Effects of Post-Fire Salvage Logging on Cavity-Nesting Birds and Small Mammals in Southeastern Montana

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We investigated how post-fire salvage logging of Ponderosa Pine (*Pinus ponderosa*) affected populations of cavity-nesting birds and small mammals in southeastern Montana in 2004 and 2005. We examined two salvage and two control plots with three point-count stations and one small mammal trap site randomly distributed across each plot. We used point counts and distance sampling methods to estimate density of cavity-nesting birds on each treatment. We also searched each plot for nests and used program MARK to construct a set of candidate models to investigate variations in nest survival related to treatment, year, and time. We used live traps arranged in webs centered on trapping sites and distance sampling methods to estimate small mammal density. Habitat characteristics were also quantified on each plot. Density of all cavity-nesting birds combined and of Hairy Woodpeckers (*Picoides villosus*) in particular were higher on the control than the salvage treatment. Density of large trees and abundance of active cavities were higher on the control treatment. Nest cavities on the salvage treatment were most often located in non-logged watersheds. Nest survival estimates were uniformly high, with only marginal variations attributed to treatment and year. Density of Deer Mice (*Peromyscus maniculatus*) was higher on the salvage than the control treatment, reflecting the amount of downed woody debris created during harvest.

Key Words: cavity-nesting birds, downed woody debris, forest management, nest survival, salvage logging, wildfire, Hairy Woodpecker, *Picoides villosus,* Deer Mouse, *Peromyscus maniculatus,* Custer National Forest, Montana.

The current fire regime within the Ponderosa Pine (*Pinus ponderosa*) forest type in western North America is thought to differ significantly from historical patterns and processes as a result of fire suppression, logging, and livestock grazing (Agee 1993; Arno and Allison-Bunnell 2002). The accumulation of woody fuels from decades of fire suppression is driving a shift from an historical regime of slow-burning ground fires to one that has a greater proportion of severe crown fires (Covington and Moore 1994; Allen et al. 2002). As a result, U.S. state and federal agencies are implementing the Healthy Forest Initiative and the Healthy Forest Restoration Act of 2003 to reduce fuels and the associated risk of severe wildfires and to address demand for commercial timber (Franklin et al. 2003). Federal policy promotes post-fire logging by exempting sales <100 ha from environmental review and allows operations to occur on lands otherwise unavailable for harvest (Federal Register 2003*). Ecologists are questioning the merit of salvage logging because of documented negative effects on soil, vegetation, and wildlife (McIver and Starr 2001; Beschta et al. 2004; Lindenmayer and Noss 2006; Hutto 2006). In addition, salvage logging may actually promote conditions suitable for severe wildfire and hinder forest regeneration (Donato et al. 2006; Greene et al. 2006).

Although burned forests are rare habitats at the landscape scale, spatial heterogeneity created by the patchy distribution of fire severities supports high biodiversity (Turner et al. 2003; Schmiegelow et al. 2006; Hutto 2006). Salvage logging homogenizes this forest structure and alters the post-fire wildlife community. Typically, large trees (>23 cm diameter at breast height [DBH]) favored by foraging and breeding cavity-nesting birds (Covert-Bratland et al. 2006; Pope et al. 2009) are harvested during salvage logging. Consequently, the abundance of cavity-nesting birds declines (Hutto 1995; McIver and Starr 2001; Kotliar et al. 2002) as they are replaced by ground- and shrub-nesting species (Morissette et al. 2002; Cahall and Hayes 2009; Castro et al. 2010). Size and distribution of burned tree stands that remain after salvage logging also shape composition of the cavity-nesting bird assemblage. For example, Black-backed Woodpeckers (*Picoides arcticus*) and American Three-toed Woodpeckers (*P. dorsalis*) require relatively large stands of burned trees, whereas Lewis's Woodpeckers (*Melanerpes lewis*) often occupy smaller stands typical of logged areas (Saab and Vierling 2001; Morissette et al. 2002; Hutto and Gallo 2006). In addition to spatial scale, temporal scale (measured as time since fire) affects the abundance of insect prey of primary and secondary cavity nesters and thus the composition of the post-fire bird assemblage (Saab et al. 2004; Smucker et al. 2005; Covert-Bratland et al. 2006; Hutto 2006).

Little is known about the effects of post-fire salvage logging on fauna other than cavity-nesting birds (McIver and Starr 2001; but see Converse et al. 2006). Salvage logging may increase the amount of downed woody debris (Donato et al. 2006), which provides small mammals with additional habitat for reproduction, foraging, and predator avoidance (Harmon et al. 1986). The accumulation of downed woody debris following wildfire correlates with the rate of recolonization and an increase in the diversity of small mammals (Carey and Johnson 1995; Fisher and Wilkinson 2005; Converse et al. 2006). In contrast, removal of downed woody debris following salvage of trees damaged by a tornado was correlated with a decrease in the abundance of small mammals (Loeb 1999).

A stand-replacement fire of moderate to high intensity that was ignited by lightning occurred over 26 527 hectares of Ponderosa Pine in southeastern Montana in 2002. The U.S. Forest Service implemented a management plan in summer 2003 to reduce the risk of fire by salvage logging all standing dead trees >25 cm DBH on 485 ha. Literature reviews (McIver and Starr 2001; Kotliar et al. 2002) urged more research into the effects of post-fire salvage logging, so we took the opportunity to compare the density of cavity-nesting birds and the density of small mammals on salvage-logged and control plots. We also estimated breeding success of cavity-nesting birds, because most studies investigating the effects of logging have not measured this important parameter (Sallabanks et al. 2000; Kotliar et al. 2002; but see Saab et al. 2011).

Nest abundance and foraging activity of cavity-nesting birds after fire has been shown to be positively correlated with the size and density of standing snags (Haggard and Gaines 2001; Nappi et al. 2003). Therefore, we predicted that salvage logging would lead to a significant decrease in the number of active nest sites and a significant decrease in the overall abundance of cavity-nesting species. We expected that the volume of downed woody debris would be greater on logged areas (Donato et al. 2006), and we predicted that the density of small mammals would be greater on salvage plots.

Methods

Study area

The study area is located in a Ponderosa Pine forest approximately 40 km southeast of Ekalaka, Montana, U.S.A., in the Long Pines unit of the Custer National Forest (45°38'N, 104°11'W). The study site (1320 ha) is part of a larger forested area (28 368 ha) intermixed with pine savannah, native grassland (*Achnatherum* spp., *Bouteloua* spp., *Carex* spp., and *Pseudoroegneria* spp.), and woody draws. The area consists of hills and rocky buttes (elevation 1000–1200 m) surrounded by lower elevation sagebrush shrubland (*Artemisia* spp.), native grassland, and cultivated hayfields. Mean annual temperature in 2004 and 2005 (January through September) was 7°C and 10°C, respectively, with mean precipitation of 20 cm and 42 cm, respectively (National Oceanic and Atmospheric Administration 2005*). All surface water was ephemeral except for cattle tanks and a few small reservoirs. The area was managed for multiple use, including recreation, grazing, and timber harvest.

We were limited in our study design by management activities and fire behavior. The U.S. Forest Service selected salvage sites based on the presence of pre-existing roads and merchantable timber rather than by randomization, a problem common to wildlife forest management studies (Marzluff et al. 2000; Sallabanks et al. 2000). Distribution and size of patches of burned forest also limited the number and interspersion of independent replicates we were able to consider. Other studies that examined effects of salvage logging faced similar design limitations (Saab and Dudley 1998; Hutto and Gallo 2006). Consistency in the results of multiple independent examinations of salvage logging could overcome lack of power associated with individual efforts. We therefore saw value in conducting this study despite the limitations in randomization, sample size, and interspersion.

We examined the response of the vertebrate community to a reduction in fuels on two salvage-logged and two control plots in 2004 and 2005 (two and three years post-fire; Figure 1). We used Geographic Information Systems (GIS) timber data to select control sites with burn severity and commercial timber value similar to pre-logged salvage sites, distributing two control and two salvage plots (45 to 50 ha), each representing continuous patches of salvaged and non-salvaged forested habitat, to improve experimental design (Hurlbert 1984; Underwood 1997). The salvage areas were mechanically logged in summer 2003. All trees >25 cm DBH with an intact bole and <50% live green crown cover were removed. Trembling Aspen (*Populus tremuloides*) and Green Ash (*Fraxinus pennsylvanica*) were not harvested, and a no-cut buffer of 15.2 m was placed on either side of ephemeral streams to maintain watershed quality.

We used the Minnesota Department of Natural Resources Sample Generator Extension v. 1.1 for ArcView 3.0 to randomly place three point-count stations and one small mammal trap site per plot, positioning point-count stations ≥250 m apart in order to reduce the likelihood of double counting individual cavity-nesting birds (Hutto et al. 1986) (Figure 1). Small mammal trap sites were placed ≥500 m apart, also to maintain sample independence, and all points were positioned ≥50 m from treatment boundaries to avoid collecting data beyond treatment boundaries.

Bird sampling

We conducted 10-minute surveys of cavity-nesting birds from each point-count station from mid-April to 1 July. Point counts were conducted from sunrise to 0900 following standard protocols (Hutto et al. 1986), and an estimated distance of detection was assigned at 10-m intervals from the observer to each bird (Buckland et al. 2001). We excluded from analyses all fly-overs or birds detected >100 m from the observer.

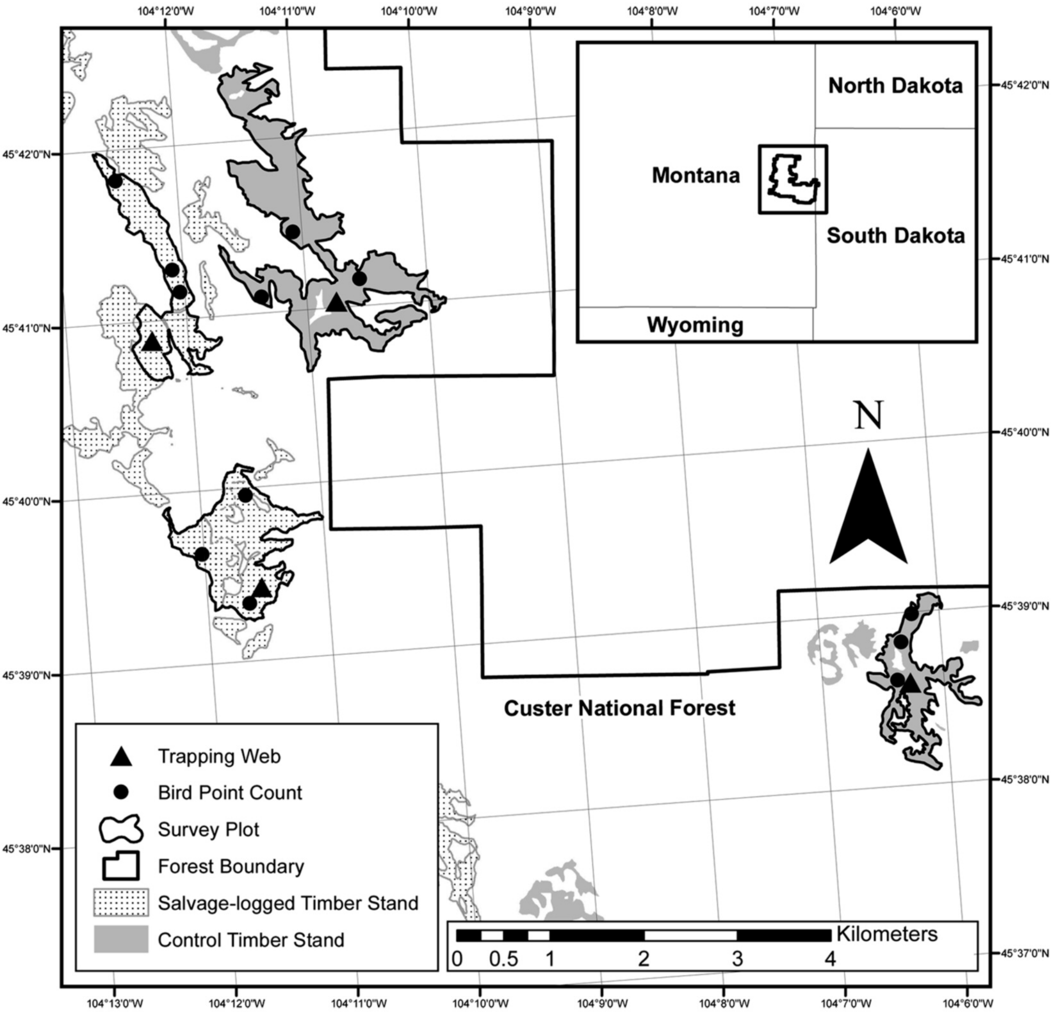

FIGURE 1. Plots and survey points sampled on salvage-logged and control treatments, Custer National Forest, Montana, 2004 and 2005.

Nest searches were conducted from mid-April through 1 July 2004 and 2005. We visited each plot every one to two days and located nests by observing adult behavior and systematically searching for cavities. Target species included Northern Flicker (*Colaptes auratus*), Red-headed Woodpecker (*Melanerpes erythrocephalus*), Hairy Woodpecker (*P. villosus*), Eastern Bluebird (*Sialia sialis*), Mountain Bluebird (*S. currucoides*), and European Starling (*Sturnus vulgaris*). We recorded the location of active nests with a Garmin E-trex Global Positioning System (GPS) receiver and flagged a bearing tree no closer than 30 m away.

We visited each cavity every three days for up to 30 minutes, or until the status of the nest (active or inactive) could be determined by observing adults or nestlings inside the cavity (Martin and Geupel 1993; Kronland 2007). We estimated nest stage according to courtship displays, duration of adult visits to the nest (courtship and egg laying vs. incubation), food deliveries, and nestling vocalizations. We monitored active cavities from the time of location to the completion of the nesting effort. We determined that a nest had failed if predation or usurpation was observed, or if the nest stage was known and inactivity occurred before the estimated fledge date (Martin and Geupel 1993; Kronland 2007). We considered a nest successful if fledglings were observed <20 m from the cavity, or if the fledge date was known and the cavity did not show signs of predation (e.g., enlarged cavity entrance or feathers at base of tree).

Small mammal sampling

We used trapping webs (one for each area) and distance sampling methods to estimate density based on likelihood of detection rather than area trapped (Anderson et al. 1983). Each web consisted of 12 traplines radiating from a central point at 30° intervals (Jett and Nichols 1987). Trap stations consisted of two Sherman style live traps (8 cm × 8 cm × 25 cm) placed every 20 m along a trapline (l = 130 m) using 100-m tapes, starting 10 m from the center, for 168 traps per web. We covered exposed traps with aluminum flashing, rocks, or bark to provide shade, and we baited all traps with peanut butter. We trapped each web over four consecutive nights in August 2004 and 2005 in random order. Traps were checked daily beginning at sunrise and baited after each check. We applied a uniquely numbered ear tag to each individual (No. 1005-1 Monel, National Band and Tag Company, Newport, Kentucky, USA) and examined capture histories to determine if new animals were being detected at the innermost ring on the final night of trapping. We also examined data *post hoc* to ensure that movement of individuals across trap stations within trapping webs did not occur (Buckland et al. 2001).

We identified the species and sex of each captured animal. We measured tail, body, ear, and hind foot to the nearest mm with a stainless steel 30-cm ruler, and we weighed individuals to the nearest 1 g with a 100-g spring scale. Numerous Deer Mice (*Peromyscus maniculatus*) were captured in 2004 (n = 761) and 2005 (n = 869). We aged Deer Mice as juvenile or adult based on mass after examining the distribution of 20 to 30 individuals aged by pelage in the field (Pearson et al. 2003). We recorded ear tag number and trap location (trapline and ring) within the web before releasing animals at the trap site.

Habitat sampling

We measured habitat characteristics, such as size and density of burned trees, because of their known influence on the distribution and abundance of cavity-nesting birds (Hutto 1995; Murphy and Lehnhausen 1998; Nappi et al. 2003; Smucker et al. 2005). We recorded habitat features on plots of 11.3 m radius at the random point-count locations used to sample cavity-nesting birds in 2005 (Figure 1). Three subplots were arranged 120° from each other and 30 m from a central subplot centered on point-count locations, for a total of four subplots (Martin et al. 1997). Bearing of the first subplot from each point-count location was chosen semi-randomly in the field by multiplying the time in seconds by 6.

We measured DBH of all trees >7.5 cm DBH on each subplot, and we also recorded species and status (alive or dead). We categorized each subplot (1 = least decayed, 7 = most decayed) according to crown condition, bark retention (%), and the severity of the burn (%) (Nappi et al. 2003). In 2005, we also arranged four subplots around each nest tree found on the two replicates per treatment, and we conducted the same habitat measurements to describe these nest sites (salvage: n = 22; control: n = 27). For each nest tree, we recorded species, DBH, crown condition, bark retention (%), and the severity of the burn (%). Nest trees were often used by multiple pairs in a single season, and we considered measurements taken at these sites as independent samples when representing different species. We measured each nest site and nest tree only once if it was reused by the same species (Hutto and Gallo 2006).

Small mammal abundance has been positively correlated with the amount of downed woody debris (Carey and Johnson 1995). We therefore measured downed woody debris on subplots centered on each random point count used to survey cavity-nesting birds (Figure 1). We recorded downed woody debris lying at an angle of less than 45° with the ground that intersected a plane 1.8 m high and extended 11.3 m from the subplot center in a random direction (Brown and Roussopoulos 1974). Mean kg of downed woody debris per ha per point was calculated following methods described in Brown and Roussopoulos (1974).

Statistical analyses

We considered mean number of detections per point across years as an index of individual species abundance between treatments. We used distance sampling methods to estimate density (individuals per ha) of all cavity-nesting birds per treatment because we lacked sufficient observations to fit detection curves to species-specific data. Concern about independence of errors associated with sampling points within replicates over multiple occasions led us to pool data across visits and within replicates. We binned observations into five distance categories (0-20 m, 21-40 m, 41-60 m, 61-80 m, 81-100 m,) and used program DISTANCE 6.0 to fit global detection curves to salvage-logged and control treatment datasets (Buckland et al. 2001; Thomas et al. 2005*). We considered the full combination of uniform, half-normal, and hazard rate key functions with cosine, simple-polynomial, and Hermite-polynomial expansion terms, and we removed models with poor fit according to shape of the detection curve (shape criterion) and χ^2 goodness-of-fit tests (Buckland et al. 2001).

We used Program MARK (White and Burnham 1999*) and methods described by Dinsmore et al. (2002) to estimate nest survival (S). We first constructed a set of candidate models that included the full combination of underlying treatment-, year-, and time-varying effects on S. We then ranked models according to difference in Akaike's Information Criterion for small samples (ΔAIC_c), removed models that contained virtually no Akaike weight ($w_i < 0.01$) and failed to estimate parameters, and calculated a weighted-average survival estimate ($\hat{S}$) across the remaining models (Burnham and Anderson 2002). We ended nest observation while some nests were still active, so we used only nests with complete histories (i.e., fledged or failed) to estimate reproductive success (n = 39). Nest survival estimates represent the period of mid-April through 1 July and were calculated for all cavity-

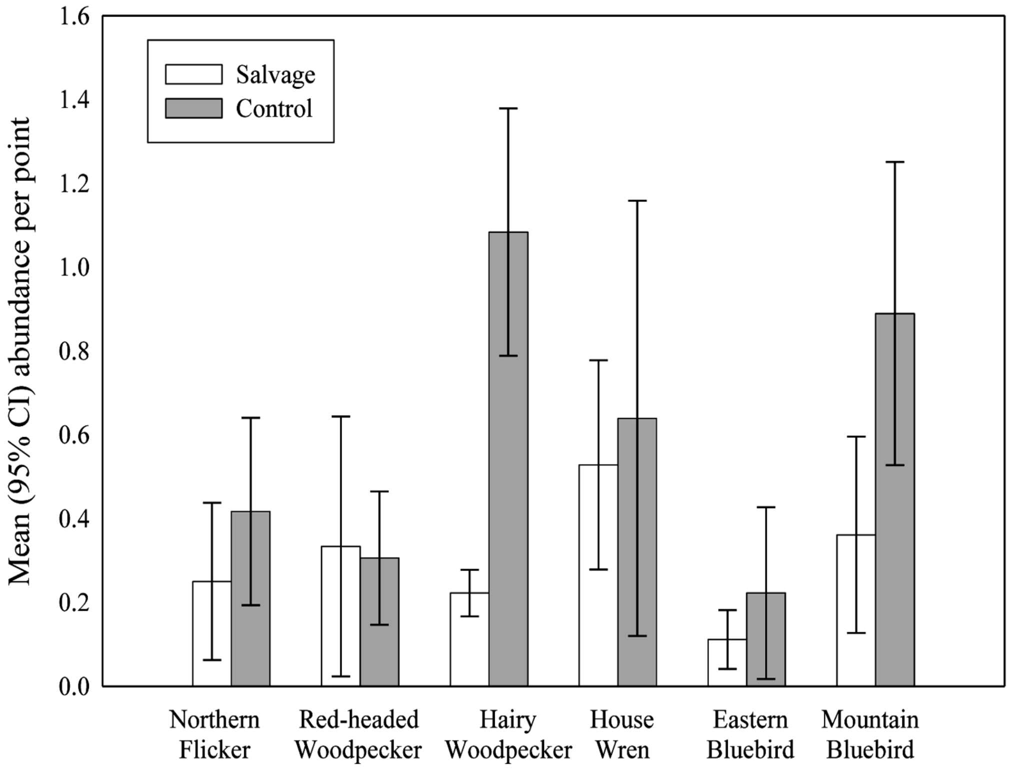

FIGURE 2. Mean (95% CI) abundance of selected cavity-nesting species per point count (pooled across years) on salvage-logged and control treatments, Custer National Forest, Montana, 2004 and 2005.

nesting species combined because sample sizes for individual species were small. We accounted for variation in size of nest-search plots by dividing the number of nests located by plot size to estimate density of active cavity nests (number of nests ha^{-1}).

We used program DISTANCE 6.0 to estimate small mammal density (individuals per ha) from initial captures by fitting detection curves to the full combination of uniform and cosine key functions combined with cosine, simple-polynomial, and Hermite-polynomial expansion terms (Buckland et al. 2001; Thomas et al. 2005*). We did not consider the hazard-rate or negative-exponential key functions because these models have been shown to overestimate density (D) and perform poorly with trapping-web data (Parmenter et al. 2003). We removed models with poor fit according to shape of the detection curve (shape criterion) and χ^2 goodness-of-fit test (Buckland et al. 2001), ranked remaining models based on difference in Akaike's Information Criterion (ΔAIC), assigned Akaike weights, and calculated weighted-average estimates of density ($\hat{D}$) across models (Burnham and Anderson 2002). Variance and 95% confidence intervals were calculated using formulas described in Buckland et al. (2001) and Burnham and Anderson (2002). Data were pooled across sampling occasions at each trapping web, and reported estimates represent the mean density of small mammals across sites within each treatment.

We used nested MANOVA to compare habitat characteristics between treatments at point-count locations (salvage: $n = 6$; control: $n = 6$) and nest sites (salvage: $n = 22$; control: $n = 27$). Variables included mean density of large trees, mean density of small trees, mean crown condition, the mean percentage of bark remaining on the tree bole, and the mean percentage of the tree that had been burned (severity). We also used nested MANOVA to examine difference in mean DBH, the crown condition, the bark remaining (%), and the severity of the burn (%) of individual nest trees on each treatment.

Results

Birds

We recorded the highest mean number of detections per point across years for Hairy Woodpecker ($\bar{x} = 0.65$, SE = 0.21), Mountain Bluebird ($\bar{x} = 0.63$, SE = 0.18), and House Wren (*Troglodytes aedon*) ($\bar{x} = 0.58$, SE = 0.2), followed by Northern Flicker ($\bar{x} = 0.33$, SE = 0.1), Red-headed Woodpecker ($\bar{x} = 0.32$, SE = 0.12), and Eastern Bluebird ($\bar{x} = 0.17$, SE = 0.08).

TABLE 1. Akaike's Information Criterion (AIC_c) ranking, Akaike weight (w_i), number of parameters estimated (K), and log likelihood (−2log(L)) of candidate models examining treatment (g), year (y), and constant (.) effects on nest survival.

Model	AIC_c	ΔAIC_c	w_i	K	−2log(L)
S(g)	137.8717	0	0.4114	2	133.8546
S(.)	138.2474	0.3757	0.3409	1	136.2417
S(y)	140.1623	2.2906	0.1309	2	136.1452
S(g*y)	140.3893	2.5176	0.1168	4	132.3322

White-breasted Nuthatch (*Sitta carolinensis*), American Kestrel (*Falco sparverius*), and Red-breasted Nuthatch (*S. canadensis*) were rarely detected during point counts (mean detections per point <0.1). No cavity-nesting species was found exclusively on either treatment, but mean abundance per point was greater on the control than the salvage treatment for Hairy Woodpecker (i.e., non-overlapping 95% CI, Figure 2).

The uniform key function with cosine expansion term was the only model that fit cavity-nesting bird data according to shape of detection curves and χ^2 goodness-of-fit tests (control: $\chi^2 = 5.7$, df = 3, $P = 0.13$; salvage: $\chi^2 = 0.1$, df = 1, $P = 0.75$). Estimated density of cavity-nesting birds was greater in 2005 ($\hat{D} = 3.83$; 95% CI – 3.5 to 4.11) than 2004 ($\hat{D} = 2.05$; 95% CI – 1.61 to 2.49) on the control treatment, and did not differ between years on the salvage treatment (2004: $\hat{D} = 1.39$; 95% CI – 0.98 to 1.59; 2005: $\hat{D} = 2.33$; 95% CI – 1.5 to 2.72). Density of cavity-nesting birds across both years was greater on the control ($\hat{D} = 2.94$; 95% CI – 2.7 to 3.15) than the salvage ($\hat{D} = 1.86$; 95% CI – 1.24 to 2.17) treatment.

We located 36 nest cavities on the control treatment (2004: n = 17; 2005: n = 19), representing 48 nest attempts (1.3 attempts per cavity), and 29 nest cavities on the salvage treatment (2004: n = 15; 2005: n = 14), representing 43 nest attempts (1.5 attempts per cavity). Red-headed Woodpeckers accounted for 34% of located cavities, and were the only species that had higher nest density on the salvage than the control treatment (0.20 nests/ha versus 0.12 nests/ha, respectively, n = 31). Other cavity nesters included Hairy Woodpecker (salvage: 0.07 nest/ha; control: 0.14 nests/ha; n = 20), Mountain Bluebird (salvage: 0.05 nests/ha; control: 0.11 nest/ha; n = 15), Northern Flicker (salvage: 0.06 nests/ha; control: 0.07 nests/ha; n = 12), Eastern Bluebird (salvage: 0.03 nests/ha; control: 0.05 nests/ha; n = 8), and European Starling (salvage: 0.02 nests/ha; control: 0.03 nests/ha; n = 5). Hairy Woodpeckers were known, through direct observation, to have constructed 32% (n = 21) of the located nest cavities. Excavator was uncertain for 52% (n = 34) of cavities, Red-headed Woodpeckers produced 11% (n = 7) of cavities, and 5% (n = 3) of cavities were created naturally.

We compared eight candidate models of nest survival, and four models received some support (Table 1). Weighted-average estimates of S between treatments and across years were high (salvage: $\hat{S} = 0.96$, SE = 0.01 (2004), $\hat{S} = 0.97$, SE = 0.01 (2005); control: = 0.98, SE = 0.01 (2004), $\hat{S} = 0.98$, SE = 0.01 (2005)) and strongly overlapped, indicating that differences in nest survival between treatments were negligible. Eight of 19 nest attempts with known histories failed on the salvage treatment, compared to 9 of 20 attempts on the control treatment. Red-headed Woodpeckers were responsible for 11 nest failures (65%) by depredating or usurping nests. House Wrens were observed filling 2 Mountain Bluebird cavities with twigs, and the cause of 5 nest failures remained unknown.

Small mammals

We captured 1630 Deer Mice and 64 Meadow Voles (*Microtus pennsylvanicus*) in 2004 and 2005. Other species that accounted for <1% of captures included Hispid Pocket Mouse (*Chaetodipus hispidus*), Thirteen-lined Ground Squirrel (*Spermophilus tridecemlineatus*), Olive-backed Pocket Mouse (*Perognathus fasciatus*), Western Harvest Mouse (*Reithrodontomys megalotis*), Bushy-tailed Woodrat (*Neotoma cinerea*), White-footed Mouse (*P. leucopus*), and Eastern Cottontail (*Sylvilagus floridanus*).

We estimated density of Deer Mice only, because other species did not comprise a large enough sample to use distance-based models. We derived yearly estimates of density because excessive lumping of detections between 70 m and 110 m in the pooled dataset prevented us from fitting a detection curve. Models consisting of the uniform and half-normal key functions with cosine adjustment had strong support across treatments and years (Table 2). Density of Deer Mice was greater on salvage-logged (2004: $\hat{D} = 24.2$, 95% CI – 18.9 to 30.9; 2005: $\hat{D} = 21.5$, 95% CI – 15.4 to 30.0) than control areas (2004: $\hat{D} = 6.5$, 95% CI – 3.3 to 12.6; 2005: $\hat{D} = 5.8$, 95% CI – 3.5 to 9.5). We categorized Deer Mice weighing ≤17 g as juveniles, based on mass of a subset of individuals that were aged by pelage. The mean ratio of juveniles to adults captured per trapping web was 1:1.3 on salvage-logged and 1:0.8 on control sites.

Habitat

Large trees (>23 cm DBH) were less abundant on salvage-logged ($\bar{x}$ = 6.64 trees ha^{-1}, SE = 2.62) than control sites ($\bar{x}$ = 53.1 trees ha^{-1}, SE = 8.64), as determined by habitat measurements at point-count locations (Table 3). Microsites surrounding nest trees on the control treatment also had greater mean density of trees >23 cm DBH (salvage: $\bar{x}$ = 26.45 trees ha^{-1}, SE = 4.97; control: $\bar{x}$ = 62.27 trees ha^{-1}, SE = 3.64) and more bark remaining on the tree bole (salvage: $\bar{x}$ = 5.17, SE = 0.29; control: $\bar{x}$ = 1.95, SE = 0.08) than salvage-logged sites (Table 3).

Nest trees on the salvage had more deteriorated crowns (salvage: $\bar{x}$ = 5.00, SE = 2.37; control: $\bar{x}$ = 2.85, SE = 1.85) and less bark remained on the tree bole (salvage: $\bar{x}$ = 3.86, SE = 2.34; control: $\bar{x}$ = 2.63, SE = 1.62) than nest trees on the control plots (Table 3). Nest attempts on the salvage were most often (61%; *n* = 15) located in non-logged stands of green Ponderosa Pine, Trembling Aspen, or Green Ash. Only 7% (*n* = 2) of nest attempts in control areas occurred in those trees.

Mean volume of downed woody debris was greater on the salvage ($\bar{x}$ = 1964 kg/ha, 95% CI – 822 to 3160) than the control treatments ($\bar{x}$ = 460 kg/ha, 95% CI – 189 to 731). Mean number of downed woody debris pieces on the salvage treatment was 5.7 per replicate with a mean volume of 89 cm^3. Mean number of pieces of downed woody debris on the control treatment was 1.9 per replicate with a mean volume of 122 cm^3.

Discussion

Our results were consistent with the growing body of evidence demonstrating that post-fire salvage logging has significant negative effects on cavity-nesting birds, at least two to three years following a wildfire (Hutto 1995; Saab and Dudley 1998; Smucker et al. 2005; Hutto and Gallo 2006). Density of cavity-nesting birds was lower on the salvage than the control treatment. Moreover, few potential nest sites existed on the salvage treatment and occupied cavities were most often located in riparian buffer strips or in stands of green trees and hardwoods not subject to harvest. In contrast, abundance of Deer Mice was greater on salvage-logged than on control plots, and was closely associated with the high amount of downed woody debris on the salvage treatments.

Dense stands of trees >23 cm DBH were also more common on the control than the salvage treatment. The stands provided potential foraging opportunities for primary cavity nesters, such as Hairy Woodpeckers, probably because large trees contain high densities of beetle larvae (Cerambycidae and Buprestidae) (Mannan et al. 1980; Nappi et al. 2003; Hanson and North 2008). Cavity nesters, particularly Hairy Woodpeckers, were infrequently detected during point counts in areas dominated by small trees. At least 18% of the excavations produced by Hairy Woodpeckers were used by other cavity nesters, and the paucity of Hairy Woodpeckers in salvage-logged areas probably had a negative effect on secondary cavity nesters. For example, both Mountain Bluebirds and House Wrens nested less often in the salvage-logged than the control areas. Post-fire logging therefore had both direct and indirect negative effects on the cavity-nesting assemblage.

TABLE 2. Akaike's Information Criterion (AIC$_c$) ranking, Akaike weight (w_i), number of parameters estimated (K), log likelihood (−2log(L)), and results of χ^2 goodness-of-fit test for candidate models used to estimate population density of Deer Mice on salvage-logged and control treatments, 2004 and 2005.

Treatment	Year	Model	AIC	ΔAIC	w_i	K	−2log(L)	χ^2	df	*P*
Salvage	2005	Half-normal + cosine	2155.73	0	0.70	4	−1073.87	2.12	2	0.35
		Uniform + cosine	2157.43	1.69	0.30	4	−1074.71	3.83	2	0.15
Salvage	2004	Half-normal + cosine	2281.54	0	0.67	2	−1138.77	7.75	4	0.10
		Uniform + cosine	2282.97	1.44	0.33	3	−1138.49	7.9	3	0.07
Control	2005	Half-normal + cosine	1180.28	0	0.54	3	−587.14	3.96	3	0.27
		Uniform + cosine	1180.56	0.29	0.46	3	−587.28	4.3	3	0.23
Control	2004	Uniform + cosine	354.95	0	0.24	2	−175.48	1.33	2	0.52
		Uniform + Hermite polynomial	355.2	0.25	0.21	2	−175.6	1.65	2	0.44
		Uniform + simple polynomial	355.2	0.25	0.21	2	−175.6	1.65	2	0.44
		Half-normal + cosine	356.22	1.27	0.13	3	−175.11	0.58	1	0.45
		Half-normal + Hermite polynomial	256.41	1.46	0.11	3	−175.21	0.77	1	0.38
		Half-normal + simple polynomial	356.56	1.61	0.11	3	−175.28	0.92	1	0.34

The distribution and abundance of breeding habitat that remained after salvage logging differed between treatments and affected nest site use. Stands of high tree density on salvage treatments existed only in non-harvested areas. Non-logged areas represented approximately 15% of the total area on salvage treatments, yet they contained 71% of nest cavities. In contrast, most nest cavities on the control were in habitats that would have been logged (e.g., stands of large dead Ponderosa Pine). Trembling Aspen and Green Ash accounted for only 6% of nest attempts on the control while representing 40% of attempts on the salvage. If Trembling Aspen and Green Ash had been preferred breeding habitat, the number of nest attempts in these habitats would probably have been similar between treatments. Regardless of treatment, cavity nesters were found most often in areas with high densities of large trees, habitat features considered important legacies in burned forests (Franklin et al. 2000; Hutto 2006).

Post-fire salvage logging did not reduce reproductive success of cavity-nesting birds on our study area in southeastern Montana, despite negative effects on bird abundance. To our knowledge, only three other studies have reported reproductive information while investigating effects of post-fire logging on cavity-nesting birds. One study found no effect and two studies found reduced reproductive success, but only for Hairy and Lewis's woodpeckers (reviewed by McIver and Starr 2001; Saab et al. 2011). The small number of existing studies on post-fire effects reflects the general pattern reported by Sallabanks et al. (2000), where only 13% of studies investigating effects of silviculture on birds collected demographic data. Clearly, data on reproductive success and survival remain a research priority (Kotliar et al. 2002).

Density of Deer Mice was greater on salvage than control plots. This reflected the four-fold difference in volume of downed woody debris across treatments. Mechanical removal of trees during logging led to an incidental and rapid accumulation of downed branches, debris used by small mammals for breeding, foraging, and predator avoidance (Harmon et al. 1986; Ucitel et al. 2003). Dead trees on the control remained standing two to three years post-fire and had not yet replaced downed woody debris consumed during the fire. Debris on the control would be expected to continue to accumulate as trees deteriorated (Tinker and Knight 2001; Russell et al. 2006), whereas the amount of debris on the salvage treatment had probably reached its maximum because most standing dead trees had been harvested.

Although Deer Mice responded favorably to the accumulation of downed woody debris on the salvage treatment, density of small mammals may not reflect habitat quality if dominant individuals exclude subordinates from the best habitats (Van Horne 1983; Rodenhouse et al. 1997). Adult Deer Mice defend territories against non-reproducing juveniles (Long and Mont-

TABLE 3. Results of Multivariate Analysis of Variance (MANOVA) tests comparing habitat characteristics at point-count locations in salvage-logged and control plots and at nest sites on salvage-logged and control plots, and comparing nest-tree characteristics on salvage-logged and control treatments, Custer National Forest, Montana, 2004 and 2005.

	Point counts salvage: $n = 6$; control: $n = 6$			Nest sites salvage: $n = 22$; control: $n = 27$			Nest trees salvage: $n = 22$; control: $n = 27$		
Habitat characteristic	*F*	df	*P*	*F*	df	*P*	*F*	df	*P*
Trees 10–23 cm DBH ha^{-1}	0.003	1,8	0.958	1.576	1,45	0.216	NA	NA	NA
Trees >23 cm DBH ha^{-1}	22.519	1,8	0.001	38.761	1,45	<0.001	NA	NA	NA
$\bar{x}$ tree DBH (cm)	NA	NA	NA	NA	NA	NA	3.267	1,45	0.077
Crown condition [a]	0.096	1,8	0.764	3.111	1,45	0.085	12.434	1,45	0.001
Bark retention [b]	0.183	1,8	0.68	163.139	1,45	<0.001	5.28	1,45	0.026
Burn severity [c]	0.019	1,8	0.894	0.748	1,45	0.392	2.987	1,45	0.091

[a] Relative amount of twigs, branches, and limbs on tree crown (1 = intact crown, 7 = broken top).
[b] Percentage of bark remaining on tree bole (1 = 100%, 7 = no bark).
[c] Percentage of tree burned (1 = unburned, 7 = completely burned).

gomerie 2006), so a large juvenile to adult ratio would indicate low-quality habitat. However, adults were more abundant than juveniles on the salvage treatment where densities of Deer Mice were highest. This supports the conclusion that density reflects high-quality habitat. Information regarding individual reproductive status (not recorded in this study) might have provided further insight into habitat quality between treatments for Deer Mouse.

Despite temporarily benefiting Deer Mice populations, the rapid accumulation of downed woody debris may have increased the short-term risk of wildfire because woody ground debris is a primary determinant of fire behavior (Donato et al. 2006). One of the goals of salvage logging is to reduce the probability of large wildfires, and failure to achieve fire management objectives is particularly important in southeastern Montana because of the historically high frequency of wildfires (Brown and Hull Sieg 1996). The risk of future fire could be reduced by creating heterogeneous landscapes of logged and non-logged areas, where woody debris would accumulate and deteriorate at different rates, thus creating fuel breaks. Retaining some intact stands of large trees (>23 cm DBH) could also mitigate the negative effects of salvage logging on cavity nesters.

Current federal and state guidelines recommend retaining 6 to 10 dead trees per hectare (Hutto 2006). However, salvage prescriptions that retain a specific number of trees per hectare or uniformly remove a specific size class of tree (e.g., >25 cm DBH) accelerate post-fire succession and create homogeneous landscapes unsuitable for many cavity-nesting birds (Hutto 1995; Kotliar et al. 2002; Hutto 2006; Schmiegelow et al. 2006). Conserving intact stands of large trees would create heterogeneous landscapes that resemble natural post-fire conditions and harbor many of the legacies deemed important in such landscapes (Franklin et al. 2000). Although further investigation is needed to determine the size and distribution of burned tree stands that should be retained, conditions resulting from salvage logging in this study provided lower quality habitat than unlogged areas.

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