

# Projecting Impacts of Fire Management on a Biodiversity Indicator in the Sierra Nevada and Cascades, USA: The Black-Backed Woodpecker

Dennis C. Odion<sup>1,2</sup> and Chad T. Hanson<sup>\*,3</sup>

<sup>1</sup>Earth Research Institute, University of California, Santa Barbara, California, CA 93106, USA

<sup>2</sup>Department of Environmental Studies, Southern Oregon University, Ashland, Oregon, OR 97520, USA

<sup>3</sup>Earth Island Institute, 2150 Allston Way, Suite #460, Berkeley, CA 94704, USA

**Abstract:** In the Sierra Nevada and southern Cascade ranges of California and Oregon, a genetically distinct population of the black-backed woodpecker has become rare due, in part, to fire suppression. This species is considered an indicator species for its primary habitat: early successional burned forests with an abundance of standing dead trees. Fuel reduction treatments such as post-fire logging, and forest thinning prior to fire (by creating insufficient snag density and enhancing fire suppression), may further reduce this habitat, but this has not been quantified. Our goal here is to address this information gap. Specifically, we first quantified the impacts of fire suppression and fuel treatments on primary habitat for the black-backed woodpecker. Our objective in this paper was to address how fire management affects the primary habitat of the black-back woodpecker and associated species in the Sierra Nevada and Cascades. We found that fire suppression was associated with a dramatic reduction in stand-initiation processes, a proxy for tree mortality, since the 1930s on public lands. We additionally found that thinning and post-fire clear cutting each exacerbated the effects of fire suppression by reducing primary habitat at an approximately 1:1 ratio with area treated. A scenario based on thinning 20 percent of mature forests over a 20 year period, and post-fire logging in 33% of potential habitat created by fire, reduced the amount of primary habitat after 27 years to 30% of the amount that would occur without these treatments, assuming that modeled effects of the fuel treatments in controlling fire may be realized. Our results indicate that conserving the distinct population of black-backed woodpeckers in the southern Cascades and Sierra Nevada and the biodiversity for which they are an indicator will require that more unthinned area be burned by wildfires and protected after fire as critical habitat. Our results also show that restoration of fire to an extent closer to historical levels would considerably increase black-backed woodpecker habitat and have minimal tradeoff with conservation of mature forest.

**Keywords:** Black-backed woodpecker, burned forest habitat, fire specialist, fire suppression, forest thinning, post-fire logging, snag basal area.

## INTRODUCTION

There may be no forest bird in western North America more restricted to a single vegetation condition than the black-backed woodpecker (*Picoides arcticus*) is to forests of relatively dense fire-killed trees [1-3], where its primary prey, wood-boring beetles, are available in sufficient numbers to offset energy costs of foraging [4, 5]. The woodpecker's reliance on this fire-specialized insect prey in montane forests makes the habitat needs of the bird exceptionally narrow [2, 6, 7]. In fact, despite extensive surveys, only three black-backed woodpecker territories have been documented in unburned forests in California and Oregon in the literature [8], and nest density surveys conducted in both burned forest and nearby unburned forest found numerous nests in post-fire habitat but none in unburned forest [9]. Most black-backed woodpecker detections in the Sierra Nevada and Cascades have been from forests having at least 20 m<sup>2</sup>/ha basal area of snags >23

cm diameter at breast height [10-12] that burned within the previous 7 years [13]. This habitat, which we refer to as primary habitat, must be constantly replenished across the landscape.

Whether the black-backed woodpecker could survive for many generations in the southern Cascades and Sierra Nevada without its primary habitat is questionable. Black-backed woodpecker territories with lower snag basal area have far larger home ranges than those with levels near or above the mean, and travel more than twice the distance to seek food that is less abundant, relative to burned forest [10]. Consistent with conservation biology principles, larger home ranges are indicative of birds that are working much harder, and expending far more energy, in order to obtain food, corresponding to lower reproduction and survival levels that are associated with non-viable "sink" populations [14, 15]. Thus, the long-term viability of the black-backed woodpecker likely depends on its primary habitat even though habitat with fewer snags may sometimes be used.

The black-backed woodpecker is also a U.S. Forest Service indicator of the status and trends of biodiversity associated with its primary habitat. Furthermore, the black-

\*Address correspondence to this author at the Earth Island Institute, 2150 Allston Way, Suite #460, Berkeley, CA 94704, USA; Tel: 530-273-4585; E-mail: [cthanson1@gmail.com](mailto:cthanson1@gmail.com)

backed woodpecker plays a key role in forest ecology by providing nesting holes in fire killed trees for other cavity-nesting birds and mammals [5, 16]. These nesting cavities may have a long lifespan in standing dead trees, linking the fire that originally created black-backed woodpecker habitat to the long-term availability of critical resources for reproduction among many species. Thus, maintaining primary habitat for the black-backed woodpecker is important for overall diversity in forested landscapes.

Pierson *et al.* [17], in a genetic analysis of black-backed woodpeckers from blood and feather samples, found that the allopatric eastern Oregon Cascades population is genetically distinct from the Rockies/boreal population. Pierson *et al.* [17] concluded that the extent of the genetic distinction between these two populations was “similar to those documented among subspecies” in other birds occupying similar ranges. Pierson *et al.* [17] did not collect genetic samples from the California population of black-backed woodpeckers. Further study is warranted to clarify the relationship of the population in California, which may also be disjunct to some degree with the eastern Oregon Cascades population, and is disjunct with other populations of the species. However, it appears that the population in the Sierra Nevada and Oregon Cascades is genetically distinct from other black-backed woodpecker populations, similar to the distinction between the northern spotted owl in the Pacific Northwest, a subspecies of *Strix caurina* that is listed as threatened [18, 19], and the California subspecies, which is not listed. Therefore, in addition to the biodiversity for which it serves as an indicator or provides vital resources for reproduction, the black-back woodpecker is an important conservation concern in its own right in the Sierra Nevada and southern Cascades.

Historical accounts by Cooper in 1870 [20] described black-backed woodpeckers as “numerous” in the Sierra Nevada and southern Cascades. They are now considered rare due to fire suppression and logging [21, 22]. On December 15, 2011, the California Fish and Game Commission accepted for consideration the petition submitted to list the black-backed woodpecker as threatened or endangered. This action has resulted in this species receiving the interim designation of “candidate species.” Under the California Endangered Species Act, candidate species are protected against habitat removal by state agencies. On May 2, 2012, the Sierra Nevada and eastern Oregon Cascades population was petitioned for listing as threatened or endangered under the federal Endangered Species Act [23]. On April 8, 2013, the United States Fish and Wildlife Service issued a positive preliminary finding on the petition, concluding that listing this black-backed woodpecker population may be warranted.

Treatments to reduce forest fuels in the Sierra Nevada and southern Cascades may remove large areas of primary habitat for the black-backed woodpecker [1, 3, 11]. The most obvious example is the harvesting of burned trees in which the woodpeckers nest and upon which they forage. A less obvious example is the thinning of unburned forests. This can impact black-backed woodpecker habitat by substantially reducing forest density and, therefore, snag availability should fire occur [2]. In addition, forest thinning is often done to improve fire suppression capabilities to

better contain wildfires [24, 25]. It has been projected that such fuel treatments, if strategic, may reduce wildfires by 50 percent [24, 26], which would exacerbate existing fire suppression impacts on black-backed woodpeckers.

To date, there have been no systematic analyses of fire management impacts to the primary habitat of the black-backed woodpecker in the Sierra Nevada and southern Cascades. Our primary objective here is to address this information gap. Specifically, we quantified the impacts of fire suppression and fuel treatments on primary habitat for the black-backed woodpecker. To address fire suppression, we considered how rates of stand-initiation, a proxy for tree mortality, have changed since fire suppression became effective. To address current fuel treatments, we quantified future burned habitat with and without thinning and post-fire logging and a 50% improvement in the efficacy of fire suppression. Secondly, we considered how mature forest would change in area under the same management scenarios we considered for black-backed woodpeckers. This provides an opportunity to test how the habitat needs of species at opposite ends of the successional spectrum may be balanced by ongoing fire management.

## METHODS

### Study Area

To define the study area we used the National Geographic range map for the black-backed woodpecker [27]. Within this area we included all conifer forest types where the woodpecker may nest in the Sierra Nevada and Cascades, from mixed-conifer forest and eastside pine up to subalpine forests at the highest elevations [28] on public lands. The analysis area defined by these criteria for the black-backed woodpecker population in the Sierra Nevada, southern Cascades of California, and eastern Oregon Cascades included 36,652 km<sup>2</sup> of middle/upper montane, and subalpine, forested landscape on federal lands in these regions. Our analysis of habitat change focused only on the public lands within this area. This is because potential habitat for black-backed woodpeckers and other species for which it serves as an indicator is typically logged immediately following fire on private lands. Therefore, the habitat is currently restricted almost entirely to public lands.

### Data on Stand-Initiation and Forest Regrowth

An estimate of the impacts of fire suppression on the availability of primary habitat for the black-backed woodpecker may be obtained by comparing the rates of stand-initiation immediately before and after the onset of fire suppression. To accomplish this, we used the extensive U.S. Forest Service Forest Inventory and Analysis (FIA) forest monitoring data (<http://www.fia.fs.fed.us/tools-data/>). FIA is a monitoring system based on one permanent, random plot per 2400 ha across all forest lands. We excluded plots from non-conifer and lower montane areas [13]. We included plots for all conifer forest types (but not pinyon-juniper, which is apparently not used by black-backed woodpeckers [13]) from montane through subalpine forest types along an elevational gradient [13, 28]. These included plot types dominated by the following: ponderosa pine (*Pinus*

*ponderosa*); sugar pine (*Pinus lambertiana*); white fir (*Abies concolor*); grand fir (*Abies grandis*); Douglas-fir (*Pseudotsuga menziesii*); incense cedar (*Calocedrus decurrens*); western red cedar (*Thuja plicata*); mixed conifer (pine and fir); western hemlock (*Tsuga heterophylla*); Engelmann spruce (*Picea engelmannii*); Pacific silver fir (*Abies amabilis*); red fir (*Abies magnifica*); noble fir (*Abies procera*); Jeffrey pine (*Pinus jeffreyi*); lodgepole pine (*Pinus contorta*); western white pine (*Pinus monticola*); mountain hemlock (*Tsuga mertensiana*); whitebark pine (*Pinus albicaulis*); foxtail pine (*Pinus balfouriana*); limber pine (*Pinus flexilis*); and subalpine fir (*Abies lasiocarpa*). FIA data were available from 2001-2009, comprising 90% of the plots available within our analysis regions. There were a total of 641 FIA plots in the database that met our criteria. We eliminated plots which had multiple stand-initiation dates.

An FIA plot consists of a 1 ha area. For tree measurements, this area is sub-sampled with four circular subplots that are 0.1 ha for large tree sampling and 0.017 ha for smaller tree sampling (defined by region). The diameter at breast height (dbh) and crown position of each tree and the ring count from two cores from dominant and co-dominant trees of each conifer species are measured in each subplot [29]. Stand age for an FIA plot is determined from the average of all ring counts from sub-plot samples, weighted by cover of sampled trees, and 8 years are added for estimated time to grow to breast height (1.4 m) [29]. We used FIA plots classified as forested. As described below, we used regression analysis of tree basal area as a function of stand age to determine existing rates of forest redevelopment following stand-initiating fire.

### Contemporary Rates of Primary Habitat Formation

To define the current rate of formation of primary black-backed woodpecker habitat across this region, we analyzed fire disturbances using all available processed U.S. government "Monitoring Trends in Burn Severity" (MTBS) data from 1984-2010 in the study area (www.mtbs.gov). We classified the data using a Relative delta Normalized Burn Ratio (RdNBR) threshold >574, as described by Miller and Thode [30]. At RdNBR of 574, mean basal area mortality of about 51% on average occurs among trees >30 cm in diameter at breast height [31]. Therefore, for RdNBR values >574, mean basal area mortality for trees selected by black-backed woodpeckers ranged from 51-100% [31]. From fire severity data we calculated rotation for fire having this range of mortality, which we call *higher severity* fire [32].

### Statistical Analyses

We used live tree diameter at breast height (dbh) data to prepare regressions with basal area and stand age, and used stand age data from the unmanaged forest landscape (areas in which stand age is a function of natural disturbance, rather than logging) to derive the existing stand age distribution and evaluate it relative to the theoretical distribution in the absence of fire suppression. Unmanaged forests included those in designated wilderness, inventoried roadless areas, national parks, and wild and scenic river corridors. To better understand the degree to which fire versus insect and disease

disturbances may naturally account for habitat for the black-backed woodpecker, we plotted the FIA stand ages and compared rates of stand initiation that occurred prior to and after fire suppression. This provides insight into the degree to which stand scale disturbances were caused by fire. A small decrease in amounts of stand initiation with fire suppression would suggest that disturbances other than fire have been important causes of forest mortality, while a large decrease would suggest that fire has been the predominant disturbance agent.

### Quantifying Future Habitat

We calculated the annual rate of higher severity fire in mature and young forests and subsequent regrowth to parameterize our calculations using annual time steps to project future proportions of burned forest habitat (H) along with mature forest (M), young forest (Y), non-habitat (N), and thinned forest (T). The proportion of each state in the landscape at time  $t$  defined a vector ( $P_t^M, P_t^H, P_t^N, P_t^Y, P_t^T$ ). Transition probabilities  $\psi_t^{rs}$  equaled the probability that any portion of state  $r$  at time  $t$  transitions to state  $s$  at time  $t + 1$ :

$$\begin{bmatrix} \psi_t^{MM} & \psi_t^{HM} & \psi_t^{YM} & \psi_t^{TM} & \psi_t^{NM} \\ \psi_t^{MH} & \psi_t^{HH} & \psi_t^{YH} & \psi_t^{TH} & \psi_t^{NH} \\ \psi_t^{MY} & \psi_t^{HY} & \psi_t^{YY} & \psi_t^{TY} & \psi_t^{NY} \\ \psi_t^{MT} & \psi_t^{HT} & \psi_t^{YT} & \psi_t^{TT} & \psi_t^{NT} \\ \psi_t^{MN} & \psi_t^{HN} & \psi_t^{YN} & \psi_t^{TN} & \psi_t^{NN} \end{bmatrix} \begin{bmatrix} P_t^M \\ P_t^H \\ P_t^Y \\ P_t^T \\ P_t^N \end{bmatrix} = \begin{bmatrix} P_{t+1}^M \\ P_{t+1}^H \\ P_{t+1}^Y \\ P_{t+1}^T \\ P_{t+1}^N \end{bmatrix}$$

Fig. (1) shows the relationship between the states and non-zero transition probabilities.

The initial amount of mature forest was the proportion of FIA plots with >20 m<sup>2</sup>/ha basal area. Initial amounts of burned habitat (H) and non-habitat (N) were determined by the amount created by higher-severity fire in mature forests (M) in 7 years using the rate of higher-severity fire from 1984-2010. The initial proportion of young forests (Y) was determined by subtracting the proportions of mature forest (M), burned habitat (H) and non-habitat (N: burned but with snag basal area <20 m<sup>2</sup>/ha) from 1.0. The initial amount of thinned forest (T) was considered zero for simplicity and because of lack of data. We used the transition rates in Table 1 and equation 1 to project 27 years forward, seven years after all thinning treatments would be completed. This represents the effect on primary habitat, during the 7-year period in which primary habitat persists [13], following full implementation of 20% thinning treatments over 20 years.

In fires in which there is 51-100% basal area mortality, not all forests would become black-backed woodpecker habitat because some would be too sparse. We estimated the amount of forest that would be converted to primary habitat for black-backed woodpeckers, and biodiversity for which they serve as indicators, by determining the proportion of FIA plots with >20 m<sup>2</sup>/ha live basal area ( $D_{75}$ ) that would have >20 m<sup>2</sup>/ha following higher severity fire, assuming an

### Black-backed Woodpecker habitat model

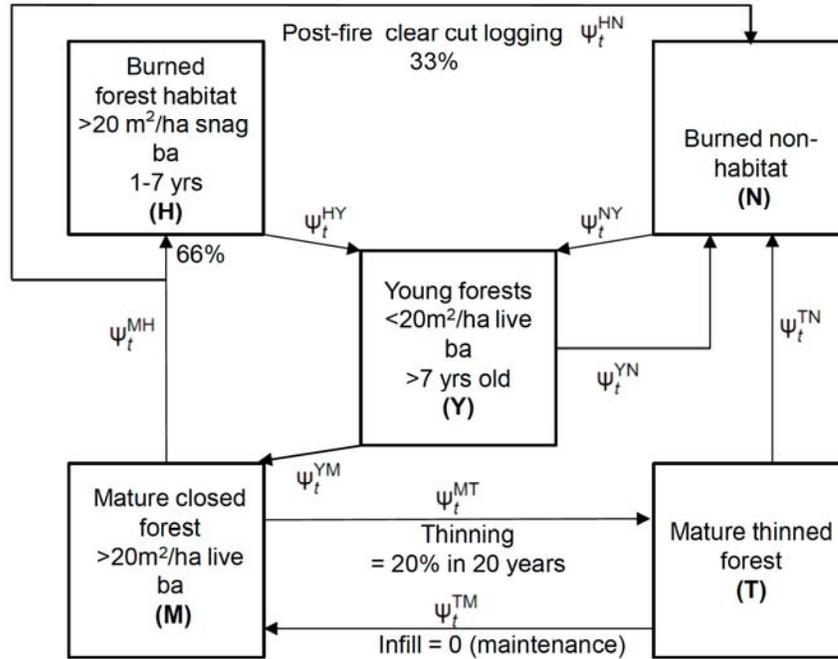


Fig. (1). State and transition model for projecting future amounts of black-backed Woodpecker habitat. Transitions that do not occur, such as between burned habitat and thinned forest, are not shown. All transitions and their calculations are listed in Table 1.

average mortality of 75% of basal area (i.e., the midpoint of the range of 51-100% basal area mortality in the fire severity data). Forests that would have <20 m<sup>2</sup>/ha snag basal area after higher severity fire were considered not to function as primary habitat. The proportions (D<sub>75</sub> and 1- D<sub>75</sub>) were multiplied with the annual rotation of higher severity fire to determine the transition rate for primary habitat and non-habitat created by fire (ψ<sub>t</sub><sup>MH</sup> and ψ<sub>t</sub><sup>MN</sup> respectively (Table 1)).

Forests with very high basal area could also burn with RdNBR values <574 and yield snag basal area >20m<sup>2</sup>/ha. However, we found that this would be <1% of the amount created by higher severity fire. We therefore did not consider effects of lower severity fire in creating primary habitat. We also did not include unburned areas with higher levels of recent tree mortality from native beetles as suitable habitat in this analysis because they have so rarely been found to function as habitat [8] and no existing data sets track and quantify the basal area of recently killed trees, but aerial monitoring data does indicate that less than one-tenth of 1% of the unburned forest in the study region might qualify as primary habitat, based upon snag densities ([http://www.fs.usda.gov/detail/r5/forest-grasslandhealth/?cid=fsbdev3\\_046677](http://www.fs.usda.gov/detail/r5/forest-grasslandhealth/?cid=fsbdev3_046677)).

We defined the longevity of burned forest habitat (H) to be 7 years after fire [13] and we considered the annual transition rate ψ<sub>t</sub><sup>HY</sup> from burned habitat to the next forest state, young forest (Y), to be 1/7 (Table 1).

The transition from young forest to mature forest ψ<sub>t</sub><sup>YM</sup> was defined by the amount of time after higher severity fire, starting at year 8, needed for forests to develop 20 m<sup>2</sup>/ha live tree basal area (Table 1). Lower severity fire can reduce

basal area from >20 m<sup>2</sup>/ha to < 20 m<sup>2</sup>/ha. However, this transition is already considered in the regrowth rate (i.e., it is the net rate), which incorporates the effects of lower severity fire. Therefore, transition from mature to young forest ψ<sub>t</sub><sup>MY</sup> was zero. Young forest was assumed to burn with the same rate of higher severity fire as mature forests, so the rotation of higher severity fire provides the transition from young forest to non-habitat, ψ<sub>t</sub><sup>YN</sup> (Table 1). We assumed that burned forest habitat (H) and non-habitat (N) do not reburn within 7 years of a previous fire. We also assumed that development of non-habitat (N) to mature forest (M) will take the same pathway and time as development of burned habitat (H) to mature forest (M). Additionally, there were a number of transitions that do not occur among states, which were assigned a transition probability of zero (e.g., burned habitat to thinned forest, ψ<sub>t</sub><sup>HT</sup>, Table 1), and are not shown in Fig. (1).

#### Treatment Assumptions

We quantified the effects of treatments over a 27-year period. The transition from mature to thinned forest, ψ<sub>t</sub><sup>MT</sup>, was calculated assuming strategic placement of thinning treatments in mature forests to help contain wildfires [26]. For our default scenario, thinning would impact 20% of the amount of the landscape that had mature forest (69%) in each year, beginning in year 1. Treatment of 20% of the landscape has been shown in modeling studies to reduce wildfires by about 50% [26]. Therefore, we also calculated the effect of doubling the length of the rotation of higher severity fire, FR<sup>hs</sup>.

**Table 1. Annual Transition Probabilities Used in Transition Matrices for Each Scenario Analyzed for Forests Used by the Black-Backed Woodpecker in the Sierra Nevada, southern Cascades, and Eastern Oregon Cascades**

Transition Probabilities	No Treat	Thin 20% Maintain	Post-Fire Clearcut Recover
$\psi_i^{MM}$	$1 - \psi_i^{MH}$	$1 - \psi_i^{MH} - \psi_i^{MT}$	$1 - \psi_i^{MH} - \psi_i^{MT} - \psi_i^{MN}$
$\psi_i^{MH}$	$(1/FR^{hs}) * D_{75}$	$(1/FR^{hs}) * D_{75}$	$(1/FR^{hs}) * D_{75} * .67 - .33(1/FR^{hs})$
$\psi_i^{MY}$	0	0	0
$\psi_i^{MT}$	0	.689*0.01	.689*0.01
$\psi_i^{MN}$	$(1/FR^{hs}) * (1 - D_{75})$	$(1/FR^{hs}) * (1 - D_{75})$	$(1/FR^{hs}) * (1 - D_{75}) + .33(1/FR^{hs})$
$\psi_i^{HM}$	0	0	0
$\psi_i^{HH}$	$1 - \psi_i^{HY}$	$1 - \psi_i^{HY}$	$1 - \psi_i^{HY}$
$\psi_i^{HY}$	1/7	1/7	1/7
$\psi_i^{HT}$	0	0	0
$\psi_i^{HN}$	0	0	0
$\psi_i^{YM}$	$1/(G^{YM} - 7)$	$1/(G^{YM} - 7)$	$1/(G^{YM} - 7)$
$\psi_i^{YY}$	$1 - \psi_i^{YN} - \psi_i^{YM}$	$1 - \psi_i^{YN} - \psi_i^{YM}$	$1 - \psi_i^{YN} - \psi_i^{YM}$
$\psi_i^{YT}$	0	0	0
$\psi_i^{YH}$	0	0	0
$\psi_i^{YN}$	$1/FR^{hs}$	$1/FR^{hs}$	$1/FR^{hs}$
$\psi_i^{TM}$	0	0	0
$\psi_i^{TH}$	0	0	0
$\psi_i^{TY}$	0	0	0
$\psi_i^{TT}$	0	0	0
$\psi_i^{TN}$	0	0	0
$\psi_i^{NM}$	0	0	0
$\psi_i^{NH}$	0	0	0
$\psi_i^{NY}$	1/7	1/7	1/7
$\psi_i^{NT}$	0	0	0
$\psi_i^{NN}$	$1 - \psi_i^{NY}$	$1 - \psi_i^{NY}$	$1 - \psi_i^{NY}$

Variables are as follows:  $FR^{hs}$  is the higher severity fire rotation; G is the time required for stands to grow from young forest to mature forest;  $D_{75}$  is the proportion of FIA plots that had  $>20 \text{ m}^2/\text{ha}$  dead basal area after burning by assuming 50-100% basal area mortality (mean of 75%); H = habitat (recently burned forest, 7 years or less post-fire, with  $>20 \text{ m}^2/\text{ha}$  snag basal area); Y = young forest; M = Mature forest (68.9% of landscape initially); and N = non-habitat.

We assumed that thinning treatments would be maintained and therefore the transition from thinned forest to mature forest,  $\psi_i^{TM}$ , equaled 0. We also assumed that no black-backed woodpecker primary habitat would be created by fire in thinned forests,  $\psi_i^{TH} = 0$ , and that thinned forests

would remain in the same state following fire ( $\psi_i^{TN} = 0$ ) (Table 1).

For scenarios involving post-fire clear cutting, we assumed that 33% of the burned habitat would be affected in year 1 after fire. This may be lower than current rates [22], as much of the forests with higher basal area favored by black-backed woodpeckers are also targeted for harvest. The

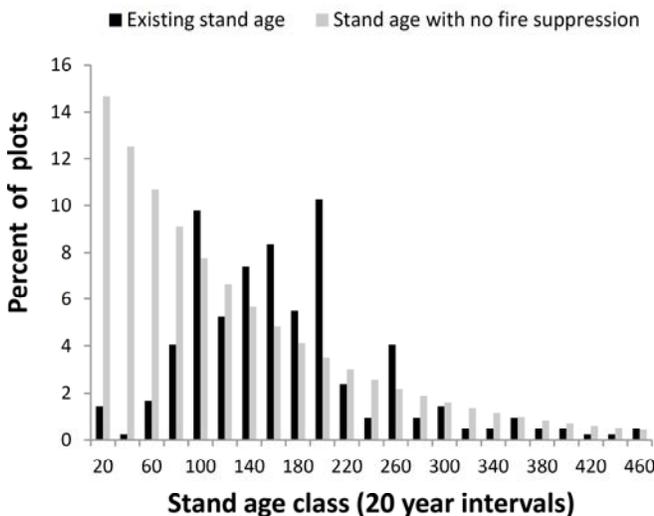
clear cutting was assumed to cause transition to non-habitat [1, 33].

Finally, we quantified the effect of both shortening and lengthening the current rotation of higher severity fire on mature forest habitat relative to burned forest habitat on the landscape. For both mature forest habitat and black-backed woodpecker primary habitat, the amount maintained under different rotations of higher severity fire can be expressed as a percentage of the maximum potential amount that could occur in 27 years. We used the equations in Table 1 to determine these maximum amounts. Potential mature habitat was determined as the amount with no fire occurring whatsoever in 27 years. One hundred percent of the potential habitat for black-backed woodpeckers was the amount when we increased the transition rate from mature forest to burned habitat to the same annual rate as burned habitat's transition back to mature forest. The same rate between these opposing processes would, over time, maintain the most black-backed woodpecker habitat.

**RESULTS**

**Stand-Initiation and Forest Regrowth**

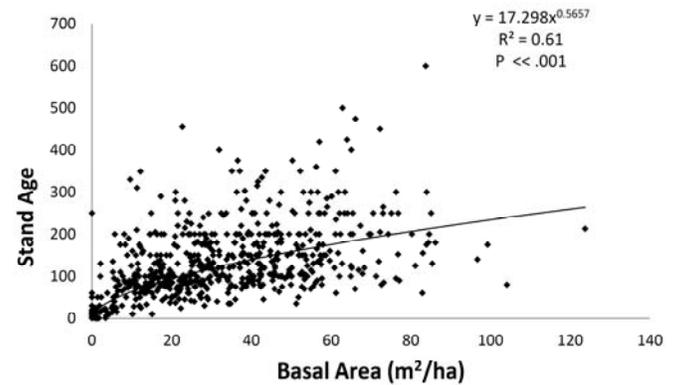
Fig. (2) shows the current age classes from the FIA data of stands in the range of black-backed woodpecker in the unmanaged portions of the study area. The theoretical age class distribution in which fire suppression had never occurred has also been shown, using the rate of stand initiation from prior to fire suppression (from 1750-1850). The rate of stand-initiation prior to fire suppression was more than six times greater than the rate since 1930 (Fig. 2). This change in the stand-initiation rate has dramatically shifted the age class distribution of forests. There is a general absence of relatively young stands, indicating that, without fire, there are few disturbances leading to new stand



**Fig. (2).** Forest stand age distribution in the study area, and the theoretical distribution with a 126-year rotation for higher severity fire as occurred prior to settlement (1750-1850), based upon FIA stand age data. This pre-settlement rotation was calculated as 100 years divided by the proportion of plots with stand-initiation from 1750-1850 out of all plots with stand-initiation in or prior to 1850.

initiation. Thus the creation of habitat for the black-backed woodpecker appears to have been predominantly due to fire, because very little stand-initiation has occurred since the onset of fire suppression and the amount that has occurred may be explained by fires that escaped suppression.

There was a highly significant relationship in the FIA plots (managed and unmanaged areas combined) between live tree basal area and stand age (Fig. 3,  $P < 0.001$ ,  $n = 640$ ). The amount of time following disturbance needed for forests to regrow late-successional live tree basal area of 20 m<sup>2</sup>/ha was 94 years. The annual transition rate from young to mature forests,  $\psi_t^{YM}$ , was  $1/(94-7)$ , with the 7 subtracted because 7 years of growth after fire were required for burned habitat to transition to young forests.



**Fig. (3).** Scatterplot of live tree basal area per hectare and stand age from U.S. Forest Service FIA data for the plots in the study area.

**Contemporary Rates of Primary Habitat Formation**

Using the U.S. government data, the rotation for higher severity fire (RdNBR >574) from 1984-2010 was 625 years over the entire analysis area. The amount of mature forest that had >20 m<sup>2</sup>/ha of snag basal area following higher severity fire in our projection (and thus became primary habitat), assuming 50-100% basal area mortality (a mean of 75% basal area mortality), was 81%. Thus, the annual transition rate from mature forest to primary habitat for black-backed woodpeckers,  $\psi_t^{MH}$ , was  $(1/625)*0.81$ . With this low rate of primary habitat formation, this ephemeral habitat would remain at very low levels (less than 1% of the forested landscape on public lands within the range of this species in the eastern Oregon Cascades, southern Cascades in California, and Sierra Nevada) even without considering impacts from thinning or post-fire clear cutting (Table 2).

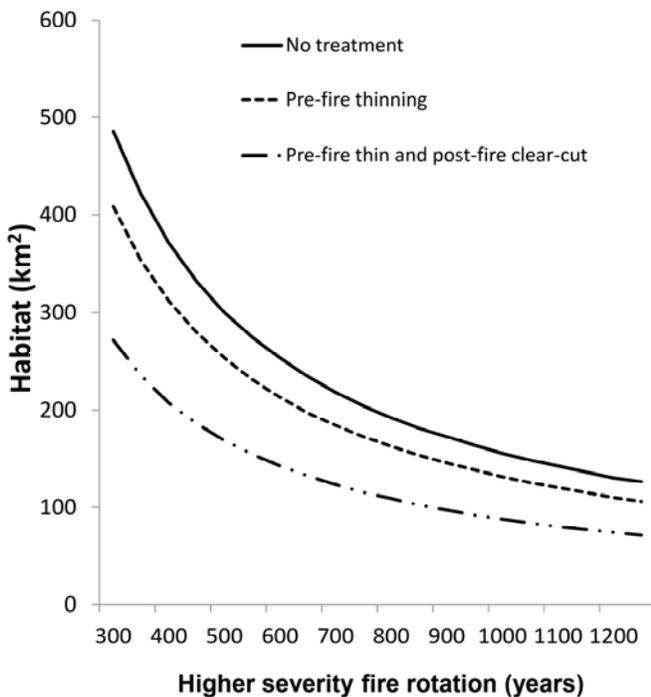
**Treatment Impacts**

With thinning of 20% of mature forests and assuming no effect of this on fire suppression, our calculations show, as would be expected, that there would be almost 20% less primary habitat than with no treatment after 27 years, or 7 years after the thinning treatments would be fully implemented (Table 2). A 50% reduction in fire, as projected from strategically thinning 20% of the landscape to achieve enhanced fire suppression [24, 26], would increase the rotation interval for higher severity fire from 625 years to

**Table 2. Amounts of Black-Backed Woodpecker Primary Habitat Created by Higher Severity Fire in Forests 27 Years in the Future with No Treatments, Pre-Fire Thinning of 20 Percent of Mature Forests Over 25 Years, Post-Fire Clear-Cutting 33% of Habitat Created by Fire, Both Pre-Fire Thinning and Post-Fire Clear Cutting, and Both Pre-Fire Thinning and Post-Fire Clear Cutting with the Assumption that Pre-Fire Thinning Enhances Fire Suppression Effectiveness by 50 Percent**

	Habitat (km <sup>2</sup> )	Amount of the Habitat-Capable Public Landscape (%)
No treatment	243	0.66
Pre-fire thinning (20%)	205	0.56
Pre-fire thinning (20%) with enhanced fire suppression	107	0.29
Post-fire clear cutting (33%) and no thinning	184	0.50
Pre-fire thinning (20%) and post-fire clear cutting (33%), assuming no enhanced fire suppression	137	0.37
Pre-fire thinning (20%) and post-fire clear cutting (33%) with enhanced fire suppression	72	0.20

1250 years. The effects can be seen in Fig. (4). The result of reduced fire, combined with the direct loss of habitat from thinning, would be a reduction of habitat by more than half after 27 years relative to no treatment (Table 2).



**Fig. (4).** Changes in amount of black-backed woodpecker primary habitat created by fire in the study area as a function of higher severity fire rotation under the following scenarios: no treatment; pre-fire thinning of 20% of mature forests; and pre-fire thinning combined with post-fire logging of 33% of habitat.

Post-fire clear cutting also removed habitat at a 1:1 ratio with area treated. Thus, the 33% treatment scenario resulted in 33% loss of primary habitat after 27 years compared to the no treatment scenario. In contrast to thinning, which takes 20 years for impacts to fully develop, post-fire clear-cutting would remove 33% of primary habitat from the start. The effects of both thinning and post-fire clear-cutting were approximately additive. With these treatments and no increase in fire suppression efficacy, after 27 years, nearly half the amount of primary habitat that would be maintained

with no treatment would be eliminated (Table 2). If thinning succeeded in lengthening fire rotations to 1250 years (Fig. 4), the effects combined with clear cutting of 33% of post-fire habitat would reduce overall primary habitat to 30% of the amount that would be maintained with no treatment (Table 2).

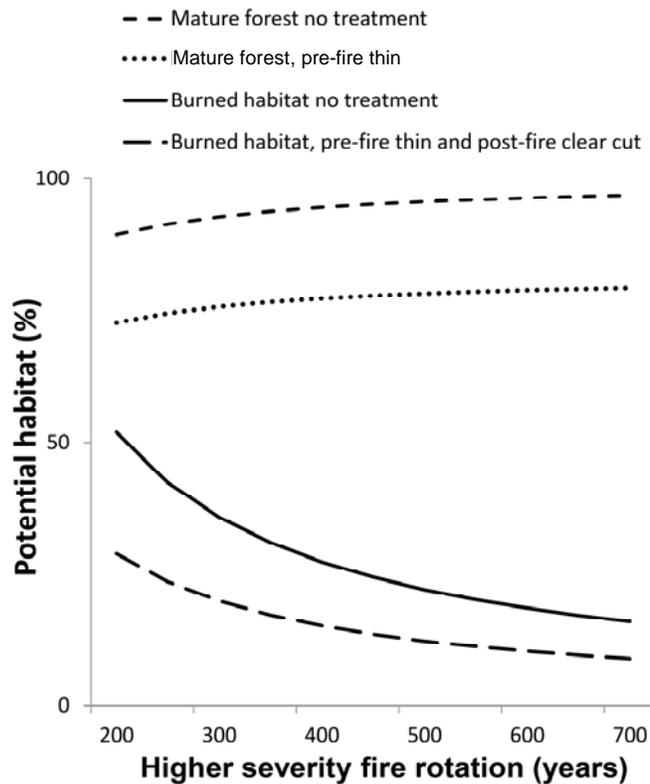
In contrast to burned habitat, the proportion of mature forest on the landscape remains relatively constant when higher severity fire increases (Fig. 5). This is because mature forest is maintained by regrowth. Mature forest amounts will remain relatively resilient and stable unless higher severity fire rotations shorten (more fire) to almost the length of the regrowth period for mature forests (94 years). At a rotation of 94 years, under which higher severity fire occurs at a level 6-7 times greater than current levels, mature forests would occupy 28,096 km<sup>2</sup>, or 77 percent of the landscape, and black-backed woodpecker primary habitat would occupy 1,361 km<sup>2</sup>, or 3.7 percent of the landscape, after 27 years.

## DISCUSSION

The stand age data we analyzed indicate that fire has been and remains the predominant natural disturbance agent capable of creating most habitat for black-backed woodpeckers in the Sierra Nevada, southern Cascades of California, and eastern Oregon Cascades, and that there has been a paucity of disturbances leading to new stand initiation since the onset of fire suppression. Primary black-backed woodpecker habitat has thus declined dramatically: only 1/6<sup>th</sup> as much has been created since the onset of fire suppression. This has been compounded by loss of habitat on private lands, where burned forests are typically logged. These factors likely explain how a bird that was historically somewhat common [20] has become rare.

Our calculations illustrate how impacts of current management further reduce habitat from levels that may be critically low already. Thinning and post-fire clear cutting (cutting most or all snags) reduced habitat at a 1:1 ratio with area treated. This makes it straightforward to infer the direct impacts of different amounts of these treatments than assumed in our default scenario. This 1:1 relationship between area treated and primary habitat lost also makes it straightforward to consider the effects of changing the

definition of primary habitat. Most significantly, using our definitions of primary habitat, we found that thinning 20% of forests and post-fire clear-cutting 33% of burned forests, along with 50% increased efficacy of fire suppression, would reduce future amounts of primary habitat for black-back woodpeckers, and the biodiversity for which they serve as indicators, to less than a third of the amount that would be maintained with no treatments.



**Fig. (5).** Changes in the percent of maximum potential habitat for mature forest and black-backed woodpecker primary habitat created by fire in the study area as a function of higher severity fire rotation under the following scenarios: no treatment; pre-fire thinning of 20% of mature forests; and pre-fire thinning combined with post-fire logging of 33% of habitat.

Our findings are only slightly affected if we relax the definition of primary habitat to include all mature forests burned with higher severity fire in the range of the black-backed woodpecker (i.e., to include forests with <math><20\text{ m}^2/\text{ha}</math> snag basal area). This is because most mature forests (81%) have over

Hanson *et al.* [23] have estimated that only several hundred black-backed woodpecker pairs may remain across the entire potential range of suitable habitat in California, and a lower number for the eastern Oregon Cascades. These population levels are substantially lower than average minimum viable populations for birds (3742 individual adults) estimated in the meta-analysis by Traill *et al.* [34]. The narrow habitat requirements of the black-backed woodpecker make it particularly vulnerable to further habitat loss. Because of fire suppression, burned habitat levels are not only lower, but availability maybe less predictable in time, with long gaps with little or no fire over large areas. Burned habitat may also be much more widely spaced geographically. This may be an important stressor because the maximum detection distance for black-backed woodpeckers for burned forests may be about 50 km [35]. Colonization of primary habitat may be prevented due to the lack of habitat nearby enough to provide a source of immigrants. Consistent with this possibility, extensive monitoring using both point counts and playback calls has failed to detect black-backed woodpeckers in over 40% of the larger mixed-severity fire areas containing suitable black-backed woodpecker habitat in the Sierra Nevada, southern Cascades in California, and Modoc Plateau [13, 28].

Whether the population in California and the eastern Oregon Cascades remains viable may depend in significant part on the degree to which fuel treatments affect future fire, which has substantial potential to impact burned habitat amounts. However, it is important to recognize uncertainty in the projected effect of strategically treating 20% of the mature forested landscape. This is based on modeling projections, not empirical findings. Future fire is also uncertain due to climate change. However, rates of fire disturbances are so much lower than occurred prior to fire suppression (Fig. 2) that even a doubling of fire would still be far lower than the historic levels that once provided habitat for black-backed woodpeckers in California and Oregon. In addition, the prediction by Littell *et al.* [36] that fire will double by 2050 in the Pacific Northwest assumes decreased summer precipitation as a main driver of increased fire. Current data indicate a pattern of increasing, not decreasing, summer precipitation in the Pacific Northwest [37, 38]. Other predictions suggest future variability in fire over the region, including increases as well as possible decreases in future fire [39]. In terms of actual patterns in fire occurrence under changing climate, there is no ongoing trend in the proportion of fire that is high in severity in the dry Cascades of Oregon [40, 41]; nor is there a trend in the amounts of high-severity fire in the southern Cascades of California [42], but data are only available since 1984. The upward trend in fire severity in the Sierra Nevada reported by Miller *et al.* [43] and Miller and Safford [44] using an incomplete regional data set does not exist when all the currently available burn severity data are analyzed, using the more comprehensive U.S. government fire severity data base from Monitoring Trends in Burn Severity, or “MTBS”, and using forest mapping that pre-dates the time series to avoid missing montane conifer forest that experiences higher severity fire and is later remapped as chaparral [45]. While increased fire in the future could help prevent further habitat decline, under current management habitat may still be limited and ultimately insufficient in the future for black-

backed woodpeckers and biodiversity for which they serve as indicators.

Although the number of black-backed woodpeckers has declined with suppression of fire, excess fire has been a concern for species that rely on mature forests. In the Sierra Nevada and southern Cascades, these include the spotted owl (*Strix occidentalis ssp. occidentalis*) and Pacific fisher (*Martes pennanti*). We calculated not only the percent of burned habitat, but also the percent of mature forest habitat that would occur with different rotations of higher severity fire after 27 years. Fig. (5) shows that the amount of mature forest is almost maximized at the current 625 year rotation for higher severity fire. It should be noted that not all of this mature forest would be habitat for all mature forest species; for example, spotted owls do not appear to nest in forests with less than 23-27 m<sup>2</sup>/ha of basal area [46, 47]. Nonetheless, due to lack of fire, mature forest habitat, in areas where logging or fuel treatments has not diminished this habitat, may be available in amounts that may currently be near historical highs. Though doubling higher severity fire would have almost no effect on mature forests, it would increase habitat for black-backed woodpeckers substantially and would likely be the most effective way to increase populations above critically low levels. The best balance between the habitat needs of fire-dependent and mature forest species would be at higher rates of fire than those occurring today and closer to those that occurred before fire suppression. Because fire-dependent and mature forest dependent species are at opposite ends of the spectrum, most biodiversity is associated with a mosaic of these habitats, and balancing the habitat needs of these species will likely balance the needs for biodiversity in general [48, 49]. Moreover, emerging data indicate that, while mature forest species like the spotted owl select denser, unburned or low-severity burned forest for nesting and roosting, they preferentially select higher severity fire areas (which have not been salvage logged) for foraging [50]. Thus, an increase from current low levels of higher severity fire may provide some overall benefits even to mature forest species.

## CONCLUSIONS

Conserving the distinct population of black-backed woodpeckers in the Sierra Nevada, southern Cascades, and eastern Oregon Cascades, and the biodiversity for which this species is an indicator, may require that more unthinned area be burned by wildfires and protected after fire as critical habitat. Options for better conserving black-backed woodpeckers within the context of competing land management goals are reviewed in Bond *et al.* [51], and include recommendations to protect higher severity post-fire habitat in mature forests, as well as to curb thinning operations in unburned mature forest. Federal land management agencies have an opportunity to propose incorporation of these conservation recommendations into forest plans, which are currently commencing a process of revision. Importantly, our results show that restoration of fire to be closer to historical levels would considerably increase black-backed woodpecker habitat and have minimal tradeoff with conservation of mature forest.

## CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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