snag: yes | positive, * | positive, * |
| DBH | positive, * | positive, * |
| No. borer holes | positive, * | positive, * |
| Intact crown | negative, NS | negative, NS |
| Scorch > 90% | positive, * | negative, NS |
| Black Oak: yes | negative, * | NA |
| Fir: yes | NA | positive, * |
| Yellow Pine: yes | positive, * | positive, NS |
| Has needles: yes | NA | positive, NS |
| Distance from nest | negative, * | positive, NS |

At the 10-m stand scale, woodpeckers selected stands for foraging that – in decreasing order of importance to the probability of an area being used for foraging – contained higher densities of: large snags (>60 cm dbh), medium snags (31-60 cm dbh), small snags (10-30 cm dbh), live trees, and logs (Table 17). The presence of stumps (i.e., snags or trees that were cut pre- or post-fire) had no significant effect on the probability of an area being used for foraging, although this result does not account for the effect of the corresponding reduction in the number of snags or live trees in the stand (Table 17).

Table 17. Relationships between characteristics of 10-m radius plots and the probability of use for foraging (summarized from Table 7). 'Positive' or 'negative' indicates the direction of the variable, followed by '*' for statistically significant ($p < 0.05$) effects or 'NS' for non-significant effects.

| Variable | Probability of foraging in a 10-m radius plot |
|------------------------|--|
| Logs > 10 cm wide | positive, * |
| Live trees > 10 cm dbh | positive, * |
| Stumps | positive, NS |
| Snags 10-30 cm dbh | positive, * |
| Snags 31-60 cm dbh | positive, * |
| Snags >60 cm dbh | positive, * |

At the 50-m scale, we looked at the factors that correlated with kernel-based utilization distributions (i.e., usage probability). At this scale, woodpeckers more heavily used portions of their home range that were closer to their nest tree, where pre-fire canopy cover had been higher, and where fire had burned the forest more severely. Within home ranges, woodpeckers generally did not forage in areas where salvage logging or other post-fire snag removal treatments had

occurred, although they frequently used immediately adjacent stands that had not been salvage-logged. While stand treatments that removed snags clearly reduced habitat suitability for foraging woodpeckers, there did not appear to be evidence of an ‘edge effect’ wherein areas adjacent to post-fire treatments were also avoided by the woodpeckers.

Like descriptions of home range resource requirements, information on the characteristics of preferred snags and preferred forest stands within Black-backed Woodpecker home ranges can help land managers to better incorporate woodpecker habitat needs into post-fire forest management plans.

Foraging in unburned forest

Perhaps our most surprising result is the finding that three of the focal birds (RO888P, TU222P and HB777P) had home ranges that were both much larger than the other 11 estimated home ranges, and encompassed large amounts of unburned forest outside the fire perimeter. Indeed, we observed the birds foraging on dead and ailing trees in unburned forest stands well over 3 km from the fire area in which they were nesting, and greater than 45% of each bird’s observed foraging points were outside the fire perimeter. For TU222P and HB777P, unburned forest foraging encompassed 93% and 89% of foraging locations, respectively.

The three unburned-forest birds exhibited subtly different foraging strategies than the burned-forest birds. This difference mostly consists of unburned-forest birds traveling much greater distances between foraging events. Additionally, the unburned-forest birds selected unburned snags (as opposed to burned snags, which of course were not available in unburned areas) that are also taller than the burned snags selected by other birds within the burned areas. However, the three unburned-forest birds spent the same amount of time foraging on each tree, and the trees had similar DBH to the trees selected by the burned-forest birds.

While the differences in most aspects of foraging behavior between burned-forest birds and unburned-forest birds were few, the foraging strategies were quite different. The unburned-forest birds traveled much greater distances between foraging events and, as a consequence, occupied

much larger home ranges. It is unclear how this might translate into fitness, competitive ability, or nesting success, but the strong relationship we found between snag availability and home range size suggests intriguing avenues for further research into factors that may limit the abundance of Black-backed Woodpeckers across the larger, unburned landscape. Although Black-backed Woodpeckers are known to inhabit portions of unburned, mid-elevation conifer forests in California at low densities, they appear to be entirely or nearly absent from many such areas. One explanation for this pattern may involve prohibitively high energetic costs of foraging where prey is diffusely distributed. Extracting large larvae from deep within dead wood would appear to be a relatively energy-intensive mode of foraging. It may be that Black-backed Woodpeckers become less able to satisfy the energy demands of growing nestlings plus maintain their own body reserves as time spent foraging – and distance flown while foraging – become greater and greater. There may be a threshold prey density at which the energetic cost of foraging simply becomes too high, and Black-backed Woodpeckers raising broods are unable to balance their energy budgets – that threshold may be exceeded in unburned forest stands with low densities of prey. Energy constraints have played an important role in explaining unusual life-histories of at least one other woodpecker species (Weathers et al. 1990).

It is important to note that, although the unburned-forest birds spent considerable proportions of their foraging time outside of burned areas, all three birds had nests located inside the fire perimeter. This suggests that while Black-backed Woodpeckers may be able to successfully employ a foraging strategy involving traveling relatively long distances in unburned forest, there may still be characteristics of burned forests that make them preferable for nesting.

Nest site characteristics, breeding phenology, and nest success

Over the course of two field seasons we identified 21 Black-backed Woodpecker nests. Of 13 variables assessed at three spatial scales (tree-level, 10-m plot, 50-m plot), seven variables had significant relationships to nest location. In particular, nests were more likely to be placed in medium-sized snags (mean = 33 cm DBH) that were extensively scorched. Snags chosen for nesting were consistently had higher densities of snags (of all three size classes we assessed) and greater snag basal area than average stands within the available habitat. These results can help

forest managers select for retention after fire the forest stands in which Black-backed Woodpeckers are more likely to nest.

Estimated dates for the initiation of incubation ranged from April 28 to June 26. Observed and estimated fledging dates of nestlings ranged from June 4 to July 25. The latest-starting nest we observed failed for unknown reasons during the nestling phase, but had it succeeded, we estimate that the nestlings would have fledged around August 2. The nesting period for Black-backed Woodpeckers at our three study sites was thus primarily confined to May, June, and July. These results provide the information needed for avoiding the scheduling of potentially nest-disturbing activities when nests are likely to be active, or for establishing dates for limited operating periods (LOPs), should they be deemed necessary for curtailing some activities during the nesting season.

Of 21 nests in which we are certain eggs were laid, 16 (76%) were confirmed or strongly believed to have fledged at least one young, and five nests failed to fledge any young. Causes of nest failure were unknown in three cases. In the fourth case, the nest cavity was clearly ripped open by a bear, as evidenced by claw marks on the bark around the newly exposed nest. In the fifth case, observers had reason to suspect the nest was predated by chipmunks, but could not be certain.

Population age structure

By determining the age class of the Black-backed Woodpeckers we captured, we were able to characterize the age structure of the populations at our 3 study areas, which included previously burned sites between 2 and 5 years post-fire. As would be expected in a species with a relatively long lifespan, the majority of the birds captured at these fires (8 of 16 males and 4 of 6 females) were after-third year individuals. In the future we hope to compare these results with the age structure of populations occupying fire areas 1 year after fire. Adult birds caught during the first breeding season after fire are presumably colonizers, who emigrated from elsewhere. If such populations are comprised of predominantly second-year birds (i.e., 1-year-old birds that hatched in the previous breeding season), this will indicate that new fires are colonized by young birds

dispersing from their natal areas. Alternately, if the population age structure is similar to that of the older fires assessed in this study (i.e., comprised mainly of older birds), it will indicate that colonizing birds are frequently adult birds that have presumably already attempted to nest elsewhere in previous years. Either way, we will acquire a key puzzle piece in understanding dispersal dynamics and population demography in this species.

Disease

The dead Black-backed Woodpecker we collected in 2011 died from an infection of *Procyrnea* nematodes. The life-cycle of *Procyrnea* requires arthropods as intermediate hosts, which are then consumed by the definitive host, where the nematodes parasitize the upper gastrointestinal tract. Apparent intermediate hosts of *P. pileata* include pillbugs (*Armadillidium vulgare*) and earwigs (*Euborellia annulipes*) (St. Leger and others, unpubl. data). Black-backed Woodpeckers forage primarily on the larvae of wood-boring beetles and bark beetles, neither of which is a known or likely vector for *P. pileata*. The birds forage mainly by excavating beetle larvae from the sapwood of dead or ailing trees, a strategy that is unlikely to result in consuming arthropods that are intermediate *Procyrnea* hosts. However, during 1198 observations of Black-backed Woodpecker foraging bouts in 2011 (unpublished data) the gleaning of prey items from the outer surface of tree bark was noted as part of 113 bouts (9.4%). Gleaning prey items from the surface of tree trunks and logs introduces the potential for more frequent consumption of arthropods that could be *Procyrnea* vectors.

This study is the first observation of *Procyrnea* in Black-backed Woodpeckers and apparently the first description of any disease findings in the species. *P. pileata* infection has previously been documented in Red-bellied Woodpeckers (*Melanerpes carolinus*) in Florida (Foster et al. 2002) and appears to have been responsible for 18 deaths in multiple species of captive rhamphastids (a family comprised of the toucans, toucanets, and aracaris) at Sea World in southern California (St. Leger and others, unpubl. data). Another *Procyrnea* nematode, *P. colaptes*, was identified as a factor in a substantial die-off of Northern Flickers (*Colaptes auratus*) in New Mexico during the winter of 1997 (J. Harden, personal communication).

The Black-backed Woodpecker fatality reported here is only an anecdotal incident, but it has been suggested that helminth parasites may be capable of regulating bird populations in some cases (Peterson 2004). If *Procyrnea* nematodes occur frequently in Black-backed Woodpeckers, they could be a significant factor limiting population growth in this species.

Extreme agonistic behavior among Black-backed Woodpeckers

Territoriality and conflict over resources or mates are common among woodpeckers, and many species have characteristic vocalizations or postures that are frequently used in agonistic interactions with individuals of the same species (Kilham 1966, 1969). However lethal conflict between conspecific woodpeckers appears to be quite rare. Cooperatively breeding Acorn Woodpeckers (*Melanerpes formicivorus*) have been reported to destroy conspecific eggs (Koenig et al. 1995), but we are aware of no published reports of woodpeckers killing conspecific adults.

The bird we collected appeared to have been foraging normally days before its death, had a beetle grub in its crop when it died, and was not emaciated. Rather, the head wounds that appear to have killed it are consistent with the bird having been pecked to death by another woodpecker. With the exception of Northern Flicker (*Colaptes auratus* and Lewis's Woodpecker (*Melanerpes lewis*)), the other woodpeckers in the study area – Williamson's Sapsucker (*Sphyrapicus thyroideus*), Red-breasted Sapsucker (*Sphyrapicus ruber*), Downy Woodpecker (*Picoides pubescens*), Hairy Woodpecker (*Picoides villosus*), White-headed Woodpecker (*Picoides albolarvatus*), and Pileated Woodpecker (*Dryocopus pileatus*) – are all species that excavate their own nest cavities and are not known to usurp other species' cavities; a scenario in which one of them would kill a Black-backed Woodpecker in its nest cavity therefore seems implausible. Lewis' Woodpeckers have been observed to displace Black-backed Woodpeckers from nests (Dixon and Saab 2000), but they were rarely seen at our study site; Northern Flickers have been observed to displace nesting American Kestrels (*Falco sparverius*; Weibe and Moore 2008) and therefore cannot be ruled out, but it nevertheless seems unlikely that one would kill a Black-backed Woodpecker in its nest cavity, rendering the cavity unsuitable for nesting. Aside from woodpeckers, other bird species that have been observed to forcibly displace primary cavity-nesting birds from their nests, such as the European Starling (*Sturnus vulgaris*) and House

Sparrow (*Passer domesticus*), have not been observed at our study site. Although we cannot be 100% certain the bird we collected was killed by another Black-backed Woodpecker, that appears to be the most likely scenario.

Our observations that a second female was present and responded to our lure, and that a woodpecker that was likely the dead bird's mate was excavating a new nest with another female shortly after the bird's death, suggests the possibility that the bird may have been killed by a rival female Black-backed Woodpecker. An alternative explanation is that a second pair of Black-backed Woodpeckers killed the female and usurped the territory, with the fate of the original male unknown to us.

Lethal agonistic behavior has not been previously documented in woodpeckers and is therefore likely quite rare. Black-backed Woodpeckers are strongly associated with recently burned forests (Hutto 1995, Dixon and Saab 2000), a somewhat rare, ephemeral habitat. This association with a limited resource (stands of recently killed conifers) that fluctuates unpredictably from year to year may severely limit breeding opportunities as local habitat quality for Black-backed Woodpeckers degrades rapidly in the years after a fire (Nappi and Drapeau 2009, Saab et al. 2007, Saracco et al. 2011). In many organisms, limited resources for breeding can foster fierce intraspecific competition that sometimes results in lethal conflict (Enquist and Leimar 1987, 1990; Innocent et al. 2011). Intense intraspecific competition, particularly in regard to reproductive opportunities, has been identified as the reason behind intraspecific lethal aggression in animals as diverse as primates (Fawcett and Muhumuza 2000) and ants (Heinze and Weber 2011). Systematic observations of intraspecific interactions could test whether agonistic behavior among Black-backed Woodpeckers is indeed more intense than among other woodpecker species that are not burned-forest habitat specialists and rely more heavily on habitats that do not fluctuate so greatly in extent and quality from year to year.

Genetic population structure

Genetic population structure of Black-backed Woodpeckers across their range has been studied and reported elsewhere (Pierson et al. 2010), but the California birds' insularity or relatedness to

other populations has never been evaluated. To facilitate this evaluation, we collected feathers from 21 Black-backed Woodpeckers and sent them to the Conservation Genetics Laboratory at the U.S. Forest Service Rocky Mountain Research Station, where DNA from 20 of the samples was successfully extracted and analyzed. Work is now underway in collaboration with personnel at the Conservation Genetics Laboratory to assess the genetic results in the context of the species' larger population structure, and especially to assess the degree of connectivity with the population of Black-backed Woodpeckers in Oregon.

Identification of possible prey species

The information developed here on potential Black-backed Woodpecker prey species at our study sites provides a good starting point for further study, but is preliminary only. Even more than spatial and temporal patterns in the availability of fire-killed trees, spatial and temporal patterns in the availability of the wood-boring beetle larvae that Black-backed Woodpeckers prey on may be the key to more fully understanding Black-backed Woodpecker ecology, distribution, and abundance. In the future we hope to collaborate closely with Forest Service entomologists to identify larvae the woodpeckers are actually feeding on (rather than only identifying adult beetles present in the area), assess patterns and predictors of abundance of those larvae in burned and unburned forests, and develop indices for assessing which trees or snags are most likely to serve as rich sources of food for Black-backed Woodpeckers. Such indices could be used to select individual snags and trees, or stands of snags and trees, for retention where partial harvest is implemented.

Conclusions

Our work on this study during the past two years has substantially advanced our understanding of Black-backed Woodpecker ecology in burned forests of California, and provides information that can directly inform management of post-fire forests. In particular, our home range estimates can aid in the estimation of Black-backed Woodpecker population sizes in burned forests, and help managers assess the likely effects of different post-fire management actions on the number of home ranges a post-fire forest may support. Our finding that home ranges across our study areas

varied in size so greatly – by as much as an order of magnitude – and that the local density of snags largely explains this variation in home range size, provides a quantitative relationship (between snag availability and home range size) that allows for nuanced predictions about the effects of specific forest management actions on Black-backed Woodpeckers. Our characterization of the individual snags, trees, and stands that support Black-backed Woodpecker foraging and nesting can form the basis of quantitative targets for managers interested in selecting for retention the habitat elements and habitat patches that are most valuable to Black-backed Woodpeckers.

Nevertheless, there are still important issues with pressing implications for post-fire forest management and Black-backed Woodpecker conservation that were beyond the scope of this study and remain unaddressed, including:

- Dynamics and demographics of dispersal between fire areas, as well as between unburned forest and new fire areas
- Degree of year-to-year site fidelity
- Winter site persistence and winter habitat use
- Before-and-after assessment of the effects of different post-fire forest management actions
- Importance of beetle-killed stands in unburned forest
- Ecology of prey species in burned and unburned forests

In the near future we hope to address many of these issues and enhance the ability of the Forest Service and other land managers to make scientifically informed decisions about management of burned forests and conservation of Black-backed Woodpeckers.

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LETHAL *PROCYRNEA* INFECTION IN A BLACK-BACKED WOODPECKER (*PICOIDES ARCTICUS*) FROM CALIFORNIA

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Abstract: The black-backed woodpecker (*Picoides arcticus*) is a species of management concern in California. As part of a study of black-backed woodpecker home range size and foraging ecology, nine birds in Lassen National Forest (Shasta and Lassen Counties, California) were radio-tracked during the 2011 breeding season. One of the marked birds was found dead after being tracked for a 10-wk period in which it successfully nested. A postmortem examination of the dead bird revealed that it was emaciated and autolyzed, with the presumptive cause being numerous spiruroid nematodes of the genus *Procyrnea* in the gizzard. This first observation of *Procyrnea* nematodes in a black-backed woodpecker is notable because the *Procyrnea* infection was considered lethal and because *Procyrnea* has been implicated in substantial die-offs in other bird species, including woodpeckers.

Key words: Black-backed woodpecker, *Picoides arcticus*, *Procyrnea colaptes*, *Procyrnea pileata*, spiruroid nematodes, woodpeckers.

BRIEF COMMUNICATION

The black-backed woodpecker (*Picoides arcticus*) is a species of management concern in California,^{7,8} where it was recently designated as a candidate species for listing as threatened or endangered in the state. Conservation concern for the species is driven by its apparently small population and substantial dependence on recently burned conifer forest,⁴ a habitat that is ephemeral, limited in extent, and vulnerable to postfire salvage logging.

As part of a study of black-backed woodpecker home range size and foraging ecology, nine birds in recently burned areas of Lassen National Forest (Shasta and Lassen Counties, California) were radio-tracked during the 2011 breeding season. Each bird was marked with an approximately 2.5-g radio transmitter glued and tied to one of its inner tail feathers. One adult male was marked in late April 2011 and then located and tracked several times each week for 10 weeks, during which it and its mate nested and successfully fledged young. On July 6, we observed the

bird behaving lethargically. Three days later, the bird's radio transmitter led us to its carcass, which was on the ground at the base of a tree, with no obvious sign of trauma. No other marked birds died during the study.

A postmortem examination at the California Animal Health and Food Safety Laboratory System at Davis, California, revealed that the bird was severely emaciated, with several nematodes noted in the gizzard koilin. Multiple tissues were immersed in 10% neutral buffered formalin and processed for routine histologic examination. Aside from the emaciation, significant histopathologic findings were limited to the gizzard, where the surface koilin and mucosal glands were markedly disrupted by numerous sections of a nematode parasite embedded within the koilin and underlying distorted and dilated mucosal gland lumina (Fig. 1). Numerous exfoliated epithelial cells and free red blood cells were also admixed with large bacterial colonies within the koilin (Fig. 1).

Several nematodes (roughly 6–10) were collected from the formalin-fixed gizzard and placed in 70% ethanol. Representative specimens were cleared and studied in temporary mounts of lactophenol and then returned to the preservative. Voucher specimens were deposited under accession number 104877 in the U.S. National Parasite Collection in Beltsville, Maryland. The nematodes (Fig. 2) were identified as spiruroids of the genus *Procyrnea* (Spiruroidea: Habronematidae) on the basis of the following combination of characters: two tri-lobed lips, thick-walled buccal cavity, esophagus divided into muscular and

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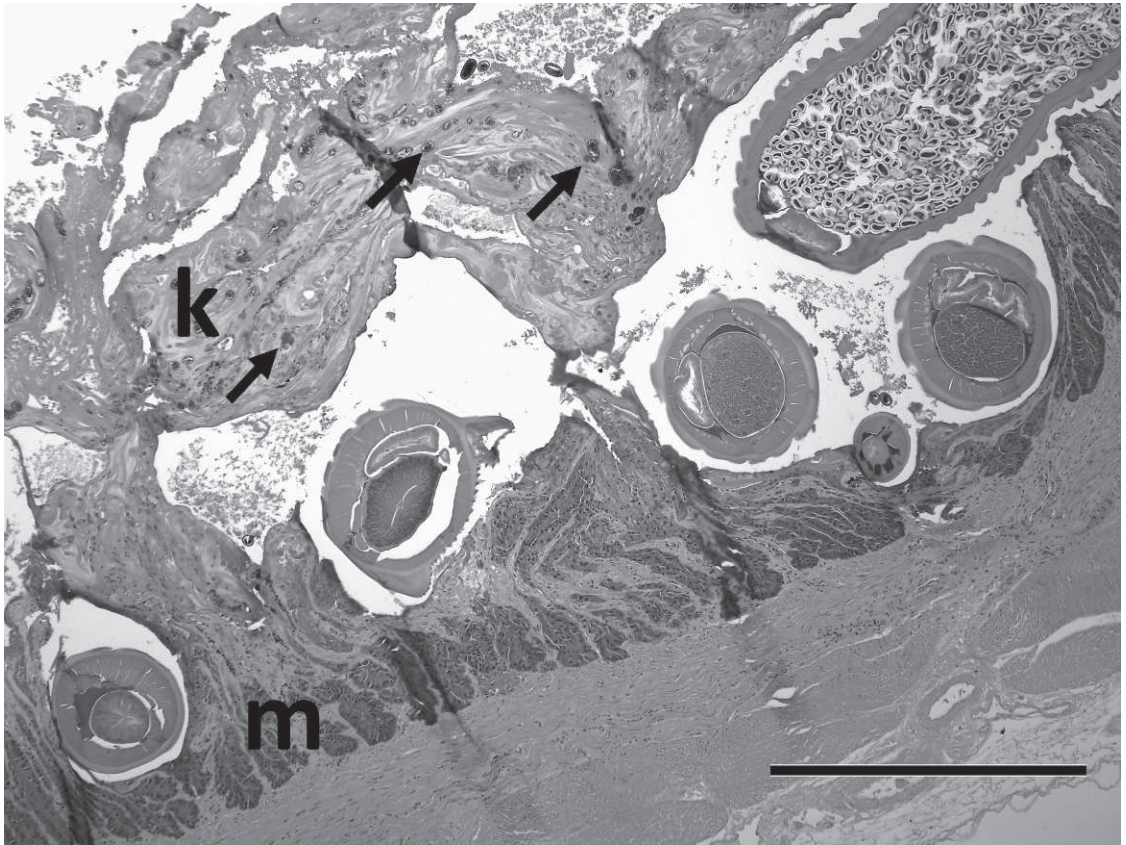


Figure 1. Low-magnification photomicrograph demonstrating the high density of nematode cross sections lying within the gizzard koilin (k) or underlying mucosal (m) dilated gland lumen. There is marked splitting of the koilin which contains numerous large bacterial colonies (arrows). H&E. Bar = 500 μ m.

glandular portions, coiled male tail with prominent caudal alae, unequal spicules, presence of a gubernaculum, and vulva in females near mid-body.¹ Identification to the species *Procyrnea pileata*⁹ was based primarily on the shape and size of the spicules in the males and the distance of the vulva from the anterior end in the females; the left spicule ranged in length from 1,560 to 1,770 μ m, and the right spicule from 380 to 430 μ m.⁶

The life cycle of *Procyrnea* requires arthropods as intermediate hosts, which are then consumed by the definitive host, in which the nematodes parasitize the upper gastrointestinal tract. Apparent intermediate hosts of *P. pileata* include pillbugs (*Armadillidium vulgare*) and earwigs (*Euborellia annulipes*) (St. Leger and others, unpubl. data). Black-backed woodpeckers forage primarily on the larvae of wood-boring beetles and bark beetles,² neither of which is a known or likely vector for *P. pileata*. The birds forage mainly by excavating beetle larvae from the sapwood of dead or ailing trees, a strategy that is unlikely to

result in consuming arthropods that are intermediate *Procyrnea* hosts. However, during 1,198 observations of black-backed woodpecker foraging bouts (R. Siegel et al., unpubl. data) the gleaning of prey items from the outer surface of tree bark was noted as part of 113 bouts (9.4%). Gleaning prey items from the surface of tree trunks and logs introduces the potential for more frequent consumption of arthropods that could be *Procyrnea* vectors.

This study is the first observation of *Procyrnea* in black-backed woodpeckers and apparently the first description of any disease findings in the species. *Procyrnea pileata* infection has previously been documented in red-bellied woodpeckers (*Melanerpes carolinus*) in Florida³ and appears to have been responsible for 18 deaths in multiple species of captive rhamphastids (a family comprising the toucans, toucanets, and aracaris) at Sea World in southern California (St. Leger and others, unpubl. data). Another *Procyrnea* nematode, *Procyrnea colaptes*, was identified as a factor

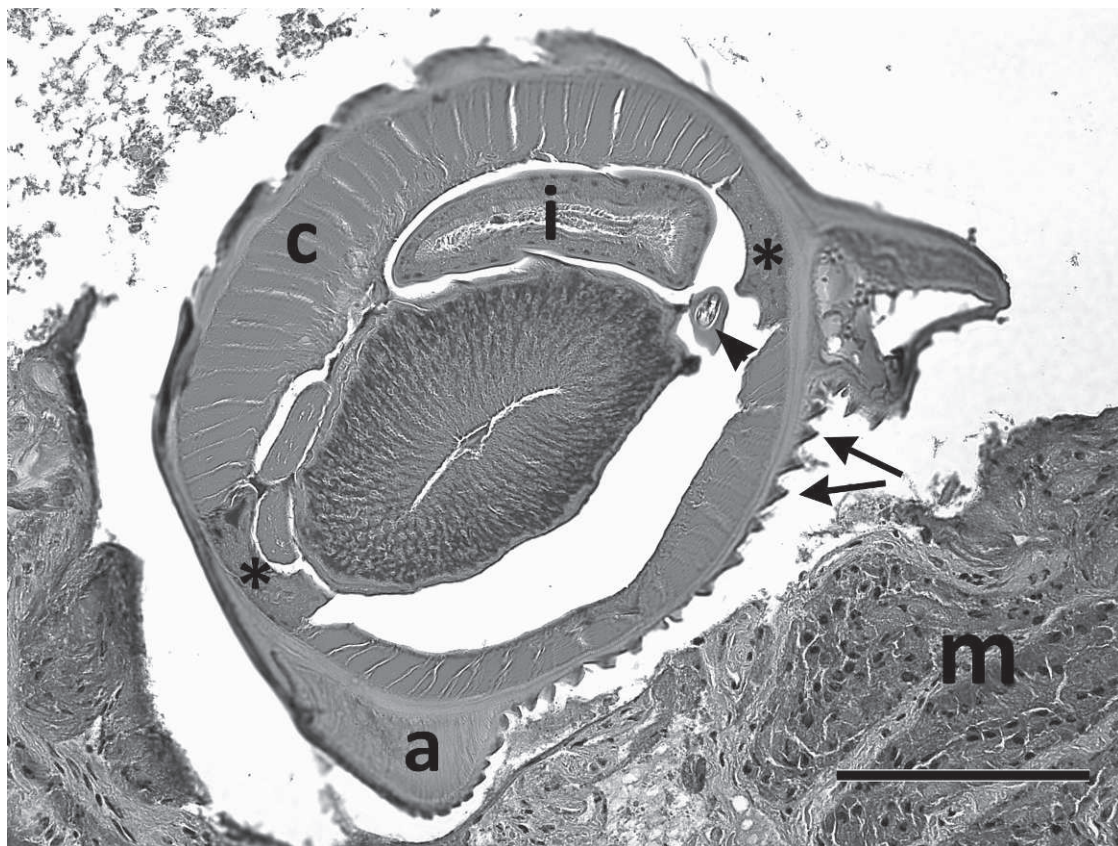


Figure 2. High-magnification photomicrograph of a single cross section through the posterior end of a male spirurid nematode. There is a small spicule (arrowhead) within the pseudocoelom. The nematode has coelomyarian musculature (c) with lateral chords (*), numerous ventral ridges (arrows) along one side of the cuticle, and two large projecting caudal alae (a). i, intestine; m, mucosa. H&E. Bar = 100 μ m.

in a substantial die-off of northern flickers (*Colaptes auratus*) in New Mexico during the winter of 1997 (J. Harden, pers. com.).

The black-backed woodpecker fatality reported here is only an anecdotal incident, but it has been suggested that helminth parasites might be capable of regulating bird populations in some cases.⁵ If *Procyrnea* nematodes occur frequently in black-backed woodpeckers, they could be a significant factor limiting population growth in this species of management concern.

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atodes. This study was completed by The Institute for Bird Populations' Sierra Nevada Bird Observatory and is contribution 425 of The Institute for Bird Populations.

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Appendix 2

Project: Genetic Analysis of Black-backed Woodpeckers (*Picoides arcticus*) from Lassen and Plumas National Forests

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Appendix 2

Between 2011 and 2012 we received feather samples collected from Black-backed Woodpeckers in California. On November 4, 2011 we received feather samples from nine individuals collected on the Lassen National Forest and on June 4, 2012 we received feather samples from 12 individuals collected on Plumas National Forest. Birds handled in 2011 were collected at the sites of the Peterson and Sugarloaf fires in the northern part of the Lassen National Forest and birds collected in 2012 were collected at the site of the Wheeler fire on the Plumas National Forest. DNA analysis on these feather samples was requested.

Table 1. Feather samples from Black-backed Woodpeckers sent for DNA analysis.

| Sample ID | Colloquial Name | Sex | Fire Name | Forest | Date collected |
|------------|-----------------|-----|-----------|--------|----------------|
| 12020-8820 | Cherry Male | M | Peterson | Lassen | 4/22/2011 |
| 12020-8821 | Kleerkutt | M | Peterson | Lassen | 4/23/2011 |
| 12020-8822 | Smith | M | Sugarloaf | Lassen | 4/26/2011 |
| 12020-8823 | Echo | M | Peterson | Lassen | 6/5/2011 |
| 12020-8824 | Farflung | M | Sugarloaf | Lassen | 6/5/2011 |
| 12020-8825 | Hurricane | M | Sugarloaf | Lassen | 6/5/2011 |
| 12020-8826 | Cherry Female | F | Peterson | Lassen | 6/5/2011 |
| 12020-8829 | Hillbender | M | Peterson | Lassen | 7/2/2011 |
| 12020-8830 | Romeo | M | Peterson | Lassen | 7/11/2011 |
| 12020-8831 | Cattle Guard | F | Wheeler | Plumas | 4/24/2012 |
| 12020-8832 | Road Rage | M | Wheeler | Plumas | 4/25/2012 |
| 12020-8833 | Cold Creek | F | Wheeler | Plumas | 4/27/2012 |
| 12020-8834 | EMP | M | Wheeler | Plumas | 4/27/2012 |
| 12020-8835 | Bounce | M | Wheeler | Plumas | 4/27/2012 |
| 12020-8836 | Houdini | M | Wheeler | Plumas | 4/28/2012 |
| 12020-8837 | Check Dam | M | Wheeler | Plumas | 4/28/2012 |
| 12020-8838 | Puddle | F | Wheeler | Plumas | 4/29/2012 |
| 12020-8839 | Speedy | F | Wheeler | Plumas | 4/30/2012 |
| 12020-8840 | Caboose | M | Wheeler | Plumas | 5/1/2012 |
| 12020-8841 | Imposter | M | Wheeler | Plumas | 5/16/2012 |
| 12020-8842 | Caboose | F | Wheeler | Plumas | 5/23/2012 |

Genetic Analyses

Twenty-one samples were analyzed using a panel of seven variable microsatellite loci used previously on black-backed woodpeckers (Pierson et al. 2010). We obtained adequate quality DNA for genotyping analysis from 20 of the samples (all but sample 12020-8831). For the purposes of these analyses, we considered the individuals grouped by the fire. Below we present some summary statistics on each population by locus. The first column is the number of samples that produced a genotype at that locus, followed by the number of alleles at that locus in the population (A), the number of alleles scaled by abundance, observed heterozygosity (Ho), and expected heterozygosity (He) given population genetic assumptions. A, Ho, and He are all measures of genetic variation.

Appendix 2

Table 2. Summary of genetic variation by population and locus

| Population | Locus | N | #Alleles | Effective #Alleles | Obs. Het | Exp. Het |
|------------|-------|----|----------|-----------------------|-------------|-------------|
| Peterson | HrU2 | 6 | 2 | 1.80 | 0.33 | 0.44 |
| | C118 | 6 | 6 | 4.00 | 1.00 | 0.75 |
| | C115 | 6 | 5 | 4.50 | 0.83 | 0.78 |
| | C111 | 6 | 3 | 2.32 | 0.67 | 0.57 |
| | DIU4 | 6 | 6 | 4.80 | 1.00 | 0.79 |
| | DIU1 | 6 | 2 | 1.95 | 0.83 | 0.49 |
| | LOX4 | 6 | 2 | 1.95 | 0.83 | 0.49 |
| | Mean | 6 | 4 | 3.04 | 0.79 | 0.62 |
| | SE | 0 | 1 | 0.50 | 0.09 | 0.06 |
| | | | | | | |
| Sugarloaf | HrU2 | 3 | 2 | 2.00 | 0.33 | 0.50 |
| | C118 | 3 | 3 | 2.57 | 1.00 | 0.61 |
| | C115 | 3 | 4 | 3.00 | 1.00 | 0.67 |
| | C111 | 3 | 2 | 1.38 | 0.33 | 0.28 |
| | DIU4 | 3 | 4 | 3.60 | 1.00 | 0.72 |
| | DIU1 | 3 | 2 | 1.80 | 0.67 | 0.44 |
| | LOX4 | 3 | 2 | 1.80 | 0.67 | 0.44 |
| | Mean | 3 | 3 | 2.31 | 0.71 | 0.52 |
| | SE | 0 | 0 | 0.30 | 0.11 | 0.06 |
| | | | | | | |
| Wheeler | HrU2 | 10 | 2 | 1.83 | 0.70 | 0.46 |
| | C118 | 10 | 5 | 3.77 | 0.80 | 0.74 |
| | C115 | 11 | 5 | 3.51 | 1.00 | 0.71 |
| | C111 | 10 | 4 | 2.99 | 0.50 | 0.67 |
| | DIU4 | 10 | 6 | 3.13 | 0.70 | 0.68 |
| | DIU1 | 11 | 2 | 1.98 | 0.36 | 0.50 |
| | LOX4 | 11 | 2 | 1.98 | 0.91 | 0.50 |
| | Mean | 10 | 4 | 2.74 | 0.71 | 0.61 |
| | SE | 0 | 1 | 0.30 | 0.08 | 0.04 |
| | | | | | | |

Next we examine genetic distance among these sampling locations. The first analysis uses a common genetic measure of gene flow called *Fst*. Numbers around 0 suggest complete gene flow, whereas higher numbers indicate some substructure.

Table 3. Genetic subdivision as measured by *Fst*.

| Peterson | Sugarloaf | Wheeler | |
|----------|-----------|---------|-----------|
| 0.000 | | | Peterson |
| 0.045 | 0.000 | | Sugarloaf |
| 0.040 | 0.051 | 0.000 | Wheeler |

Appendix 2

We also examined these samples using a principle components analysis (PCA). Figure 1 below shows an individual level PCA for the birds from your CA study, while Figure 2 compares them to previously analyzed birds sampled in Oregon (Pierson et al. 2010).

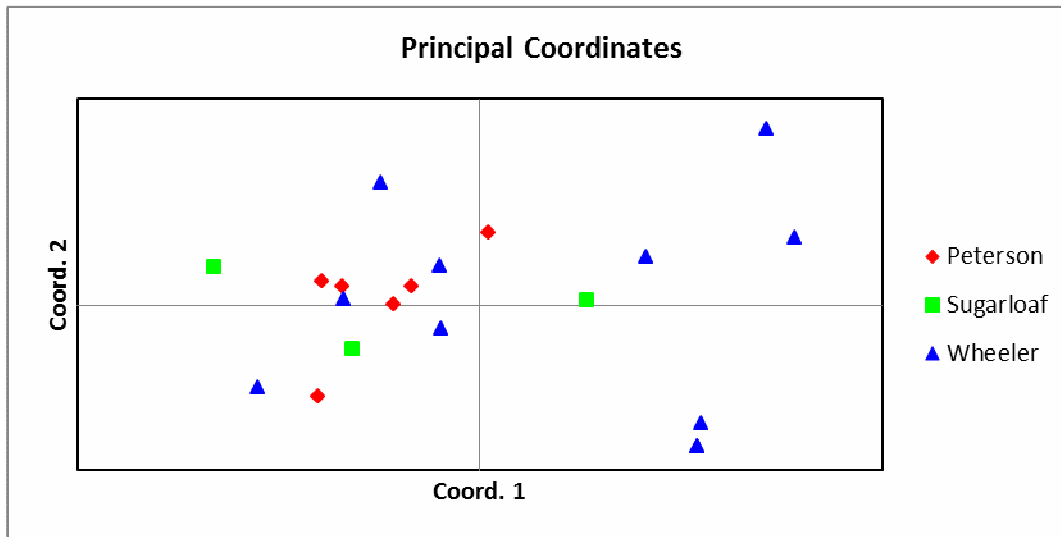


Figure 1. Principal components analysis showing genetic substructure among sampled CA individuals

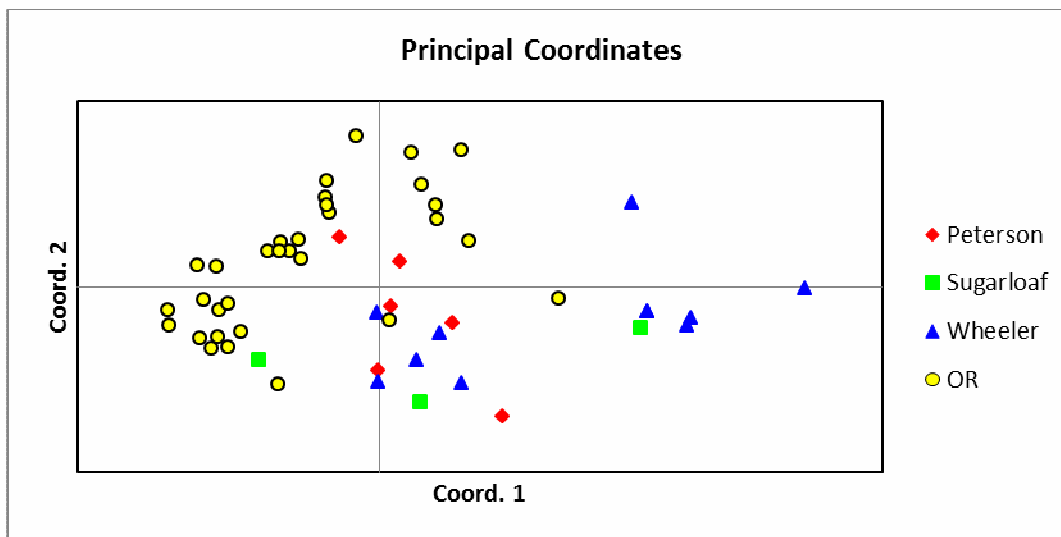


Figure 2. Principal components analysis showing genetic substructure among sampled CA individuals

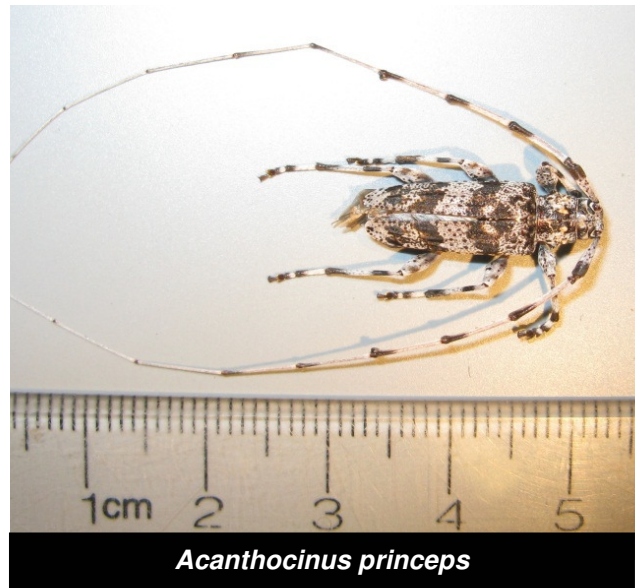
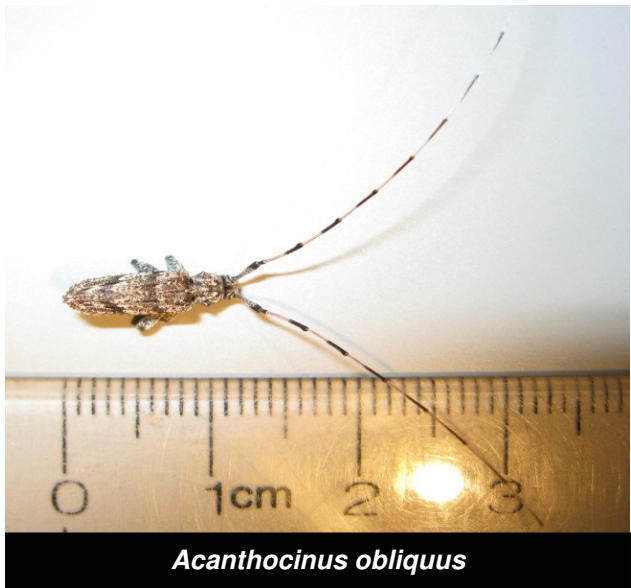
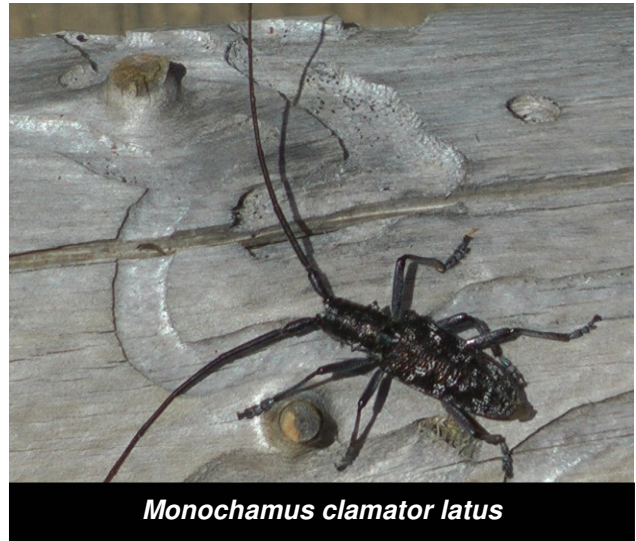
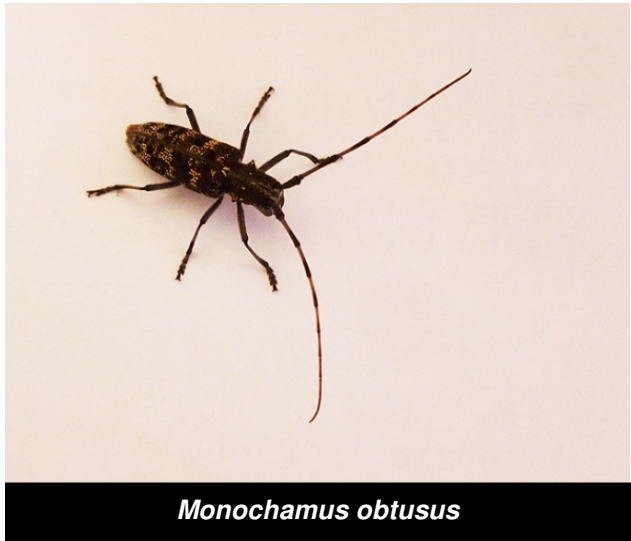
Please contact us if you would like to discuss your data further; we look forward to working with you in the future.

Appendix 3. Photo Gallery of Wood-boring Beetles Captured at the Peterson Complex and Sugarloaf Fires

The photos below are all of individual beetles that were caught in our traps and used for identification.

1. Wood-boring Beetles

a. Cerambycidae



b. Buprestidae



Scolytidae – Bark Beetles

Dendroctonus spp.

Ips spp.

2. Bark Beetles

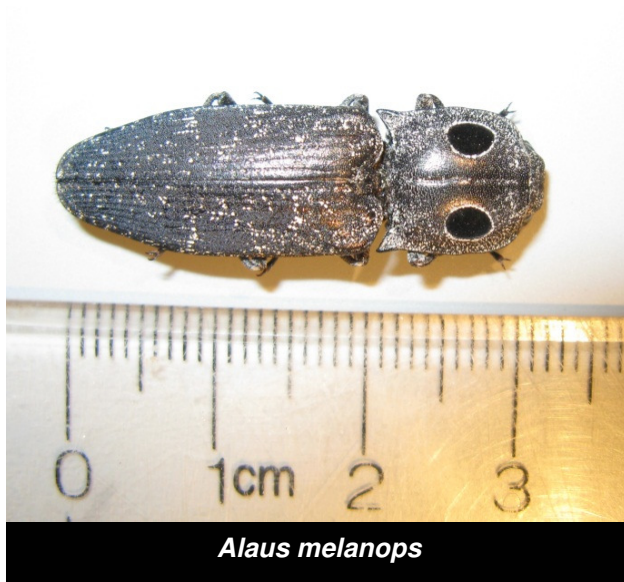
a. Scolytidae

Dendroctonus spp. (not pictured)

Ips spp. (not pictured)

3. Wood-boring Larvae Predators

a. Elateridae



3. Bark Beetle Predators

a. Cleridae



Enoclerus sphegeus

b. Trogossitidae



Temnoscheila chlorodia