AN ABSTRACT OF THE THESIS OF

Rebecca E. Cahall for the degree of Master of Science in Forest Science presented on May 31, 2007.

Title: Influences of Salvage Logging on Forest Birds after Fire in the Eastern Cascades, Oregon.

Abstract approved:

John P. Hayes Joan C. Hagar

Previous research examining the influences of post-fire salvage logging on abundances of birds has focused primarily on the response of cavity-nesting species. There is limited research in regard to the impact of salvage logging on a broader range of bird species. In addition, little is known about how different intensities of salvage logging influence bird abundances. I compared densities and relative abundances of bird species among two different intensities of salvage logging and an unsalvaged treatment in a post-fire forest of mixed conifers at Davis Lake, Oregon. I also examined the potential of vegetation variables that describe habitat structure to predict densities of birds, and the use of snags for foraging by two species of woodpeckers.

Salvage logging influenced the density or relative abundance of seven species of birds, though the pattern of the influence varied. Five species (black-backed woodpecker, hairy woodpecker, western wood-pewee, brown creeper, and yellow-rumped warbler) had greater densities or relative abundances in the unsalvaged treatment than in either treatment of salvage logging. Two species (dark-eyed junco

and fox sparrow) had greater densities in salvaged treatments than in the unsalvaged treatment. Salvage logging did not significantly influence density or relative abundance of eight species (red-breasted nuthatch, white-breasted nuthatch, dusky flycatcher, house wren, American robin, western tanager and chipping sparrow) and one genus of swallows (*Tachycineta*).

Densities of yellow-rumped warblers increased with increasing density of snags. Densities of fox sparrows and dark-eyed juncos increased with increasing volume of shrubs. Vegetation variables did not strongly predict densities or relative abundances for twelve species and one genus of birds.

Diameter of snags selected for foraging by black-backed and hairy woodpeckers did not differ between species of woodpecker or among treatments of salvage logging. Both species of woodpeckers selected snags for foraging with larger diameters than the mean diameter of snags in both unsalvaged and salvage treatments.

Salvage logging influenced densities or relative abundances of some non-cavity nesting birds and cavity-nesting birds. Maintaining unsalvaged areas in burned forests will provide habitat for species of birds negatively influenced by salvage logging. Retaining large snags after salvage logging will provide foraging habitat for woodpeckers.

Influences of Salvage Logging on Forest Birds After Fire in the Eastern Cascades, Oregon

by
Rebecca E. Cahall

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes the release of my thesis to any reader upon request.

Rebecca E. Cahall, Author

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CONTRIBUTION OF AUTHORS

Dr. John P. Hayes contributed to the study design, interpretation of data, and writing of chapters 2-3. Dr. Joan C. Hagar contributed to the writing of chapter 2-3. John Cissel contributed to the study design. Manuela Huso contributed to interpretation of the data and wrote statistical code for AIC_c model selection chapter 3.

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CHAPTER 1: INTRODUCTION

Fire suppression, grazing, and logging in dry forest types have altered stand conditions, increasing the potential for stand-replacing fire by accumulation and continuity of fuels and decreased height to live crown ratio (Agee 1993, Pyne et al. 1996). After stand-replacing fires, removal of standing dead trees from an area, or salvage logging, is used to meet management goals of facilitating recovery of habitat (USDA and USDI 1994), recovery of economic value from burned trees (McIver and Starr 2001), prevention of future fires (Ne'eman et al. 1997), and reduction of the risk of insect infestation of surrounding forests (Amman and Ryan 1991).

Yet, McIver and Starr (2001) found that few studies worldwide have examined the ecological impacts of salvage logging, although they encompassed a wide array topics, including erosion and sediment transport, structural changes and abundance of plants, diversity and abundance of rodents and birds, and density and nest success of cavity-nesting birds. Subsequent to McIver and Starr's (2001) review, more studies devoted to understanding the ecological effects of salvage logging have been published (Brias et al. 2000, Haggard and Gaines 2001, Van Nieuwstadt et al., Morissette et al. 2002, Karr et al. 2004, Donato et al. 2006, Hutto and Gallo 2006, Lindenmayer and Ough 2006, Reeves et al. 2006, Russell et al. 2006).

Still, few studies have focused on the response of abundances of birds following salvage logging. Much of the research on the response of species of birds to salvage has focused on cavity-nesting species and suggests that salvage logging has an overall negative effect on these birds (Caton 1996, Saab and Dudley 1998, Haggard and Gaines 2001, Hutto and Gallo 2006). There are few studies on the response of the broader bird community (except see: Morissette et al. 2002, Schwab et al. 2006), even though several species of birds that do not nest in cavities are associated with post-fire forests (Hutto 1995, Morissette et al. 2002). Knowledge of the response of these species is fundamental to a comprehensive understanding of impacts of salvage logging on species of birds in post-fire habitat.

While species may be associated with one type of disturbance, the combined ecological effects of two disturbances, such as fire and logging, are likely to be profound (Lindenmayer and Noss 2006). Olive-sided flycatchers (*Contopus cooperi*) and mountain bluebirds (*Sialia currucoides*) respond favorably to post-fire habitat (Hutto 1995, Kotliar et al. 2002), and Townsend's solitaires (*Mayadestes towsendi*) and dark-eyed junco (*Junco hyemalis*) are associated with open habitats that occur after logging (Morrison and Meslow 1983, Bowen 1997, Nolan et al. 2002). Yet, birds that are relatively restricted to post-fire habitat (e.g. black-backed [*Picoides arcticus*] and American three-toed woodpecker [*P. dorsalis*]) (Hutto 1995, Kotliar et al. 2002, Smucker et al. 2005) decrease in abundance or nesting densities after post-fire salvage logging (Caton 1996, Saab and Dudley 1998, Haggard and Gaines 2001, Hutto and Gallo 2006).

With an increased understanding that complete removal of snags negatively affects some species of birds that inhabit post-fire habitat (Kotliar et al. 2002), researchers and managers are asking about the effects of different intensities of salvage logging. For managers, maintaining different densities of snags may meet two management goals, partial economic recovery of trees killed in a fire while at the same time maintaining some habitat for wildlife. Biologically, removing only a portion of snags is interesting because it examines what quantity of snag structure would maintain similar bird abundances to unsalvaged forests after fire. Overall, the question addresses whether any intensity of salvage logging can be congruent with sustaining abundances of birds that are similar to post-fire forests.

Snag retention policies after salvage logging frequently are similar to retention policies for harvested green forests on U. S. National Forest lands (6-10 snags/ha) (Hutto 2006). The level of snag retention is based on supporting viable populations of cavity-nesting birds (Thomas et al. 1979, Bull et al. 1997). Snags of large diameter are retained because cavity-nesting species select larger diameter snags for nesting and foraging disproportionately to their availability in green forests (Raphael and White 1984, Weikel and Hayes 1999) and burned forests (Harris 1982, Raphael and White 1984, Hutto 1995, Caton 1996, Powell 2000). Yet, lower nesting densities of cavity-nesting birds that are restricted to post-fire habitat following salvage logging relative to burned forests (Saab and Dudley 1998, Kotliar et al. 2002) suggests that these minimums may be inadequate to meet the nesting requirements to maintain species in salvaged forests. Furthermore, foraging habitat is crucial to maintaining abundances of species. Yet little information exists regarding selection of foraging substrates of cavity-nesting species after salvage logging.

The few studies that have examined the effects of partial salvage-logging show negative effects for species that are restricted to post-fire habitat (Caton 1996, Saab and Dudley 1998, Haggard and Gaines 2001, Koivula and Schmiegelow 2007). A broader range of intensities of salvage logging are needed to better understand the relationships between abundances of birds and densities of snags.

We developed this study to provide managers with an increased understanding of the response of forest birds to salvage logging after fire. In chapter two, we examined the relative influence of two intensities of salvage logging on abundances of birds after fire, and the correlation between vegetation characteristics of the salvage treatments and abundances of bird species. We compared α-diversity and densities or relative abundances of species of birds among treatments of salvage. Our study design had four replicates of three treatments of salvage with two years of post-treatment data.

In chapter three, we examined the use of foraging resources by two species of woodpeckers. Black-backed woodpeckers and hairy woodpeckers (*Picoides villosus*) both occur in greater abundance after fire relative to green forests. We compared selection of foraging substrates between the two species of woodpeckers, foraging selection among salvage treatments, and selection of foraging substrates by woodpeckers compared to availability of substrates in the salvage treatments. Information of foraging substrates used by these species of woodpeckers in salvage-logged and post-fire habitat, in addition to information on the nesting requirements, will provide mangers with a broader understanding of habitat necessary to support adequate abundances of species.

Our research is part of a larger study examining the effects of salvage logging on wildlife abundances. This is the first phase of a long-term project to evaluate the influences of post-fire logging at these sites. Our research focuses on the immediate influences of salvage logging 2-3 years post-fire.

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CHAPTER 2: INFLUENCES OF SALVAGE LOGGING AFTER FIRE ON FOREST BIRDS IN THE EASTERN CASCADES, OREGON

ABSTRACT

Responses of birds to salvage logging after fire have recently received more study with increased concern over the ecological impacts of salvage logging on forest ecosystems. However, research has focused primarily on the response of cavity-nesting species to the removal of snags. We compared abundances of forest birds among unsalvaged burned forests and two intensities of salvage logging (moderate, 30 snags retained/ha and heavy, 5-6 snags retained/ha) after fire, in the Deschutes National Forest, Oregon. We used analysis of variance with repeated measures to evaluate three hypotheses concerning the influence of different intensities of salvage on abundance of birds, and two hypotheses concerning the influence of time since salvage logging on abundances of birds. We also examined the correlation of three vegetation variables with densities of each bird species. We detected significant differences among densities or relative abundances of seven species, though the patterns of differences varied. Eight species and one genus of birds did not differ in density or relative abundance among the treatments. Our findings suggest that both cavity-nesting and non-cavity nesting species respond to salvage logging, and that some species responds uniquely to habitat features influenced by salvage logging. For species that responded negatively to salvage logging, the moderate salvage intensity did not mitigate the negative influence of salvage logging.

INTRODUCTION

Post-fire forests are unique habitats with structural and vegetation elements that differ from pre-fire forests. These forests support distinct communities of vegetation and wildlife, and have structural components, such as snags, that are typically limited in number before a fire. General relationships between composition of bird communities and vegetation structure are well established (Willson 1974, Weins and Rotenberry 1981, James and Warner 1982), with different forest structures supporting different communities of birds. Changes in composition and structure of vegetation after fire can yield different community compositions and greater species richness of birds in burned forests than in unburned forests (Bock and Lynch 1970, Huff et al. 1985).

Post-fire habitats support distinct avian communities (Rocky mountains: Hutto 1995, Caton 1996, Kotliar et al. 2002; Sierra Nevada: Bock and Lynch 1970; boreal: Hobson and Schieck 1999, Morissette et al. 2002), and some species of birds respond positively after fire. Kotliar et al. (2002) found that nine species of birds, including woodpeckers and aerial insectivores, were typically more abundant in burns than in unburned habitats. Aerial insectivores (flycatchers and swallows) are typically more abundant after fire (Caton 1996, Kotliar et al. 2002) when insect prey and snags, used as perches from which to forage, are abundant. Abundances of ground and shrub-foragers also tend to increase after fire (Bock and Lynch 1970, Caton 1996) in response to creation of more open habitat than in pre-fire forests. Conifer-seed foragers can be more abundant in recently burned forests than in other cover types (Hutto 1995) because of cones opening in response to fire and increasing the availability of conifer seeds.

Many species of birds that nest in cavities respond favorably to early post-fire habitat (Hutto 1995, Saab and Dudley 1998, Kotliar et al. 2002). Cavity-nesting birds are primarily insectivorous (Ehrlich et al. 1988), and early post-fire habitat provides two essential habitat components for these species: abundant nesting habitat and insect biomass. Fire can kill or weaken trees thereby increasing the availability of snags for nesting.

Burned forests attract a flush of insects, including bark beetles (Scolytidae) and wood-boring beetles (Buprestidae and Cerambycidae) (Rasmussen et al. 1996, McHugh et al. 2003), which may influence the abundances and community composition of birds after a fire. In western coniferous forests, the flush of insects is nearly immediate and lasts about three years, after which abundances of wood-boring beetles decline (Harris 1982). One reason abundances of woodpeckers, and in particular black-backed woodpeckers (*Picoides arcticus*), typically increase in recently burned areas (Bent 1939, Blackford 1955, Hutto 1995, Murphy and Lehnhausen 1998) may be in response to increases in a primary food resource, beetle larvae (Beal 1911, Murphy and Lehnhausen 1998).

While post-fire forests are unique habitats, there are competing interests for the use of these forests. Salvage logging is the removal of dead or dying trees from a landscape after a large-scale natural disturbance, such as fire or insect outbreak (Gorte

1996). Rationale to remove trees may include reducing the risk of future fire (Ne'eman et al. 1997), preventing the spread of insect infestation (Amman and Ryan 1991), and recovering economic value from snags (McIver and Starr 2001, Beschta et al. 2004).

To maximize economic benefits, snags ideally are removed from a forest stand one to three years post-disturbance to mitigate damage from insect infestation and deterioration of the sapwood (Gorte 1996, Lowell and Cahill 1996). However, some species of birds (e.g., black-backed woodpecker) are relatively limited to early post-fire habitat (Hutto 1995) and remain for two to seven years post-fire (Kotliar et al. 2002). Some species of birds dependent on post-fire habitat decrease in abundance after salvage logging (Caton 1996, Saab and Dudley 1998, Haggard and Gaines 2001, Hutto and Gallo 2006). Therefore, the timing of salvage logging necessary to meet economic goals may conflict with the goal of maintaining post-fire habitat for birds (Hutto 1995, Murphy and Lehnhausen 1998, Saab and Dudley 1998, Kotliar et al. 2002).

After stand-replacing fires, the quantity of standing snags increases dramatically from the unburned forest. In post-fire habitat, snags appear to function as a keystone structure for cavity-nesting birds. Tews et al. (2004) define a keystone structure as “a distinct spatial structure providing resources, shelter or ‘goods and services’ crucial for other species.” Reducing the quantity or quality of keystone structures can negatively impact abundances of associated species and change community composition. The influence of snags as keystone structures is evidenced by decreases in abundances and nesting densities of cavity-nesting birds after salvage logging in post-fire habitat (Caton 1996, Saab and Dudley, Morissette et al. 2002, Hutto and Gallo 2006). Although several studies have examined the effects of removing nearly all the snags (Caton 1996, Saab and Dudley 1998, Morissette et al, 2002, Hutto and Gallo 2006), the effect of removing a portion of the snags on cavity-nesting and other birds has received little study. Removing only a portion of snags is interesting biologically. We wanted to examine whether a threshold of snag structure exists that maintains similar abundances of cavity-nesting birds as in unsalvaged post-fire habitat.

The few studies examining the influences of different intensities of salvage logging after fire on birds have occurred in ponderosa pine-Douglas fir forests in Idaho (Saab and Dudley 1998) and Washington (Haggard and Gaines 2001), black spruce forests in Labrador (Schwab et al. 2006), and mixed-wood forests in Alberta (Koivula and Schmiegelow 2007). In ponderosa pine-Douglas-fir forests, moderate retention (15-35 snags/ha) of snags supported greater numbers of cavity-nesting birds than did low retention (0-12 snags/ha) or high retention (37-80 snags/ha) (Haggard and Gaines 2001). This may have resulted from clumping of retained snags or a higher density of ponderosa pine snags in the moderate retention. Nest abundance and nesting success of the Lewis' woodpecker (*Melanerpes lewis*) was greatest in partially salvaged stands (50% of snags >30cm removed), while black-backed woodpeckers, hairy woodpeckers (*Picoides villosus*), and mountain bluebirds (*Sialia currucoides*) had greater numbers of nests in unsalvaged stands compared to a standard salvage prescription (15 snags/ha retained on north facing slopes; 33% of snags >30cm on south facing slopes) after a stand-replacing fire (Saab and Dudley 1998). In post-fire forests of black spruce, the number of territories of black-backed woodpeckers did not differ among four intensities (0%, 25%, 50% and 100%) of salvage logging (Schwab et al.). In mixed-wood forests, salvage logging negatively affected *Picoides* woodpeckers, but not the northern flicker (*Colaptes auratus*) (Koivula and Schmiegelow 2007). The limited geographic extent and focus on cavity-nesting species of these studies highlights the need for further study on the effects of variable intensities of salvage logging on birds.

Not all species of birds that respond positively to post-fire habitat are dependent upon snags for nesting or foraging, but can be affected by salvage logging. Morissette et al. (2002) found a decrease in the number of insectivorous birds in sites salvage-logged after fire. Number of territories of hermit thrushes decreased with decreasing densities of snags in boreal forests after fire, even though hermit thrushes are not cavity-nesters (Schwab et al. 2006). There is little information on responses of birds that do not nest in cavities to salvage, although salvage logging is likely to affect the entire community of birds (Hutto 1995, Morissette et al. 2002).

To our knowledge, only two studies have compared the effects of different intensities of salvage logging after fire on non-cavity nesting birds (LeCoure et al. 2000, Schwab et al. 2006). LeCoure et al. (2000) found species richness did not differ among levels of intensity of salvage, but numbers of territories of some species (American robin, dark-eyed junco and fox sparrow) decreased in partially-salvaged stands (60% of snags removed) relative to numbers in unsalvaged-burned stands. Numbers of territories of shrub and ground nesters increased in sites that had all snags removed relative to pretreatment and unsalvaged stands (LeCoure et al. 2000). Number of territories of dark-eyed juncos (*Junco hyemalis*) and Wilson's warbler (*Wilsonia pusilla*) did not significantly differ among intensity levels of salvage logging in burned forests (Schwab et al. 2006).

While we would not expect all species of birds to respond similarly to decreasing densities of snags, salvage logging may generate habitat conditions that are important to birds that do not nest in cavities. Salvage logging can increase availability of downed wood (Donato et al. 2006), which can be used for nesting cover by some species of birds (e.g., Townsend's solitaire, *Mayadestes towsendi*) (Bowen 1997). Species of birds that are shrub-nesting or granivorous are positively associated with shrub understory (Schulte and Niemi 1998, Hobson and Schieck 1999) that can develop following logging of green forests. As habitat structures change through time (e.g., shrub growth) or with management activities (e.g., fuels treatments), abundances of associated species of birds will change, altering the community of birds (James and Warner 1982). Understanding relationships between densities of birds and vegetation soon after fire and salvage may provide insight into the transformation of bird communities through time.

The objective of this study was to determine how species of birds vary among different intensities of salvage logging. We compared densities and relative abundance of species of birds among three treatments of salvage logging: unsalvaged, moderately salvaged, and heavily salvaged. We also examined the correlation of three vegetation variables that varied among treatments with densities of each bird species. Knowledge of the influences of different intensities of salvage logging on abundances of birds will inform post-fire management in two ways. First, our results will provide additional information about some species of birds that are positively associated with post-fire habitat, and whether partial removal of snags mitigates the negative impact of salvage logging. Second, our results will help discern the quantity of snags necessary to provide habitat for birds after fire when conservation is a goal of management.

METHODS

Study Area

We selected stands for study within the perimeter of an 8511 hectare (ha) fire that occurred on Davis Mountain, located just east of the crest of the Cascade Mountains in Deschutes County in Central Oregon (Figure 2.1). The pre-fire forest was composed primarily of ponderosa pine (*Pinus ponderosa*), with components of Douglas-fir (*Pseudotsuga menziesii*) and sugar pine (*P. lambertiana*). Due to fire suppression, the stands differed from historic forest conditions and included lodgepole pine (*P. contorta*), white fir (*Abies concolor*), and Shasta red fir (*A. magnifica* var. *shastensis*) (USDA 2004). Primary species of understory shrubs included snowbrush (*Ceanothus velutinus*), green-leaf manzanita (*Arcostaphylos patula*), and western chinquapin (*Castanopsis chrysophylla*). Soils were comprised of a deep mantle of ash and pumice over an older layer of similar soil, and are characterized as highly permeable and well drained (USDA 2004). Elevation ranged from 1200-1800 m.

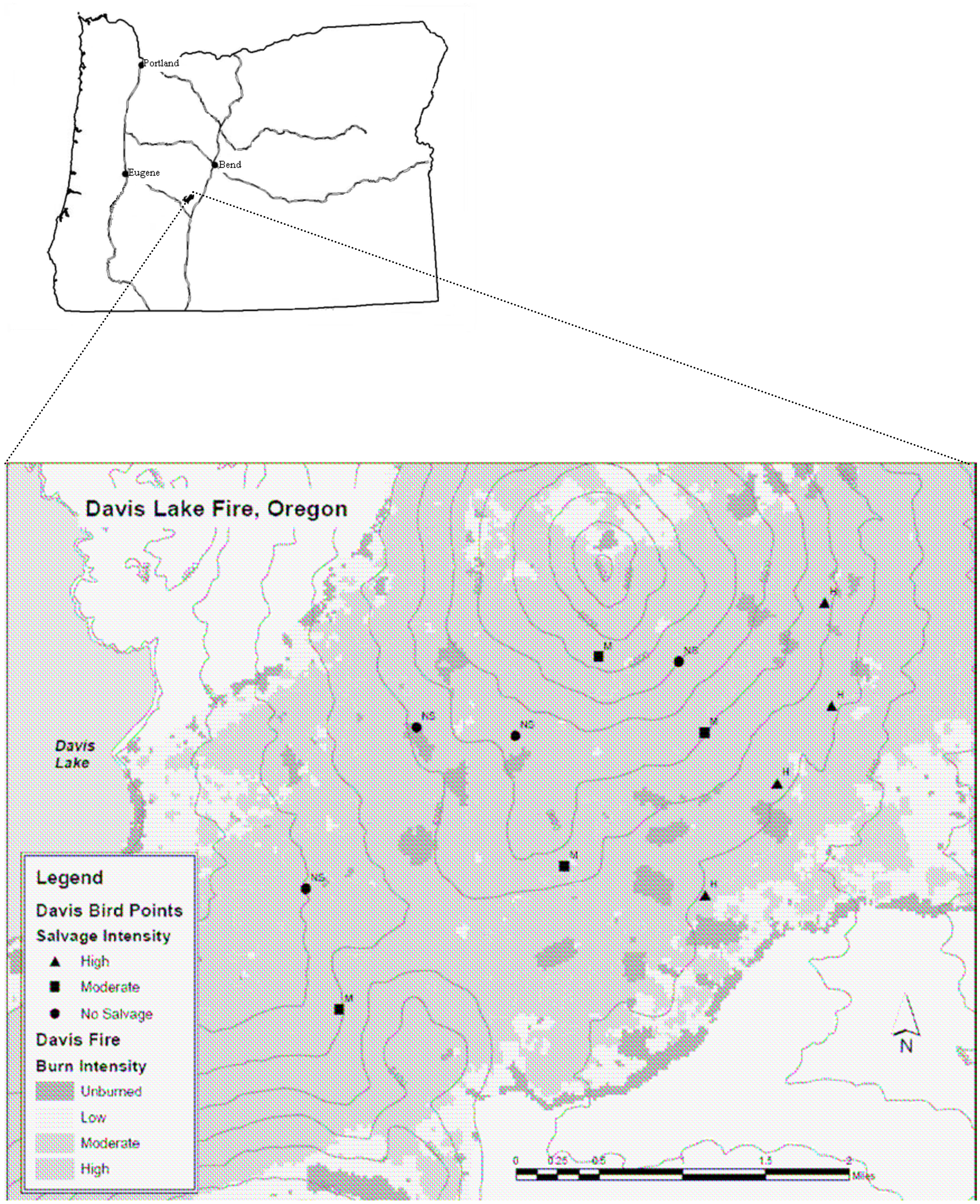

Figure 2.1. Map of Davis Lake Fire with study stands of three treatments of salvage logging in a post-fire forest, Deschutes National Forest, Oregon, summers 2005-2006.

The Davis Mountain fire occurred from late June through early July 2003. Within the fire perimeter, at least 95% tree mortality occurred within 75% of the burned forest. Pre-fire land-use designations were matrix forest and late-successional reserves (LSR), as defined by the Northwest Forest Plan (USDA and USDI 1994). Between the fall of 2004 and early summer 2005, 2514 ha of the burned forest were salvage-logged. Three management prescriptions were implemented: unsalvaged, and moderate and heavy intensities of snag removal. Within salvaged stands, all snags with a diameter at breast height (dbh) greater than 91 cm were retained. Salvaged stands of heavy intensity were located in lands designated as matrix, and 5-8 snags/ha with a minimum 50.8 cm dbh were retained. Salvaged stands of moderate intensity were located in LSR and 30 snags/ha with a minimum 35.6 cm dbh were retained. Unsalvaged stands were located in LSR.

Study Site Selection

We restricted our selection of stands to those having similar aspect and elevation, moderate or high burn intensity, good pre-fire conifer stocking (≥3.5 trees ≥91.4 cm dbh per acre), an area of at least 7 ha, and a shape allowing placement of at least three non-overlapping 80 m radius bird survey circles. Only four stands of each treatment met these criteria, and as a consequence we used all potential study stands (N=12). Study stands ranged from 10-112 ha in size (unsalvaged stands: 10-18 ha, moderately salvaged stands: 20-112 ha, and heavily salvaged stands: 13-45 ha). We established three bird sampling points per stand with point centers at least 160 m apart and 100 m from the edge where possible. We permanently marked points with rebar and polyvinyl chloride (PVC) pipe, and determined the latitude and longitude coordinates with hand-held global positioning satellite (GPS) units.

Fuel treatments were implemented in seven (all of the heavily and three of the moderately salvaged stands) stands in the fall of 2005 and spring of 2006. Fuels treatments involved felling snags less than 20.3 cm dbh and cutting them into 4.3 m lengths. In the heavy salvage stands, wood was piled after cutting and piles were burned after the study concluded in the fall of 2006. One moderate salvage stand was broadcast burned in the fall of 2005, and two others were burned after the study concluded in the fall of 2006.

Data Collection

Vegetation sampling

We established four vegetation plots at each bird sampling point. One plot was centered on the bird sampling point and three satellite plots were centered 30 m from the center point and radially spaced 120° from one another (Fig. 2.2). We used randomly generated numbers to determine the compass bearing of the first satellite point. Each vegetation plot consisted of two nested 5 and 11.3 m radii circular subplots (Fig. 2.2). We modified the BBIRD vegetation protocols (Martin et al. 1997), and visually estimated the percent ground cover of grass, forbs, shrubs, downed wood (•10 cm in diameter), small wood (<10 cm in diameter), and bare soil within the 5 m radius circular subplot. Within the 11.3 m radius circular subplot, we recorded all standing snags •10 cm dbh and • 2 m tall by marking snags with a unique number,

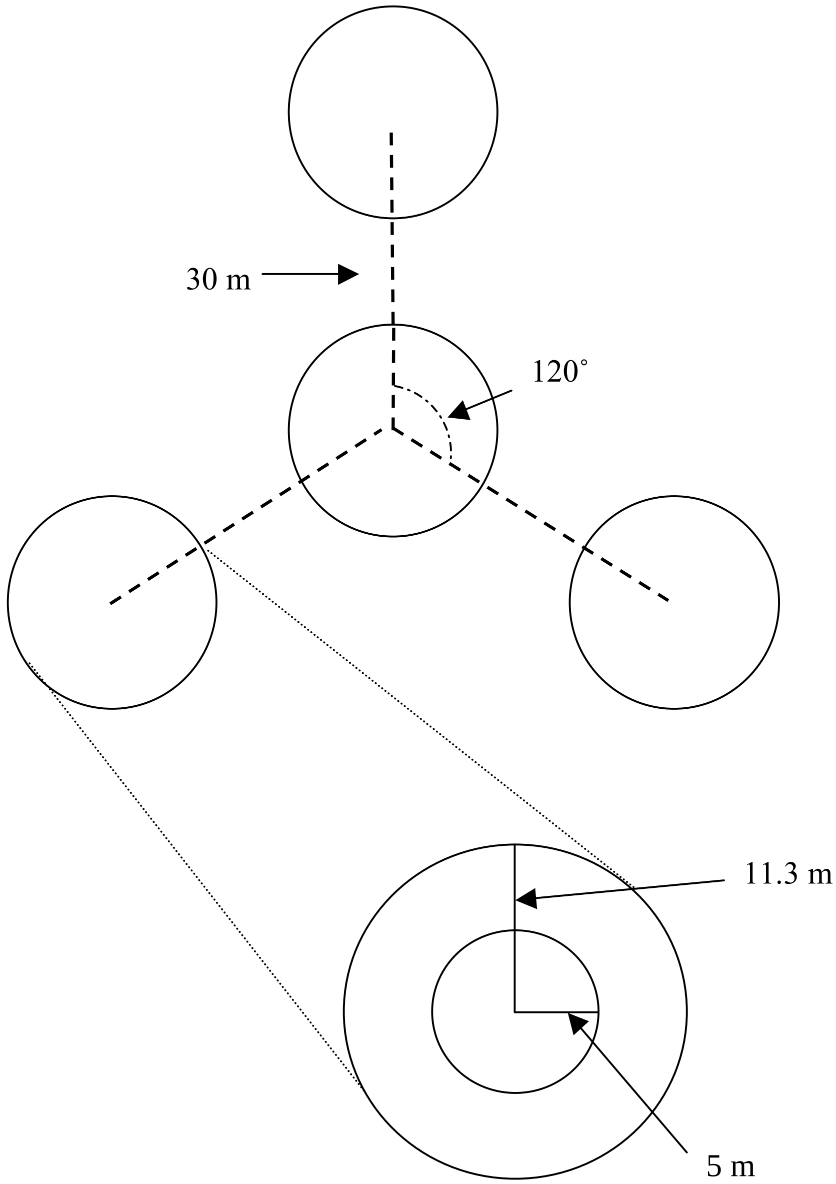

Figure 2.2. Sampling design of vegetation plots in post-fire forests with three treatments of salvage logging in Deschutes National Forest, OR, summers 2005-2006. We estimated percent vegetation cover within the 5 m circles, and measured snags ≥10 cm and ≥2 m tall within the 11.3 m circles. Each set of nested circles represents one vegetation sampling plot.

and characterizing condition of the top, number of remaining branches, estimated amount of bark remaining and decay class (Parks et al. 1997). We tallied the number of snags <10 cm dbh and • 2 m tall. We divided all snags into 5 dbh categories (<20 cm, >20-35, >35-50, >50-90, >90). We calculated snag densities for each stand using snags >35cm dbh.

At each plot, we established two transects to measure volume of downed wood and shrubs. We measured aspect and added and subtracted 45° to this bearing to establish transects. Transects were 22.6 m long and intersected at their midpoints at the center of the vegetation plot. We identified and tallied all shrubs •0.25 m tall that intersected the transect for •0.05 m. We measured height, maximum width parallel to the transect, and width perpendicular to the transect for each of these shrubs. We recorded a shrub twice if it intersected both transects. We calculated volume of shrubs by the formula:

$$\text{Shrub volume} = \frac{4}{3}\pi abc$$

where a=length/2, b=width/2, and c=height/2.

We adapted Waddell's (2002) protocol for measuring downed wood. Downed wood was measured if 1) it was •10 cm in diameter where crossed by the transect; 2) its central longitudinal axis intersected the transect; 3) it was not decay class 5 (Table 2.1); and 4) it no longer had roots in the ground and was not elevated more than 45° above the ground.

For downed wood, we recorded the diameter of downed wood at large and small ends (minimum 10 cm), overall length (to 10 cm diameter), percent burn,

Table 2.1. Decay class definitions with structural and indicators of wood texture indicators used to classify downed wood in vegetation plots in study investigating abundances of species of birds in post-fire forests that are salvage logged; Deschutes National Forest, OR, summers 2005-2006. Adapted from Waddell (2002).

Class	Structure	Wood Texture
1	Sound	Intact, no rot
2	Heartwood sound, sapwood somewhat decayed	Mostly intact; wood cannot be pulled apart by hand
3	Heartwood sound; log supports its weight	Large hard pieces of sapwood can be pulled apart by hand
4	Heartwood rotten; log does not support its weight	Soft, small blocky pieces
5	No structural integrity; shape no longer maintained	Soft, powdery when dry

percent char, and decay class. We calculated volume of downed wood using the formula:

$$\text{volume}_m = \frac{(\pi*8)(D_S^2+D_L^2)*l}{10,000}$$

where D_S=diameter of small end (cm), D_L=diameter of large end (cm), and l=length of downed wood (m). We measured length and diameter to the first clean break of the piece of downed wood, even if the "same piece" of downed wood continued. We did not record downed wood if it was decay class 5. Downed wood was recorded twice if it intersected both transects (Waddell 2002).

Bird Sampling

We counted birds between one half-hour before and four hours after sunrise, on days without heavy rain, fog, snow, or wind between 20 May and 5 July, 2005 and 2006. We recorded all birds seen or heard at the point within eight minutes, and estimated the distance from the observer to each bird to estimate density (Ramsey and Scott 1979, Reynolds et al. 1980). We determined survey order within a site by randomly selecting the first of three points and ordered subsequent points to maximize logistic efficiency. We surveyed two stands each morning, with all 12 stands surveyed before any were resurveyed. Each stand was surveyed five times each year.

Density estimates

We used program DISTANCE v4.0 (Thomas et al. 2002) to estimate densities of all species with >90 detections and ≥ 1 detection in each treatment. Six species and one genus satisfied these criteria, and we estimated densities for each species among stands while accounting for potential variation in detectability due to salvage intensity and year (Buckland et al. 2001). We analyzed violet-green and tree swallows together (genus *Tachycineta*) as we were unable to reliably identify all individuals to species during point counts. Before fitting a detection probability to a species, we pooled data from all salvage treatments and years and truncated the data at a distance where the probability of detection fell below 0.1 (Buckland et al. 2001). We then grouped the data into distance intervals. We assessed detection functions using Akaike's Information Criterion corrected for small sample sizes (AIC_c), chi-square goodness of fit, and visual inspections of detection probability plots (Buckland et al. 2001). We selected a hazard-rate detection function with a cosine expansion series for each species based on the model having the smallest AIC_c value.

To assess constancy of detection probabilities across years, salvage treatments, and observers, we modeled detection probabilities for each species by stratum (salvage treatment*year), all detections, and all detections with three potential covariates (year, salvage treatment, and observer). We calculated Δ AIC_c as the difference between AIC_c for a given model and the model with the lowest AIC_c value for each species (Burnham and Anderson 2004). For models with $\Delta AIC_c \leq 2.0$ that were stratified by treatment*year or that included a covariate, we modeled detection probability as a function of salvage treatment or year independently. We selected the final method of stratification using the lowest AIC_c value (Appendix A).

For nine species that we did not detect frequently enough to estimate density (<90 detections or zero detections in one treatment), we calculated relative abundance using the formula:

$$RA_{ijk} = D_{ijk}/V_{jk} \,,$$

where RA_{ijk}=relative abundance of species *i* in stand *j* and year *k*, D_{ijk}=number of detections of species *i* in stand *j* and year *k*, and V_{jk}=number of visits to stand *j* in year *k*. We used all detections ≤75 m from the sampling point for all of these species except black-backed woodpeckers; we extended the radius to 100 m for black-backed woodpeckers, which we readily detected at distances ≥75m.

Statistical Analysis

Vegetation

We conducted statistical tests using SAS 9.1.3 (SAS Institute Inc. 2004). We used a generalized linear mixed model with repeated measures on year (PROC MIXED) to determine if vegetation structure (shrub volume, volume of downed wood, number of pieces of downed wood, diameter of snags ≥10 cm, and number of snags >35cm dbh) and percent cover differed among salvage treatments or between years. We considered the fixed effects of salvage treatment, year, and the interaction of salvage treatment and year, and the random effects of stand variation within treatments. Our model allowed variance to differ with year. We selected a covariance structure from four possible structures (compound symmetry, unstructured covariance [1] or [2], and autoregressive covariance) and used the model with the lowest AIC_c

value. We used a natural log transformation on vegetation variables as necessary to better meet model assumptions of constant variance and normal distribution of residuals.

Birds

We used three indices to examine α-diversity: species richness (S), Shannon index (H') and Shannon evenness index (E). We calculated species richness as the number of species per stand per year. We calculated Shannon index of diversity (Shannon 1948) using relative abundance of all species of birds to determine diversity of species among salvage treatments using the formula:

$$H' = -\sum_{i=1}^{s} pi * \ln(pi)$$

where H'=diversity of species in treatment *j*, S=number of species, and p_i=proportion of species *i* in treatment *j*. We calculated Shannon evenness index (Krebs) using the formula:

$$E = H' / \ln S$$

Where H'= Shannon index and S=species richness. We used an analysis of variance model (described in the vegetation section) to test for differences in diversity of species among salvage intensities and between years.

We used the same analysis structure (described in the vegetation section) to determine if density or relative abundance of each species differed among salvage treatments or between years (PROC MIXED). Standard errors associated with estimate of densities varied depending on the number of observations of each species. To account for this variation, we weighted densities by the inverse of the standard error, giving more weight to estimates with more confidence (Ramsey and Schafer 2002). We tested for significance (α=0.05) of the fixed effects before evaluating six *a priori* hypotheses regarding density or relative abundance of each species.

We evaluated two orthogonal contrasts using ANOVA results to assess three *a priori* hypotheses regarding the influence of salvage. Our contrasts examined the differences between estimates for 1) unsalvaged treatment (U) and the average of moderate and heavy salvage treatments (M+H), and 2) the moderately salvaged treatment (M) and heavily salvaged treatment (H) for each species. Our hypotheses were:

1) Null hypothesis– there are no differences in abundances among salvage treatments (U=M+H; M=H);

2) Salvage hypothesis– abundances differ between the unsalvaged treatment and the moderate and heavy salvage treatments (U ≠M+ H), but are similar between salvage intensities (M=H); and

3) Graded-response hypothesis– abundances differ between the unsalvaged treatment and the moderate and heavy salvage treatments (U≠M+H), and abundances differ between the moderate salvage and heavy salvage intensities (M≠H).

A fourth response is also possible; abundances could be similar between the unsalvaged treatment and moderate and heavy treatments (U=M+H), but differ between the moderate and heavy salvage treatment (M≠H). Although statistically conceivable, this does not correspond to any *a priori* hypothesis we generated and as no response follows this pattern we will not consider this further.

We also evaluated two *a priori* hypothesis regarding year effect for each species:

1) Null hypothesis– abundances are not different between years (2005=2006); and

2) Year-effect hypothesis– abundances are different between years (2005 $\neq$2006).

We ln transformed densities before analysis to better meet the assumption of normally distributed residuals. Back-transformation of the natural log of the differences between treatments yielded an estimate of the ratio of differences between treatments. Confidence limits that include 1 indicate no significant difference in density or relative abundance between treatments, and confidence limits >1 or <1 indicate greater or lower densities in one treatment relative to other treatments.

Birds and vegetation

We used linear regression to model the density or relative abundance of each species of bird as a discrete function of three mean characteristics of vegetation (volume of shrubs, volume of downed wood, and the number of snags >35 cm dbh) at the stand level (PROC REG) to determine if vegetation characteristics were related to abundances of species. We tested for correlations among three variables of vegetation structure (volume of shrubs, volume of downed wood, and number of snags >35cm dbh), before using them as predictors of densities of birds. If correlation coefficient ($|r|$) was $\geq$0.5 between two variables, we interpreted one of the variables, but reported the regression coefficients for both. We ln transformed the variables shrub volume and downed wood volume to meet the model assumptions of normal distribution and constant variance of the residuals, as there was an order of magnitude difference in volume for both variables.

RESULTS

Vegetation

The distribution of all snags ≥2 m tall changed in the moderate and heavy salvage treatments between 2005 and 2006 primarily because of reductions in the number of snags <20 cm dbh class resulting from fuel treatments (Fig 2.3). Mean diameter of snags ≥10 cm dbh did not differ among salvage intensities in 2005 ($F_{2,9}$=0.25, p=0.78). Mean diameter of snags was 12.95 cm larger (95% Confidence interval [CI]: 1.42 to 24.29) in the heavy salvage treatment than in the unsalvaged treatment in 2006. Because of the fuels treatment, the mean diameter of snags increased by 9.36 cm (95% CI: 3.45 to 15.28) in the moderate salvage treatment and by 13.7 cm (95% CI: 7.79 to 19.61) in the heavy salvage treatments from 2005 to 2006 (Fig. 2.4).

Mean density of snags >35 cm dbh did not differ between 2005 and 2006 among treatments ($F_{1,9}$=0.06, p=0.81). The unsalvaged treatment had significantly greater densities of snags than the moderate salvage treatment ($\bar{x}$ difference=91.71, 95% CI: 53.7 to 129.7, t_9=6.74, p=0.0002) and the heavy salvage treatment in 2005 and 2006 ($\bar{x}$ difference= 110.15, 95%: 72.2 to 148.1, t_9=8.1, p<0.92; Table 2.2, Fig. 2.4). Although our point estimates suggest that densities of snags >35 cm dbh differed between moderately and heavily salvaged stands (Fig 2.4), mean densities were not statistically significantly different between the moderate and heavy salvage treatments

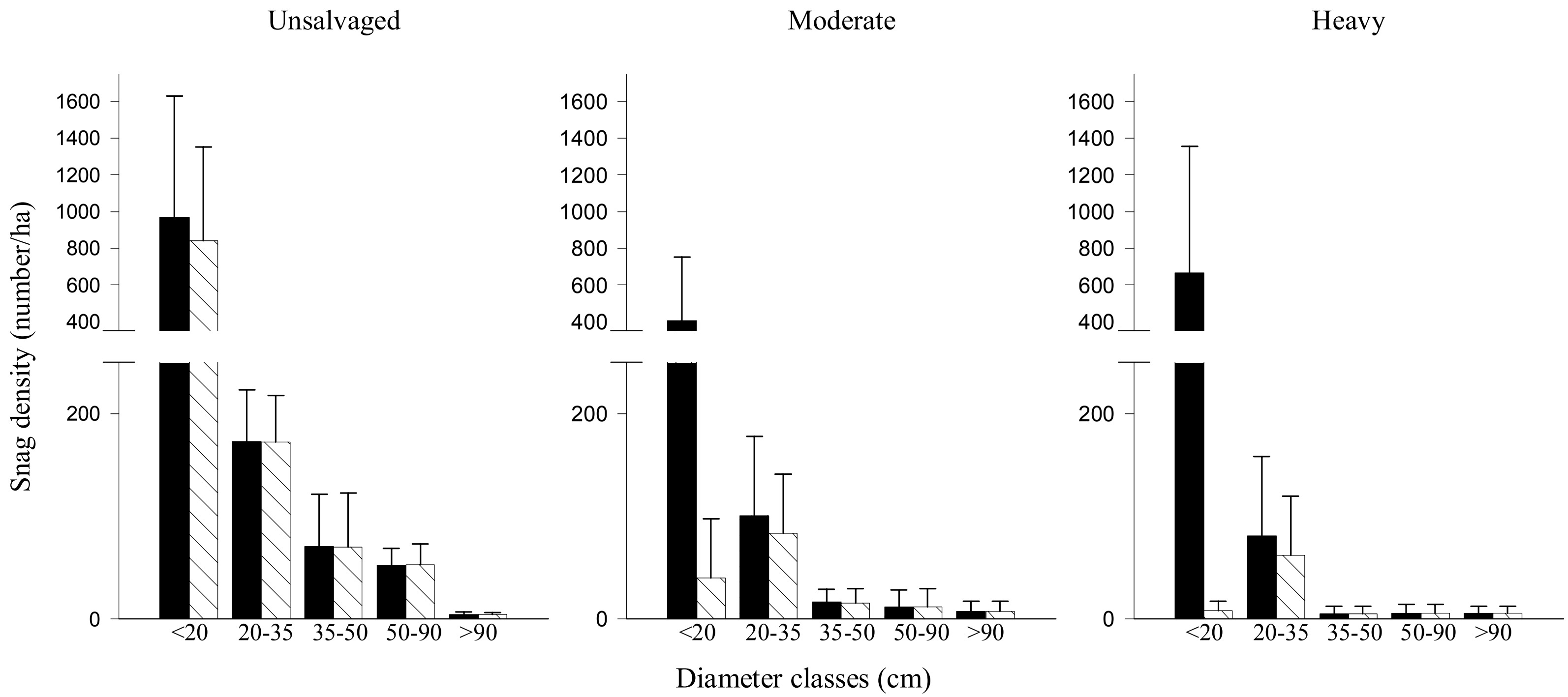

Figure 2.3. Diameter distribution of snags in a post-fire forest with three treatments of salvage logging in Deschutes National Forest, OR, summers 2005-2006. Mean estimates for 2005 (black) and 2006 (hatched); error bars represent 95% confidence limits. Minimum height of snag to be counted was 2 m.

Figure 2.4. Mean or median estimates of vegetation variables in post-fire forests with three treatments of salvage logging in Deschutes National Forest, OR, summers 2005-2006. Point estimates for 2005 (●) and 2006 (△); error bars represent 95% confidence limits.

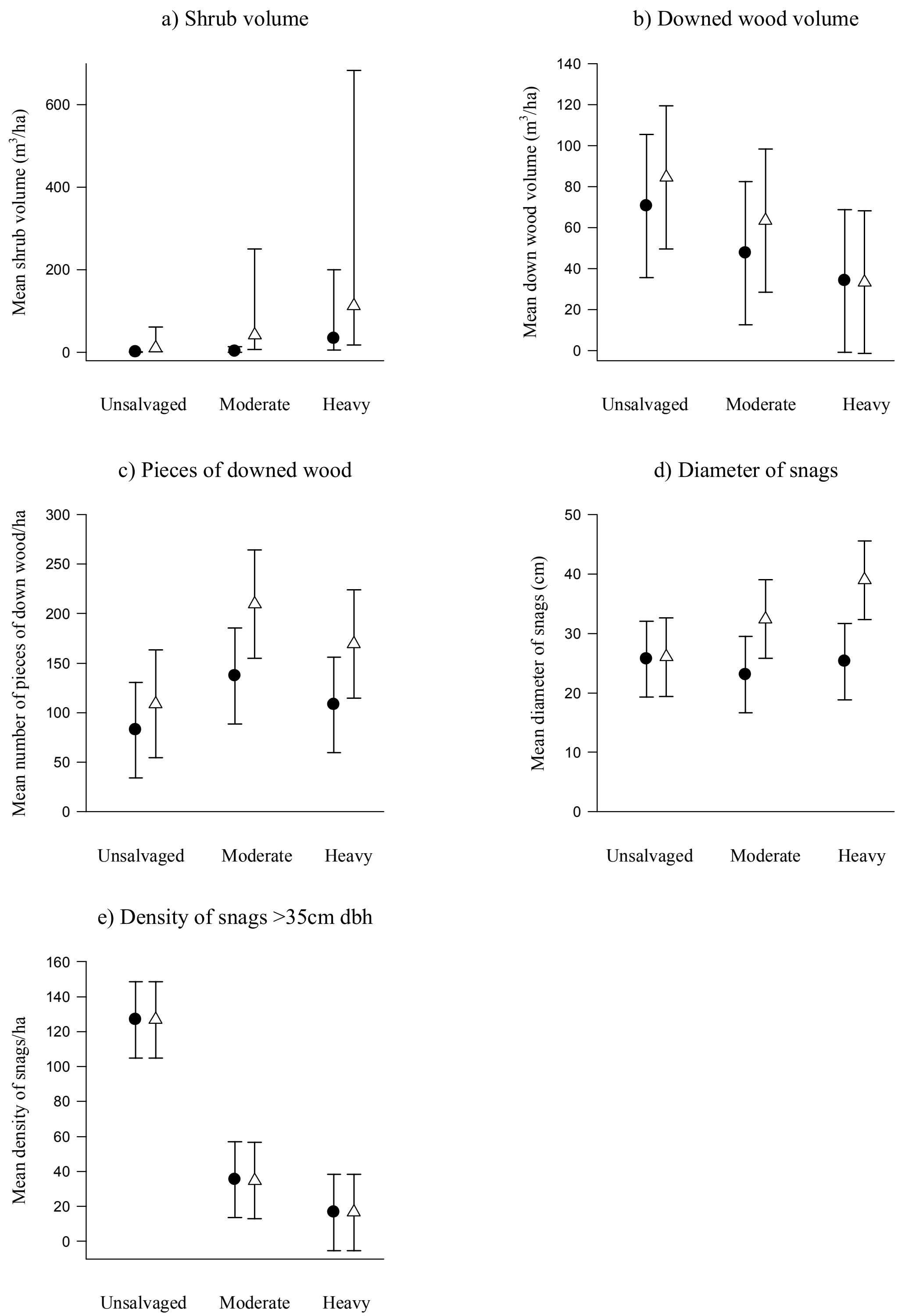
a) Shrub volume
Mean shrub volume (m3/ha)
0
200
400
600
Unsalvaged
Moderate
Heavy
b) Downed wood volume
Mean down wood volume (m3/ha)
0
20
40
60
80
100
120
140
Unsalvaged
Moderate
Heavy
c) Pieces of downed wood
Mean number of pieces of down wood/ha
0
50
100
150
200
250
300
Unsalvaged
Moderate
Heavy
d) Diameter of snags
Mean diameter of snags (cm)
0
10
20
30
40
50
Unsalvaged
Moderate
Heavy
e) Density of snags >35cm dbh
Mean density of snags/ha
0
20
40
60
80
100
120
140
160
Unsalvaged
Moderate
Heavy

Table 2.2. Results of ANOVA comparing mean vegetation estimates as a function of the fixed effects of year, salvage treatments, and the interaction between year and salvage treatment (year*treatment) in post-fire forests with three treatments of salvage logging in Deschutes National Forest, OR, summers 2005-2006. F-statistic (F) with numerator (N df) and denominator (D df) degrees of freedom. Bold indicates a significant fixed effect ($p<0.05$).

Vegetation measurement	Fixed Effect	N df	D df	F	p
Shrub volume	Year	1	9	73.25	**<.0001**
	Intensity	2	9	6.45	**0.0183**
	Year*Intensity	2	9	6.48	**0.0181**
Downed wood volume	Year	1	9	13.95	**0.0047**
	Intensity	2	9	2.06	0.1835
	Year*Intensity	2	9	3.93	0.0594
Pieces of downed wood	Year	1	9	30.31	**0.0004**
	Intensity	2	9	3.36	0.0812
	Year*Intensity	2	9	2.03	0.1877
Snag density[a]	Year	1	9	0.06	0.8138
	Intensity	2	9	37.62	**<0.0001**
	Year*Intensity	2	9	0.06	0.9452
Snag diameter[b]	Year	1	9	65.83	**<.0001**
	Intensity	2	9	1.36	0.3037
	Year*Intensity	2	9	16.77	**0.0009**

[a] Includes snags ≥35 cm dbh
[b] Includes snags ≥10 cm dbh

(t_9=1.46, p=0.40). The lack of statistical significance is likely the result of high spatial variability in distribution of snags and the inability of our sampling techniques to fully capture stand-level differences using our plot-based sampling.

Differences in shrub volume among salvage treatments depended on year ($F_{2,9}$=6.48, p=0.018; Table 2.2, Fig. 2.4). Shrub volume increased across all treatments between 2005 and 2006. Greatest volume of shrubs in heavy salvage in 2006, and the least volume of shrubs occurred in the unsalvaged treatment in 2005.

Volume of downed wood increased significantly in moderately salvaged and unsalvaged treatments between 2005 and 2006 (moderate: $F_{1,9}$=12.24, p=0.0067; unsalvaged: $F_{1,9}$=9.55, p=0.013; Fig. 2.4). This increase in volume of downed wood is likely the result of snags falling. Number of pieces of downed wood increased significantly between 2005 and 2006 in moderate and heavy salvage treatments (moderate: $F_{1,9}$=18.53, p=0.002; heavy: $F_{1,9}$=13.33 p=0.0053; Fig 2.4), likely reflecting the influences of the fuels treatment implemented between 2005 and 2006.

Bare ground was significantly greater in unsalvaged than in moderate ($\bar{x}$ difference=15.59%, 95 % CI: 2.49 to 28.68, t_9=3.32, p=0.009; Table 2.3) and heavy salvage treatments ($\bar{x}$ difference=13.45%, 95 % CI: 0.36 to 26.55, t_9=2.87, p=0.045), and decreased significantly between 2005 and 2006 ($\bar{x}$ decrease= 15.72%, 95% CI: 10.91 to 20.53, $F_{1,9}$=54.71, p<0.0001). Cover of shrubs increased significantly ($\bar{x}$ increase=15.74%, 95% CI: 9.52 to 21.96, $F_{1,9}$=31.79, p=0.0003), and cover of downed wood increased significantly ($\bar{x}$ increase=3.80%, 95% CI: 1.71 to 5.81, $F_{1,9}$=16.89, p=0.003) between 2005 and 2006. Cover of shrubs and downed wood did not differ

Table 2.3. Mean percent cover of vegetation in post-fire forests with three treatments of salvage logging in Deschutes National Forest, OR, summers 2005-2006. Estimates for unsalvaged (U), moderate salvage intensity (M), and heavy salvage intensity (H) with 95% confidence limits in parentheses.

	2005			2006		
Variable	U	M	H	U	M	H
Bare ground	60.11	39.79	45.31	40.34	29.48	28.23
	(51.01, 69.20)	(30.69, 48.89)	(36.22, 54.41)	(32.30, 48.37)	(21.44, 37.51)	(20.19, 36.26)
Shrub[a]	13.73	13.02	15.83	31.75	29.4	28.67
	(3.96, 23.50)	(3.25, 22.79)	(6.06, 25.61)	(20.53, 42.97)	(18.17, 40.62)	(17.45, 39.89)
Downed wood[b]	5.75	12.36	8.46	6.91	15.31	15.75
	(1.69, 9.81)	(8.29, 16.42)	(4.40, 12.52)	(2.03, 11.78)	(10.43, 20.19)	(10.87, 20.63)
Small wood[c]	4.62	23.5	16.53	7.29	16.25	16.65
	(-0.40 9.63)	(18.49, 28.51)	(11.52, 21.55)	(3.51, 11.07)	(12.47, 20.03)	(12.87, 20.42)
Grass[a]	1.02	1.19	0.75	1.52	1.94	1.44
	(-0.12, 2.16)	(0.05, 2.33)	(-0.39, 1.89)	(0.38 2.66)	(0.80, 3.08)	(0.30, 2.58)
Forbs[a]	2.33	0.92	0.89	0.74	0.76	0.78
	(0.92, 3.73)	(-0.49, 2.32)	(-0.52, 2.29)	(-0.68, 2.15)	(-0.65, 2.17)	(-0.62, 2.19)

[a] Amount of exposed soil
[b] All species combined.
[c] Woody material ≥10 cm diameter, including material left after salvage logging operations.
[d] Woody material <10 cm diameter, including branches and material left after salvage logging operations

significantly among treatments. Cover of small wood (<10 cm dbh) was significantly greater in the heavy ($\bar{x}$ difference=10.64%, 95% CI: 4.68 to 16.59, t_9=4.99, p=0.002) and moderate salvage treatments ($\bar{x}$ increase=13.92%, 95% CI: 7.97 to 19.88, t_9=6.53, p=0.0003) compared to the unsalvaged treatment, but did not differ between years ($F_{1,9}$=1.06, p=0.33). Cover of forbs and grasses did not differ significantly among treatments (forbs: $F_{2,9}$=0.58, p=0.58, and grass: $F_{2,9}$=0.23, p=0.80). Grasses and forbs were not a dominant ground cover at our study site, and while we detected a statistically significant increase in grass between years ($\bar{x}$ increase =0.65%, 95% CI; 0.33% to 0.97%, $F_{1,9}$=20.92, p=0.0013), the biological significance is negligible.

Density of snags >35 cm dbh positively correlated with volume of downed wood (r=0.54, p=0.006; Fig. 2.5), and negatively correlated with shrub volume (r= -0.61, p=0.002). Downed wood volume negatively correlated with shrub volume (r= -0.553, p=0.005; Fig. 2.5).

Birds

We detected 34 species of birds, of which 29 species were detected both years (see appendix B for scientific names). In 2005 and 2006 the four most commonly detected species were mountain bluebird, dark-eyed junco, yellow-rumped warbler, and hairy woodpecker.

Species richness did not significantly differ between unsalvaged treatment and salvaged treatments ($\bar{x}$ difference=0.63, 95% CI: -1.65-2.90, t_9=0.62, p=0.55), but

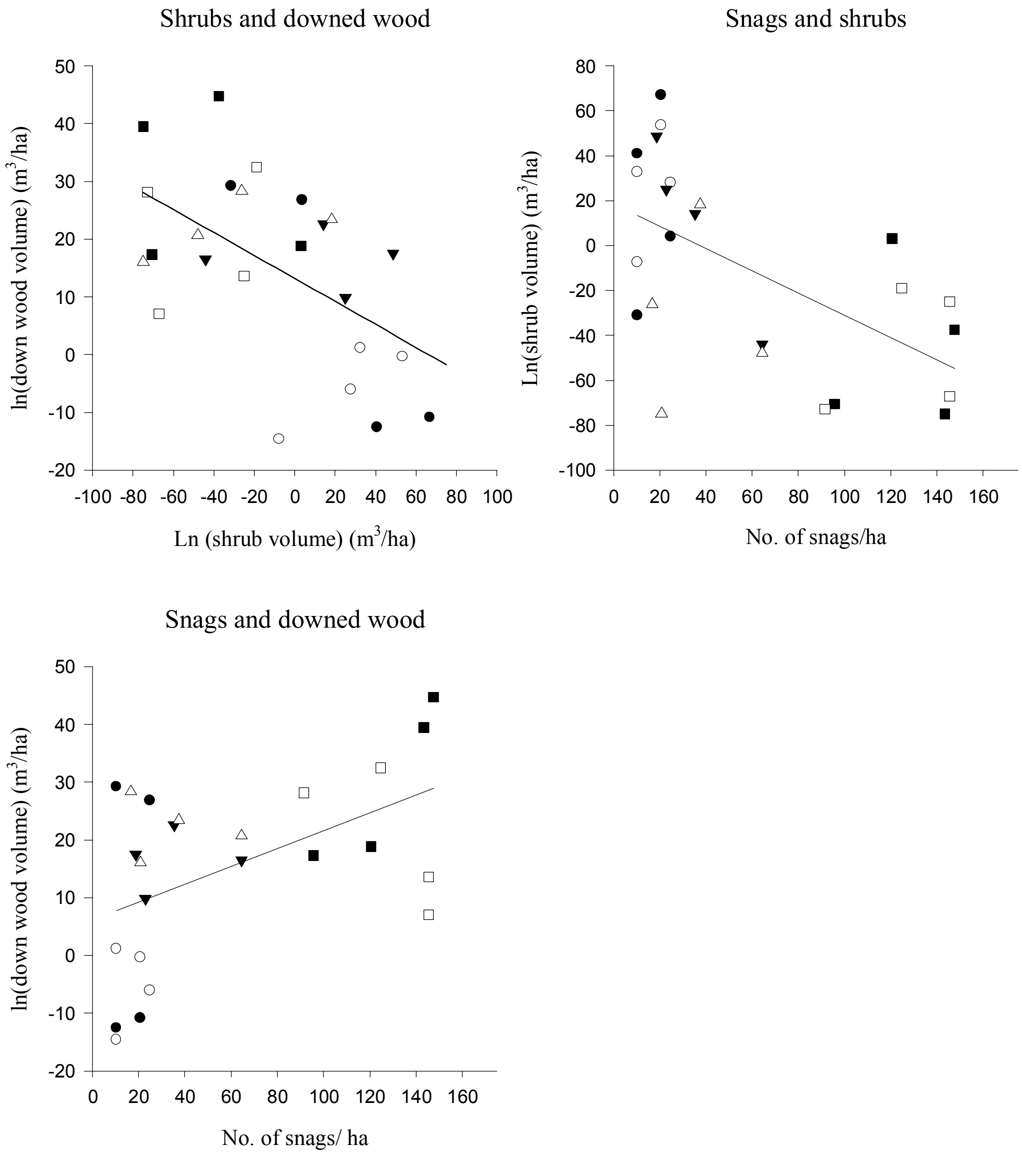

Figure 2.5. Relationships between vegetation variables in post-fire forests with three treatments of salvage logging in Deschutes National Forest, OR, summers 2005-2006. Mean values in stands of unsalvaged (□), moderate (△) and heavy (○) salvage treatments in 2005 (filled) and 2006 (unfilled) with best fitting line (—). Correlations (r) between vegetation variables a) r=0.12, p=0.58 b) r=-0.61, p=0.001 and c) r=0.54, p=0.006.

was significantly less in moderate salvage treatment than in heavy salvage treatment ($\bar{x}$ difference=5.5, 95% CI: 2.88 to 8.12, t_9= 4.74 p=0.0011). Species diversity (H') did not significantly differ between unsalvaged treatment and salvaged treatments ($\bar{x}$ difference=0.12 , 95% CI: -0.08 to 0.32, t_9=1.32, p=0.22), but was significantly less moderate salvage treatments relative to heavy salvage treatments ($\bar{x}$ = 0.40, 95% CI: 0.17 to 0.63, t_9=3.92, p= 0.004). Species evenness did not differ significantly among treatments ($F_{2,9}$=2.29, p=0.16). Species richness, species diversity, and species evenness decreased from 2005 to 2006 (Table 2.4).

We estimated density for six species and one swallow genus (*Tachycineta*) for each treatment of salvage and for each year (Table 2.5). Treatment by year interactions were not significant for any group (p>0.3; Table 2.6). Of the seven taxa for which we estimated densities, density of three species did not significantly differ among treatments (mountain bluebird, house wren, and *Tachycineta*) (Table 2.7).

Densities of hairy woodpeckers and yellow-rumped warblers were greater in the unsalvaged treatment than in salvaged treatments, but did not differ between salvage intensities (Table 2.7). Densities of dark-eyed juncos were lesser in the unsalvaged treatment than in salvage treatments, but did not differ between salvage intensities (Table 2.7). Fox sparrows were the only species for which we documented differences between both salvage and intensity (Table 2.7). Densities of fox sparrows were greatest in the heavy salvage treatment compared to the moderate and unsalvaged treatments (table 2.7).

Table 2.4. Indices of α-diversity of bird species in post-fire forests with three treatments of salvage logging in Deschutes National Forest, OR, summers 2005-2006.

	2005			2006		
Index	U	M	H	U	M	H
Species richness	16	13	20.5	15.3	11.5	15
	(14.0-18.0)	(11.0-15.0)	(18.5-22.5)	(12.4-18.1)	(8.7-14.3)	(12.2-17.8)
Species diversity	2.41	2.14	2.61	2.29	1.93	2.26
	(2.27-2.55)	(1.99-2.28)	(2.46-2.75)	(2.07-2.51)	(1.71-2.15)	(2.04-2.48)
Species evenness	0.87	0.84	0.86	0.85	0.80	0.84
	(0.83-0.91)	(0.80-0.88)	(0.82-0.91)	(0.81-0.89)	(0.76-0.84)	(0.80-0.88)

Table 2.5. Median density/ha of species for each salvage intensity by year in post-fire forests with three treatments of salvage logging in Deschutes National Forest, OR, summers 2005-2006. Estimates for unsalvaged (U), moderate salvage intensity (M), and heavy salvage intensity (H) with 95% confidence limits in parentheses.

	2005			2006		
Species	U	M	H	U	M	H
Hairy woodpecker	0.32 (0.25, 0.42)	0.28 (0.22, 0.36)	0.30 (0.24, 0.39)	0.37 (0.30, 0.46)	0.24 (0.20, 0.28)	0.29 (0.24, 0.35)
Tachycineta	0.20 (0.13, 0.31)	0.18 (0.12, 0.26)	0.23 (0.14, 0.35)	0.39 (0.30, 0.51)	0.28 (0.23, 0.35)	0.32 (0.25, 0.42)
House wren	0.06 (0.03, 0.12)	0.10 (0.05, 0.22)	0.08 (.04, 0.15)	0.07 (0.04, 0.13)	0.08 (0.04, 0.14)	0.11 (0.06, 0.22)
Mountain bluebird	0.55 (0.34, 0.89)	0.86 (0.50, 1.47)	0.74 (0.44, 1.24)	0.69 (0.50, 0.95)	0.79 (0.57, 1.10)	0.88 (0.63, 0.1.24)
Yellow-rumped warbler	0.65 (0.44, 0.97)	0.35 (0.25, 0.48)	0.36 (0.26, 0.50)	0.54 (0.34, 0.87)	0.21 (0.152, 0.30)	0.25 (0.18, 0.37)
Fox sparrow	0.14 (0.10, 0.18)	0.17 (0.12, 0.24)	0.25 (0.16, 0.40)	0.18 (0.13, 0.25)	0.20 (0.14 0.28)	0.38 (0.24, 0.62)
Dark-eyed junco	0.37 (0.31, 0.44)	0.53 (0.43, 0.65)	0.54 (0.44, 0.66)	0.68 (0.53, 0.86)	0.94 (0.72, 1.23)	0.79 (0.61, 1.01)

Table 2.6. Results of ANOVA comparing densities/ha for six species and 1 genus of birds as a function of the fixed effects of year, salvage treatment, and the interaction between year and salvage treatment (year*treatment) in post-fire forests with three treatments of salvage logging in Deschutes National Forest, OR, summers 2005-2006. F-statistic (F) with numerator (N df) and denominator (D df) degrees of freedom. Bold indicates a significant fixed effect (p<0.05).

Species	Fixed effect	N df	D df	F	p
Hairy woodpecker	Year	1	9	0.07	0.794
	Treatment	2	9	**4.69**	**0.040**
	Year*Treatment	2	9	1.19	0.347
Tachycineta	**Year**	1	9	**17.94**	**0.002**
	Treatment	2	9	1.26	0.330
	Year*Treatment	2	9	0.57	0.587
House wren	Year	1	9	.12	0.740
	Treatment	2	9	0.38	0.692
	Year*Treatment	2	9	0.78	0.487
Mountain bluebird	Year	1	9	0.55	0.479
	Treatment	2	9	1.27	0.327
	Year*Treatment	2	9	0.44	0.656
Yellow-rumped warbler	**Year**	1	9	**7.42**	**0.024**
	Treatment	2	9	**9.69**	**0.006**
	Year*Treatment	2	9	0.47	0.642
Fox sparrow	Year	1	9	5.06	0.051
	Treatment	2	9	**6.26**	**0.020**
	Year*Treatment	2	9	0.41	0.673
Dark-eyed junco	**Year**	1	9	**65.6**	**<.0001**
	Treatment	2	9	**5.09**	**0.033**
	Year*Treatment	2	9	1.17	0.354

Table 2.7. Comparison of median density estimates for each species among three treatments of salvage logging in post-fire forests in Deschutes National Forest, OR, summers 2005-2006. Comparisons are unsalvaged to average of moderate and heavy salvage (U v (M+H)), and moderate salvage to heavy salvage (M v H). Difference refers to the difference in densities between comparisons. 95% confidence limits that exclude 1 are significant at $p \leq 0.05$ and indicated in bold.

Species		Comparison	
		U v (M+H)	M v H
Hairy woodpecker	Difference	**1.258**	0.875
	95% confidence limits	**1.034-1.530**	0.712-1.075
	p-value	**0.027**	0.18
Tachycineta	Difference	1.15	0.827
	95% confidence limits	0.832-1.590	0.573-1.194
	p-value	0.36	0.27
House wren	Difference	0.885	0.985
	95% confidence limits	0.644-1.216	0.675-1.437
	p-value	0.41	0.93
Mountain bluebird	Difference	0.754	1.020
	95% confidence limits	0.504-1.127	0.629-1.655
	p-value	0.15	0.93
Yellow-rumped warbler	Difference	**2.078**	0.901
	95% confidence limits	**1.420-3.043**	0.619-1.313
	p-value	**0.002**	0.55
Fox sparrow	Difference	**0.654**	**0.588**
	95% confidence limits	**0.467-0.916**	**0.371-0.932**
	p-value	**0.019**	**0.029**
Dark-eyed junco	Difference	**0.737**	1.09
	95% confidence limits	**0.591-0.920**	0.832-1.428
	p-value	**0.012**	0.49

We compared relative abundances of nine species among salvage treatments, none of which had significant treatment by year interactions (Table 2.8). Of the nine species for which we estimated relative abundances, six did not significantly differ with treatment (dusky flycatcher, white-breasted nuthatch, red-breasted nuthatch American robin, western tanager, and chipping sparrow).

Black-backed woodpeckers, western wood-pewees and brown creepers responded negatively to salvage logging (Table 2.9), with greater relative abundances in unsalvaged treatments than in salvaged treatments. Relative abundances for these species did not differ among the salvage intensities (Table 2.9). This indicates the negative response of species to salvage was not mitigated by a lower intensity of salvage logging.

Densities of dark-eyed juncos and *Tachycineta* increased significantly between 2005 and 2006 (dark-eyed juncos, $\bar{x}$ increase=1.68, 95% CI: 1.45 to 1.94, $F_{1,9}$=65.6, $p<0.001$; *Tachycineta,* $\bar{x}$ increase=1.61 95% CI: 1.25 to 2.09, $F_{1,9}$=17.94, p=0.002). Densities of yellow-rumped warblers and relative abundance of red-breasted nuthatches decreased significantly between 2005 and 2006 (yellow-rumped warbler, $\bar{x}$ decrease= 0.72, 95% CI: 0.54 to 0.95, $F_{1,9}$=7.42, p=0.024; red-breasted nuthatch $\bar{x}$ decrease=0.52, 95% CI: 0.27 to 0.77, $F_{1,9}$=22.01, p=0.001; Table 2.6, 2.8).

Densities of three species (hairy woodpecker, house wren, and mountain bluebird) and one genus (*Tachycineta*) were not strongly correlated with any of the vegetation variables measured ($r^2<0.20$; Table 2.10). Densities of yellow-rumped warblers correlated positively to density of snags >35 cm dbh ($r^2=0.50$; Fig. 2.6).

Table 2.8. Results of ANOVA comparing relative abundances per stand of nine species of birds as a function of the fixed effects of year, salvage treatment, and the interaction between year and salvage treatment (year*treatment) in post-fire forests with three treatments of salvage logging in Deschutes National Forest, OR, summers 2005-2006. F-statistic (F) with numerator (N df) and denominator (D df) degrees of freedom. Bold indicates a significant fixed effect ($p<0.05$).

Species	Fixed effect	N df	D df	F	p
Black-backed woodpecker	Year	1	9	3.66	0.088
	Treatment	2	9	**10.18**	**0.005**
	Year*Treatment	2	9	3.39	0.080
Western wood-pewee	Year	1	9	1.00	0.343
	Treatment	2	9	**4.38**	**0.047**
	Year*Treatment	2	9	2.33	0.153
Dusky flycatcher	Year	1	9	1.00	0.340
	Treatment	2	9	2.38	0.148
	Year*Treatment	2	9	1.28	0.325
Brown creeper	Year	1	9	3.27	0.104
	Treatment	2	9	**9.62**	**0.006**
	Year*Treatment	2	9	1.16	0.356
White-breasted nuthatch	Year	1	9	0.26	0.620
	Treatment	2	9	0.22	0.800
	Year*Treatment	2	9	0.12	0.890
Red-breasted nuthatch	**Year**	1	9	**22.01**	**0.001**
	Treatment	2	9	0.62	0.560
	Year*Treatment	2	9	1.81	0.219
American robin	Year	1	9	0.74	0.411
	Treatment	2	9	2.50	0.137
	Year*Treatment	2	9	0.83	0.466
Western tanager	Year	1	9	1.62	0.236
	Treatment	2	9	0.63	0.560
	Year*Treatment	2	9	0.63	0.556
Chipping sparrow	Year	1	9	2.21	0.171
	Treatment	2	9	0.50	0.624
	Year*Treatment	2	9	0.08	0.925

Table 2.9. Comparison of mean relative abundances for each species among three treatments of salvage logging in post-fire forests in Deschutes National Forest, OR, summers 2005-2006. Comparisons are unsalvaged to average of moderate and heavy salvage (U v (M+H)), and moderate salvage to heavy salvage (M v H). Difference refers to the difference in densities between comparisons. 95% confidence limits that exclude 0 are significant at $p \leq 0.05$ and indicated in bold.

Species		Comparisons	
		U v (M+H)	M v H
Black-backed woodpecker	Difference	**0.538**	-0.275
	95% confidence limits	**0.153- 0.923**	-0.720- 0.170
	p-value	**0.012**	0.2
Western wood-pewee	Difference	**0.288**	-0.025
	95% confidence limits	**0.067- 0.508**	-0.279- 0.229
	p-value	**0.016**	0.83
Dusky flycatcher	Difference	-0.363	-0.575
	95% confidence limits	-1.001- 0.276	-1.312- 0.162
	p-value	0.23	0.11
Brown creeper	Difference	**0.888**	-0.125
	95% confidence limits	**0.426- 1.349**	-0.658- 0.408
	p-value	**0.002**	0.61
White-breasted nuthatch	Difference	-0.100	-0.050
	95% confidence limits	-0.468- 0.268	-0.475- 0.375
	p-value	0.55	0.80
Red-breasted nuthatch	Difference	0.000	-0.150
	95% confidence limits	-0.264- 0.264	-0.455- 0.155
	p-value	1.0	0.30
American robin	Difference	0.225	0.050
	95% confidence limits	-0.007- 0.457	-0.281- 0.318
	p-value	0.06	0.68
Western tanager	Difference	-0.013	-0.125
	95% confidence limits	-0.233- 0.208	-0.379- 0.129
	p-value	0.90	0.30
Chipping sparrow	Difference	0.275	-0.100
	95% confidence limits	-0.379- 0.929	-0.855- 0.655
	p-value	0.37	0.77

Table 2.10. Coefficients for relationships between estimated density of species of birds and mean variable of vegetation, where Density= $\beta_o + \beta_1$ * Vegetation. Negative β values indicate a negative relationship among variables.

		Model		
Density		Shrub volume*	Downed wood volume *	Snags >35cm/ha
Hairy woodpecker	β_o	0.2125	0.2148	0.1782
	β_1	-0.0002	0.0000	0.0006
	r^2	0.01	0.00	0.16
Tachycineta	β_o	0.1961	0.1891	0.1722
	β_1	0.0007	-0.0001	0.0003
	r^2	0.11	0.00	0.02
House wren	β_o	0.9200	0.1003	0.1011
	β_1	0.0005	-0.0009	-0.0002
	r^2	0.09	0.04	0.03
Mountain bluebird	β_o	0.7460	0.7627	0.8188
	β_1	0.0015	-0.0021	-0.0015
	r^2	0.05	0.02	0.08
Yellow-rumped warbler	β_o	0.2956	0.2774	0.1722
	β_1	-0.0023 [a]	0.0028	0.0025[a]
	r^2	0.31	0.06	0.50
Fox sparrow*	β_o	-2.0357	-1.6540	-1.5631
	β_1	0.0162 [a]	-0.0365 [b]	-0.0110 [a]
	r^2	0.65	0.43	0.41
Dark-eyed junco	β_o	0.6022	0.5733	0.6500
	β_1	0.0033 [a]	-0.0005	-0.0014
	r^2	0.36	0.00	0.09

* ln transformed variables

[a] slope coefficients (β_1) significant at $p<0.001$

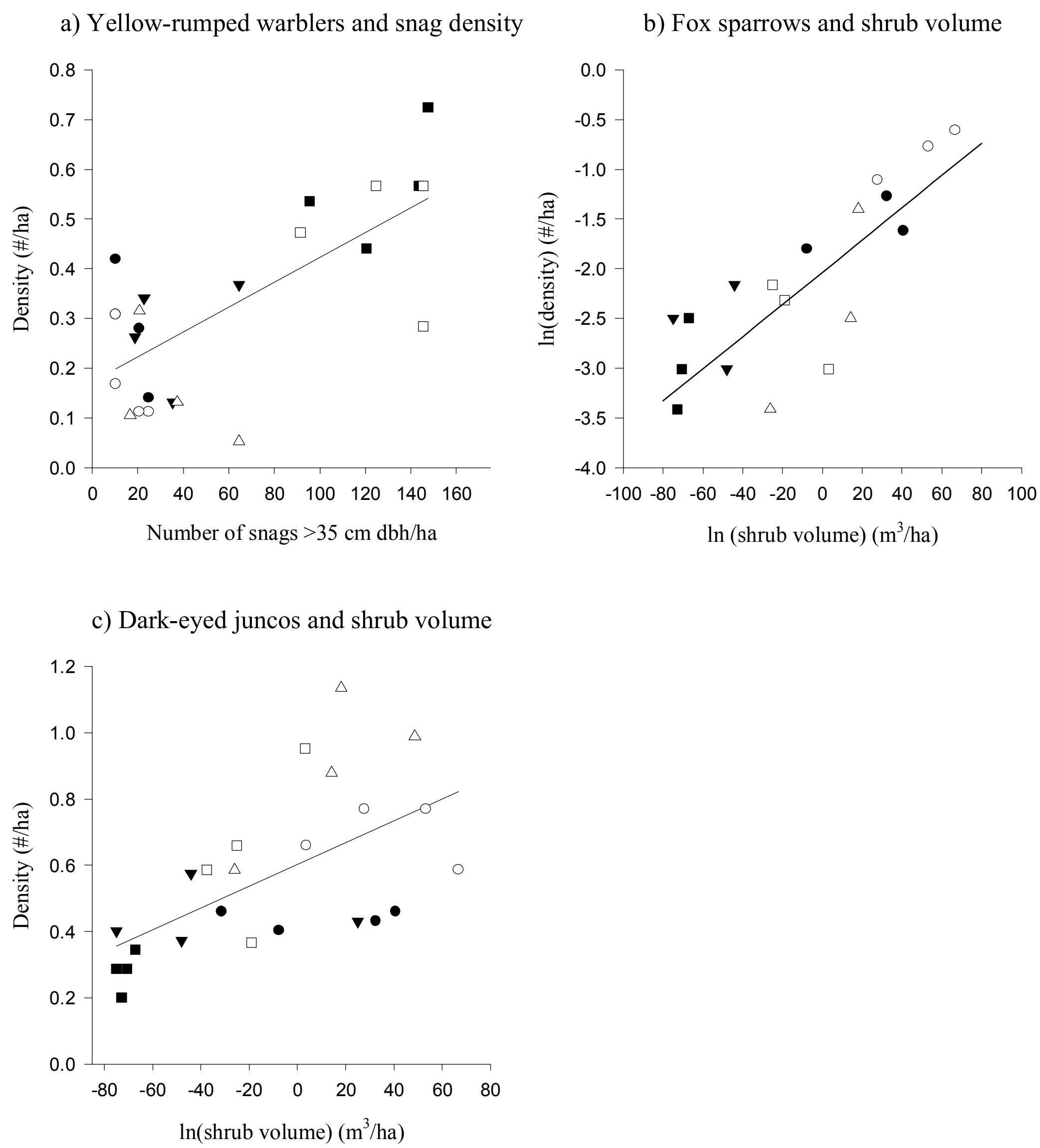

Figure 2.6. Densities of species of birds as a function of vegetation variables that explained >30% of the variation in densities in post-fire forests with three treatments of salvage logging in Deschutes National Forest, OR, summers 2005-2006. Mean values in stands of unsalvaged (□), moderate (△) and heavy (○) salvage treatments in 2005 (filled) and 2006 (unfilled) with best fitting line (—). Correlations between vegetation variables a) r^2=0.50, b) r^2=0.65 and c) r^2=0.36.

Densities of fox sparrows correlated strongly and positively with volume of shrubs (r^2=0.65; Fig. 2.6). Densities of dark-eyed juncos correlated positively to shrub volume (r^2=0.36; Fig.2.6). Relative abundances of nine species (Table 2.9) were not strongly correlated with any of the vegetation variables (r^2<0.25).

DISCUSSION

We observed species-specific differences to salvage. We were unable to detect differences among salvage treatments for nine species, consistent with our null hypothesis. We detected differences in densities or relative abundances among treatments for nearly half (7 of 16) of the species we analyzed, with six species responding in a pattern consistent with the salvage hypothesis, and with one species responding in a pattern consistent with the graded response hypothesis.

Abundances of black-backed woodpeckers, hairy woodpeckers, brown creepers, western wood-pewees, yellow-rumped warblers, and dark-eyed juncos) were consistent with predictions of the salvage hypothesis, where species abundances differ between the unsalvaged and salvage treatments, but no differences detected between salvage intensities. All of these species responded negatively to salvage except dark-eyed juncos which were more abundant in salvage treatments relative to the unsalvaged treatment. Moderate salvage did not seem to mitigate the negative response of the other five species.

Black-backed woodpeckers are associated with burned forests, and populations typically dramatically increase after fire (Blackford 1955, Hutto 1995, Murphy and Lehnhausen 1998). Our findings are consistent with those of other studies that have demonstrated the negative effect that salvage logging has on this species (Caton 1996, Saab and Dudley 1998, Haggard and Gaines 2001, Hutto and Gallo 2006). The moderate intensity of salvage logging that we examined did not mitigate the negative impacts of salvage logging on the black-backed woodpecker.

Although hairy woodpeckers inhabit a mix of forest types, abundances and nesting densities of hairy woodpeckers are generally greater in burned habitat relative to unburned habitat (Caton 1996, Kotliar et al. 2002, Kotliar et al. 2007). Hairy woodpeckers respond negatively to salvage logging, with lower abundances and nesting densities in intensely salvaged forests relative to unsalvaged forests (Caton 1996, Saab and Dudley 1998, Haggard and Gaines 2001, Hutto 2006). Previous studies have reported differing responses of hairy woodpeckers to partial salvage logging. Similar nesting densities of hairy woodpeckers have been reported in post-fire forests of partial and standard salvage in one study (Saab and Dudley 1998), but abundances of hairy woodpeckers in partial salvage were intermediate between salvaged and unsalvaged forests in another study (Haggard and Gaines 2001). In our study, a moderate intensity of salvage logging did not seem to lessen the negative influences of salvage logging on densities of hairy woodpeckers compared to heavy intensity of salvage.

Brown creepers are typically associated with late-successional forests (Carey et al. 1991, Hutto and Young 1999, Hejl et al. 2002), but can be more abundant in burned forest than in unburned forests (Huff et al. 1985, Morissette et al. 2002). Brown creepers select large snags (Franzreb 1985, Morrison et al. 1987, Lundquist and

Manuwal 1990, Weikel and Hayes 1999) and snags with deeply furrowed bark (Raphael and White 1984, Morrison et al. 1987, Weikel and Hayes 1999) for foraging. Deeply furrowed bark has greater densities of arthropods (Jackson 1979) that are prey for brown creepers. Greater densities of snags in unsalvaged treatments likely provided better foraging habitat than the salvaged treatments for brown creepers. Our results are consistent with those of Haggard and Gaines (2001) who also found that brown creepers are more common in unsalvaged forests relative to salvaged forests after fire.

Western wood-pewees respond positively to fire, with greater abundances in burned forests relative to unburned forests (Kotliar et al. 2002, Morissette et al. 2002, Bock and Block 2005, Saab et al. 2005, Kotliar et al. 2007). To our knowledge, only one other study has reported the response of western wood-pewees to salvage logging (Morissette et al. 2002). In boreal forests, they found that numbers of western wood-pewees were significantly lower in salvaged forests than in unsalvaged burned forests. Our results provide further support for the hypothesis that western wood-pewees are negatively effected by salvage logging.

Yellow-rumped warblers are habitat generalists found in mixed-conifer forests that are unburned, burned, and clear-cut (Franzreb 1978, Hutto 1995, Schulte and Niemi 1998). Meta-analyses of the responses of birds to burned habitat in different geographic regions have found variable responses of yellow-rumped warblers to burned forests, with abundances sometimes increasing and other times decreasing (Kotliar et al. 2002, Bock and Block 2005, Saab et al. 2005). Although not typically associated with snags, yellow-rumped warblers can successfully nest in snags in burned forests (M. Cannon, personal communication). In our study, densities of yellow-rumped warbler were lower in salvage treatments than unsalvaged treatments, further suggesting the importance of snags to birds not typically associated with snags.

Dark-eyed juncos use a wide variety of habitats, but select more open habitat rather than closed canopy habitat (Nolan et al. 2002). Compared to uncut forests, numbers of dark-eyed juncos were greater in clear-cut (Franzreb 1978) and thinned forests (Hagar et al. 1996, Artman 2003, Hayes et al. 2003, Hagar et al. 2004). The response of dark-eyed juncos has been reported to be neutral or mixed in burned forests compared to unburned forests (Kotliar et al. 2002). The only other previous study to examine responses of dark-eyed juncos to salvage logging reported a mixed response in boreal forests (Morissette et al. 2002). In jack pine forests, dark-eyed juncos occurred more frequently in unsalvaged forests than in salvaged forests, but less frequently in unsalvaged mixed-wood forests relative to salvaged mixed-wood forests (Morissette et al. 2002). Our results are consistent with the latter finding, with lesser densities of dark-eyed juncos in unsalvaged stands relative to salvaged stands.

Patterns of densities of fox sparrows supported the graded-response hypothesis, which predicts that abundances differ between the unsalvaged treatment and the salvage treatments, and abundances differ between the moderate and heavy salvage intensities. Densities of fox sparrows were greatest in the heavy salvage treatment compared to the other treatments, and strongly positively correlated with volume of shrubs. Following fire, fox sparrows select brushy habitat (Austin 1968), and densities of fox sparrows increase as shrubs increase in density (Bock and Lynch 1970). In our study, the heavily salvaged treatment had the greatest of shrub volume compared to the other treatments. Fox sparrows may have been responding to the increasing shrub volume rather than salvage logging. To our knowledge, abundances of fox sparrows in salvage-logged habitat after fire have not been documented previously.

The null hypothesis, no detectable difference in densities or relative abundances among treatments, could not be rejected for one genus and eight species that we analyzed (*Tachycineta*, dusky flycatcher, white-breasted nuthatch, red-breasted nuthatch, house wren, mountain bluebird, American robin, western tanager, and chipping sparrow). Additionally, we did not find significant relationships between abundance or relative abundances of these taxa with any habitat variable that we measured. Five of the taxa that did not respond are cavity-nesters (*Tachycineta*, white-breasted nuthatch, red-breasted nuthatch, house wren, and mountain bluebird) and have demonstrated mixed responses to fire and/or salvage logging in other studies. The response of *Tachycineta* to post-fire habitat is varied (Hannon and Drapeau 2005, Saab et al. 2005), but previous studies have found higher nesting densities of tree-swallows in unlogged than in salvage-logged areas (Hutto and Gallo 2006). For white-breasted nuthatches and red-breasted nuthatches, Hutto and Gallo (2006) reported greater nesting densities in unsalvaged than in salvaged areas. However, nuthatches are not typically associated with burned habitat (Raphael and White 1984, Kotliar et al. 2002, Bock and Block 2005). The lack of difference in relative abundances among treatments that we observed may be related to the aberration of nuthatches occurring in burned habitat. Numbers of house wrens (Bock and Lynch 1970, Hejl et al. 1995, Kotliar et al. 2002), and mountain bluebirds (Hejl et al. 1995, Kotliar et al. 2002) have been reported to increase after fire, but their responses to salvage logging differs among studies. Morissette et al. (2002) found greater numbers of house wrens in salvaged compared to unsalvaged stands, while Hutto and Gallo (2006) found greater numbers in unsalvaged compared to salvaged stands. Haggard and Gaines (2001) found greater numbers of mountain bluebirds in stands with moderate retention of snags compared to low or high retention of snags, while other studies found greater nesting densities in unsalvaged stands compared to salvaged stands (Saab and Dudley 1998, Hutto and Gallo 2006). Mountain bluebirds use open habitat for foraging, but require cavities for nesting. Removing all snags in salvage logging decreases available nesting habitat, but retaining larger snags may provide mountain bluebirds, and other cavity-nesting species, with necessary habitat components for nesting and foraging. The mixed response of these species across a range of habitat types from previous studies suggests that their response may be dependent on region or habitat type. Further, these species may require specific habitat components, such as open habitat or shrubs for foraging, in addition to snags that occurred among the treatments.

Three additional species (American robin, chipping sparrow, and western tanager) for which we did not detect differences among salvage treatments have demonstrated mixed responses to fire in previous studies (Kotliar et al. 2002, Hannon and Drapeau 2005, Saab et al. 2005). American robins use a wide variety of habitats, including post-fire and clear-cut areas (Hutto 1995, Schulte and Niemi 1998). In response to salvage logging in boreal forests, number of territories and relative abundances have been found to both increase (LeCoure et al. 2000, Schwab et al. 2006) and decrease (Morissette et al. 2002) after fire in different forest types. Relative abundances of chipping sparrows were less in salvaged stands relative to unsalvaged burned stands (Morissette et al. 2002). To our knowledge, there is no information regarding the response of western tanagers to salvage logging. Given the variable response of these three species to post-fire habitat, it is not surprising that we did not detect a response to salvage logging.

Four species exhibited significant changes between 2005 and 2006 supporting the year-effect hypothesis. Although bird community changes are associated with habitat changes through time (James and Warner 1982), vegetation and habitat changes may not have differed adequately from the initial conditions to cause measurable differences in abundance for most of the species in our study. Species whose densities or relative abundances differed between years may be of particular interest as forest succession proceeds. Persistence of these early patterns (increasing or decreasing abundances) could indicate future patterns as forest succession occurs.

Parallels exist between our findings of differences in numbers of some species of birds between burned and salvage-logged forests to differences in numbers of species of birds between unlogged-burned forests and logged-green forests (Schulte and Niemi 1998, Hobson and Schieck 1999). Species of birds that nest or forage on the ground or in shrubs were more abundant in logged-green forests than in unlogged-burned forests (Schulte and Niemi 1998, Hobson and Schieck 1999). Species of birds associated with large snags had greater relative abundances in unlogged-burned forests (Hobson and Schieck 1999). We found similar patterns in our study, with greater abundances of ground-nesting species (fox sparrows and dark-eyed juncos) in salvaged treatments than in the unsalvaged treatment, and greater abundances birds associated with large snags (black-backed woodpecker, hairy woodpecker, and brown creeper) in the unsalvaged treatment than in salvaged treatments. These similarities suggest that some species of birds may respond in a similar manner to salvage logging in burned forests as they do following logging in green forests.

Parallels between salvage logging of burned forests and thinning of green forests are not as strong. Some of our results are similar to previous studies in mixed-conifer forests that have received thinning treatments. Following thinning in green forests, no species were extirpated from the habitats (Hayes et al. 2003, Hagar et al. 2004). Similarly, in our study no species were extirpated from any of the treatments. Dark-eyed juncos increased following thinning in green forests relative to unthinned forests (Hagar et al. 1996, Artman 2003, Hayes et al. 2003, Hagar et al. 2004), and we found greater densities of dark-eyed juncos in salvaged treatments. We also detected a similar response for brown creepers, which had greater frequencies in unthinned treatments relative to thinned treatments (McGarigal and McComb 1995, Hayes et al. 2003). However, our results for western wood-pewee and hairy woodpecker contrasted the results from other studies of thinned forests. Initial frequencies of western-wood pewees and hairy woodpeckers increased in thinned stands compared to unthinned stands (Hayes et al. 2003, Hagar et al. 2004). In contrast, we found that greater relative abundances or densities of western wood-pewees and hairy woodpeckers in unsalvaged (unthinned) stands.

Differences between the initial forest structures prior to treatment and the resulting forest structure following thinning treatments highlight a conceptual difference between thinning in green and burned forests. Thinning treatments in green forests often increase the heterogeneity of the vegetation structure by removing smaller diameter trees, increasing understory development, and retaining large diameter trees. While fires can also create a heterogeneous composition of habitats, areas of high severity are comparatively more homogenous than areas of low severity. In forest areas of moderate and high severity, salvage logging further homogenizes the habitat by removing snags of a merchantable diameter. These differences may preclude drawing meaningful parallels between thinned green forests and thinned burned forests regarding the response of birds.

While species may be associated with one type of disturbance, the combined ecological effects of two disturbances, such as fire and logging, are likely to be profound for some species (Lindenmayer and Noss 2006). Our results suggest that salvage logging is likely to impact densities or abundances of some birds immediately following fire. Further study of the response of all forests birds will give managers a better understanding of the influences of salvage logging following fire. Additionally, the longer term impacts of salvage logging may not be apparent two years after implementing salvage logging. Longer term studies are necessary to understand the influences of salvage logging beyond the immediate time period following logging in burned forests.

Scope and limitations

We are cognizant of the limitations of our study resulting from use of small area, and the small size of stands in our study may have influenced the results. Territories of some species of birds (e.g. woodpeckers) likely extend beyond the area of our stands. While we were unable to sample areas large enough to encompass these territories, we were able to document use of a particular habitat that comprises a portion of the total territory. In addition, abundances can be a misleading indicator of habitat quality (Van Horne 1983), and our results do not inform how the treatments may have imparted breeding success, fitness, or population viability.

We are unable to infer causation due to our inability to randomly allocate treatments and collect pre-salvage data. However, the similarities between the results of our study and other studies of salvage logging in moderately or severely burned western conifer forests (Saab and Dudley 1998, Haggard and Gaines 2001, Hutto and Gallo 2006) suggest that our findings may be robust. Our results are likely applicable to the same species of birds throughout dry ponderosa pine and Douglas-fir forests after fire and salvage logging. We believe greater abundances of ground and shrub-nesting species in salvaged forests, and lower abundances of species dependent on post-fire habitat in salvage forests should be particularly consistent throughout this habitat type. Responses of species of birds that we studied in other forest types to salvage logging are uncertain.

Communities of birds change over time as forests succeed after disturbance (Hobson and Schieck 1999, Schieck and Song 2006). Our results pertain to the early (<3 years post-disturbance) stage of forest succession following fire and subsequent salvage logging.

Management implications

Residual densities of trees after timber harvest in unburned forests and of snags in burned stands influence communities and abundance of birds (Lehmkuhl et al. 2003, Stuart-Smith et al. 2006). The salvage prescription for the Davis Lake fire retained snags of large diameter (>35.6 cm dbh) of various tree species present in the pre-fire forest. The retention of large snags in our study likely influenced the densities and relative abundances of bird species that we observed. Retention of snags of large diameter may be particularly important for species of birds for which we did not detect differences among salvage treatments. Some of these species may need open or shrubby habitat for foraging, while the snags provide habitat structure for nesting or perching.

Our results indicate that salvage logging can influence abundances of non-cavity nesting species in addition to cavity-nesting species. Morissette et al. (2002) similarly found that salvage logging influenced the numbers of non-cavity nesting birds in boreal forests of mixed-wood and jack pine after fire. We recommend that the response of non-cavity nesting of forest birds, especially sensitive and those of conservation concern be considered, in addition to the response of cavity-nesting species, when implementing management prescriptions of salvage logging.

The black-backed woodpecker is a species of management concern and is designated "sensitive species" in Oregon (Oregon Natural Heritage Information Center 2004) and Idaho (USDI 2003), and a "species of concern" in Montana (Montana Natural Heritage Program and Montana Fish Wildlife and Parks 2006). While black-backed woodpeckers occurred in all intensities of salvage logging that we examined, the relative abundance of this species was significantly less in salvaged treatments relative to the unsalvaged treatment. Our results support previous conclusions that abundance of black-backed woodpeckers is lower in salvaged forests than unsalvaged. Additionally, our observations of black-backed woodpeckers in areas up to 1800 m in elevation suggest that previous recommendations for limiting management of habitat for black-backed woodpeckers below 1372 m in elevation in Oregon (Goggans et al. 1988) should be modified. We recommend including a larger range of elevations for management areas, and reserving portions of burned forests within these areas to be managed for the black-backed woodpecker.

Thus, our recommendations are three-fold. First, reserving some areas of burned that are not salvage logged will provide habitat for species of birds that increase following fire, but respond negatively to some level of salvage logging. Second, in areas that are salvaged logged, retaining some large snags may benefit species of birds that need snags and other habitat structures for nesting or foraging. Third, the influences of salvage logging are not limited to cavity-nesting species, and the response of non-cavity nesting birds should also be considered when implementing salvage logging.

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CHAPTER 3: FORAGING ECOLOGY OF TWO WOODPECKERS AFTER SALVAGE LOGGING IN A POST-FIRE FOREST IN THE EASTERN CASCADES, OREGON

ABSTRACT

Research on habitat use by cavity-nesting birds after fire and subsequent salvage logging has focused on habitat necessary for nesting. Limited research exists on these species' habitat requirements for foraging. We examined habitat use by two species of woodpeckers, black-backed woodpeckers (*Picoides arcticus*) and hairy woodpeckers (*P. villosus*), in unsalvaged forests and two different intensities (moderate, 30 snags retained/ha, and heavy 5-6 snags/ha) of salvage logging after the Davis Lake Fire in the Deschutes National Forest, Oregon. We used analysis of variance with repeated measures to determine differences in the characteristics of snags used by each species of woodpecker among treatments and between species. We compared snags used by woodpeckers to snags available among the treatments. Black-backed and hairy woodpeckers foraged on snags of similar diameter. Black-backed woodpeckers foraged on snags with more bark cover than hairy woodpeckers. The two species of woodpeckers selected snag characteristics similarly among treatments. Compared to snags available in treatments, woodpeckers foraged on snags of larger diameter than expected given availability of large diameter snags. Our findings highlight the importance of large snags to woodpeckers, and we suggest that snag retention policies for salvage logging incorporate habitat requirements for foraging for woodpeckers.

INTRODUCTION

The foraging ecology of a species gives us a broader understanding of the resources necessary to maintain suitable habitat. Combining the habitat requirements of a bird species for nesting and foraging allows better management of forest habitat when sustaining wildlife is a goal. Understanding what resources are used is particularly important when a key habitat structure is removed, such as live trees in a green forest or snags in a burned forest.

Snags are an important habitat component for nesting, roosting, and foraging for many species of wildlife (Thomas et al. 1979, Raphael and White 1984), particularly for woodpeckers. Snags are abundant after stand-replacing fires, and abundances of some woodpecker species increase after fire (Blackford 1955, Harris 1982, Murphy and Lehnhausen 1998). Woodpecker abundances increase presumably in response to increased availability of nesting habitat and foraging prey (Hutto and Gallo 2006).

Abundances of black-backed woodpeckers (*Picoides arcticus*) and hairy woodpeckers (*P. villosus)* increase following fire in coniferous forests (Blackford 1955, Hutto 1995, Murphy and Lehnhausen 1998). Though the geographic ranges of the species overlap, they only occur together in burned forests. Typically, sympatric woodpeckers have morphological or behavioral differences for acquiring food when in the same habitat (Spring 1965, Williams 1975). Black-backed and hairy woodpeckers are similar in size and morphology (Dixon and Saab 2000, Jackson et al. 2002) and have similar diets in post-fire forests, comprised primarily of larvae of bark and wood-boring beetles (Beal 1911, Bent 1939, Murphy and Lehnhausen 1998). They also have specialized foraging techniques for extracting larvae of bark beetles from the bark and cambium of snags, and larvae of wood-boring beetles from the sapwood of snags (Bent 1939, Bock and Bock 1974, Jackson et al. 2002).

Though black-backed and hairy woodpeckers are similar in morphology and diet, they occur together in burned forests. Furthermore, previous studies suggest that black-backed and hairy woodpeckers may not differ in selection of foraging substrates (Bull et al. 1986), characteristics of snags (Villard and Beninger 1993), or habitats (Murphy and Lehnhausen 1998) in burned or insect-infested forests. Bull et al. (1986) found that black-backed and hairy woodpeckers selected the same substrates, live and dead trees, in similar proportion to one another after an insect irruption in a conifer forest. Villard and Beninger (1993) found that male black-backed woodpeckers foraged predominantly on the lower bole of snags and on slightly larger trees, though both the foraging heights and snag diameters overlapped with male hairy woodpeckers in a post-fire forest. The selection of foraging habitat did not differ significantly between the two species following a stand-replacing fire in Alaska (Murphy and Lehnhausen 1998).

Murphy and Lehnhausen (1998) hypothesized that the large quantity of beetles allows the two sympatric species to simultaneously inhabit the same foraging niche. After a fire, bark and wood-boring beetles increase (Saint-Germain et al. 2004). For the black-backed and hairy woodpeckers, this results in an abundance of food allowing coexistence while using the same foraging niche. Lack (1946) suggested that a similar relationship occurred between two species of falcons that did not compete with one another when the primary prey species was superabundant.

Decreasing availability of prey resources may increase the partitioning resources for foraging, cause a shift in the primary foraging resource of a species (Svardson 1949), or broaden the prey base on which a species forages (Krebs and Davies 1981). Decreasing densities of black-backed woodpeckers are associated with the emergence of wood-boring beetles from the sapwood of snags (Blackford 1955), thus the woodpecker effectively changes the habitat that it occupies by moving to a different habitat. If snags, which provide breeding habitat for some beetles, are removed from post-fire forests, densities of black-backed and hairy woodpeckers also decreases (Caton 1996, Hitchcox 1996, Saab and Dudley 1998, Haggard and Gaines 2001, Hutto and Gallo 2006). Thus, removal of snags may decrease the availability of foraging resources for these woodpecker species.

The negative effect of salvage logging on abundances of black-backed woodpeckers is of concern (Murphy and Lehnhausen 1998, Kotliar et al. 2002) because decades of fire suppression has limited the availability of post-fire habitat (Agee 1993). Black-backed woodpeckers are closely associated with post-fire habitat (Hutto 1995) and population irruptions occur after large-scale fire disturbances (Blackford 1955, Hutto 1995, Caton 1996, Murphy and Lehnhausen 1998, Hoyt and Hannon 2002, Kotliar et al. 2002). The black-backed woodpecker is classified as a “sensitive species” by the U.S. Forest Service and Bureau of Land Management (USDI 2003, Oregon Natural Heritage Information Center 2004, Montana Natural

Heritage Program and Montana Fish Wildlife and Parks 2006). Regional and state agencies include the woodpecker as a species of conservation concern (Dixon and Saab 2000). Previous studies have found that abundances and nesting densities of black-backed woodpeckers decrease after salvage logging (Hutto 1995, Caton 1996, Hitchcox 1996, Saab and Dudley 1998, Haggard and Gaines 2001, Hutto and Gallo 2006). The influence of salvage logging on the foraging ecology of black-backed and hairy woodpeckers has yet to be studied.

Decreasing the number of snags, and thereby the prey resource, may cause a change in the use of habitat or selection of foraging substrates by hairy and black-backed woodpeckers. Understanding the selection of foraging habitat by these two woodpeckers after salvage logging, and whether it differs from foraging in burned-unsalvaged forests, will strengthen the ability of managers to effectively manage post-fire habitat for these woodpeckers, and particularly black-backed woodpeckers.

The objective of this study was to compare the foraging ecology of black-backed and hairy woodpeckers among three treatments of salvage logging after forest fire. Specifically, we determined if decreasing densities of snags influenced selection of substrates for foraging between these woodpeckers, and if selection by each species differed among treatments. We compared snags selected for foraging by these woodpeckers to snags available in the treatments.

METHODS

Study Area

We identified study stands within the perimeter of an 8511 hectare (ha) fire that occurred on Davis Mountain, located just east of the crest of the Cascade Mountains in Deschutes County in Central Oregon (Figure 3.1). The pre-fire forest was composed primarily of ponderosa pine (*Pinus ponderosa*), with components of Douglas-fir (*Pseudotsuga menziesii*) and sugar pine (*P. lambertiana*). Due to fire suppression, the stands differed from historic forest conditions and included lodgepole pine (*P. contorta*), white fir (*Abies concolor*), and Shasta red fir (*A. magnifica* var. *shastensis*) (USDA 2004). Primary understory shrubs included snowbrush (*Ceanothus velutinus*), green-leaf manzanita (*Arcostaphylos patula*), and western chinquapin (*Castanopsis chrysophylla*). Soils were comprised of a deep mantle of ash and pumice over an older layer of similar soil, and are characterized as highly permeable and well drained (USDA 2004). Elevation ranged from 1200-1800 m.

The Davis Mountain fire occurred from late June through early July 2003. Within the fire perimeter, at least 95% tree mortality occurred within 75% of the forest burn. Pre-fire land-use designations were matrix forest and late-successional reserves (LSR), as defined by the Northwest Forest Plan (USDA and USDI 1994). 2514 ha were salvage logged between the fall of 2004 and early summer 2005. Three management prescriptions were implemented: unsalvaged, and moderate and heavy intensities of snag removal. Within salvaged stands, all snags with a diameter at breast height (dbh) greater than 91 cm were retained. Salvaged stands of heavy

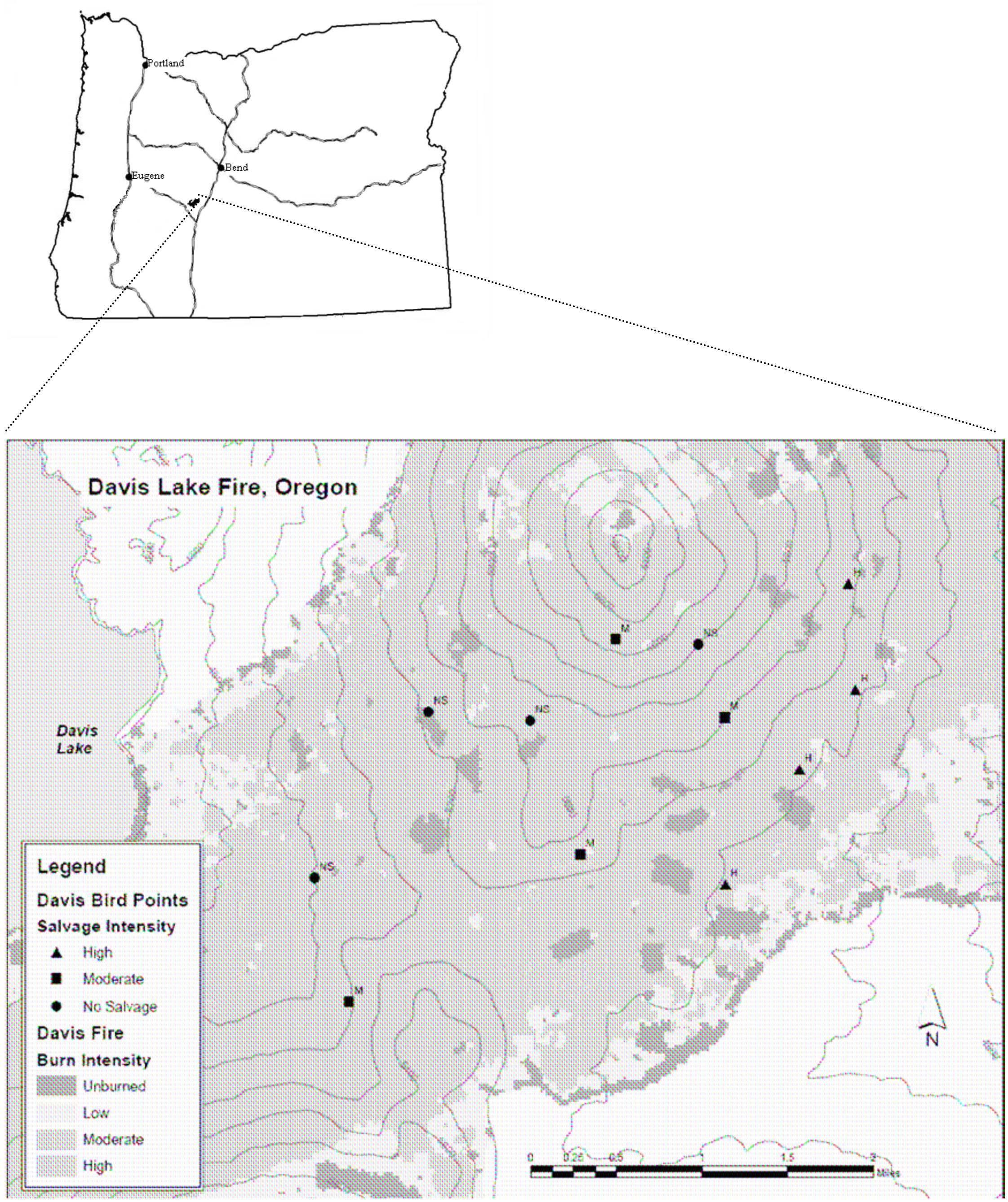

Figure 3.1. Map of Davis Lake Fire with study stands of three treatments of salvage logging in a post-fire forest, Deschutes National Forest, OR, 2005-2006.

intensity were located in lands designated as matrix, and 5-8 snags/ha with a minimum 50.8 cm dbh were retained. Salvaged stands of moderate intensity were located in LSR and 30 snags/ha with a minimum 35.6 cm dbh were retained. Unsalvaged stands were located in LSR.

Study Site Selection

We restricted our selection of stands to those having similar aspect and elevation, moderate or high burn intensity, good pre-fire conifer stocking (≥3.5 trees ≥91.4 cm dbh per acre), an area of at least 7 ha, and a shape allowing placement of at least three non-overlapping 80 m radius bird survey circles. Only four stands of each treatment met these criteria, and as a consequence we used all potential study stands (N=12). Study stands ranged in size from 10-112 ha (unsalvaged stands: 10-18 ha, moderately salvaged stands: 20-112 ha, and heavily salvaged stands: 13-45 ha).

Fuel treatments were implemented in seven (all of the heavily and three of the moderately salvage stands) stands in the fall of 2005 and spring of 2006. Fuels treatments involved felling snags less than 20.3cm dbh and cutting them into 4.3 m lengths. In the heavy salvage stands, downed wood was piled after cutting and the piles were burned after the study concluded in the fall of 2006. One moderate salvage stand was broadcast burned in the fall of 2005, and two others were burned after the study concluded in the fall of 2006.

Data Collection

Snag sampling

To sample and record snag diameter, percent bark and evidence of beetles in each stand, we established 12 vegetation plots in each stand. We centered one plot on each point established for bird sampling as another portion of this study (see chapter 2; Figure 3.2). Three satellite plots were positioned 30 m from this center plot, radially spaced at 120 degrees. We selected a random azimuth to determine the location of the first satellite plot.

We sampled all snags ≥10 cm diameter and >2 m tall that were within 11.3 m of plot center. We measured diameter (cm) at 1.4 m above the ground (dbh), estimated amount of bark cover (percent), and counted the number of Scolytid and Buprestid (bark and wood-boring beetles) entrance and emergence holes (holes) in an 8 cm swath around the bole of the snag at 1.4 m above ground. Scolytid holes are round and 0.8 to 2.4 mm wide (Amman et al. 1989, Halloin 2003). Buprestid holes are oval shaped and 2 to 10 mm wide (Hagle et al. 2003). We calculated an index of density of holes (number/m^2) using the formula:

$$\text{Index of density of holes} = \frac{H}{(0.08\text{m}\pi D)/100}$$

where H is the number of emergence and exit holes and D is the dbh (cm), to adjust for difference in snag diameter. We assumed that counting the number of emergence and exit holes provided an index to the abundance of larvae of bark and wood-boring beetles (Ross 1960, Zhang et al. 1993).

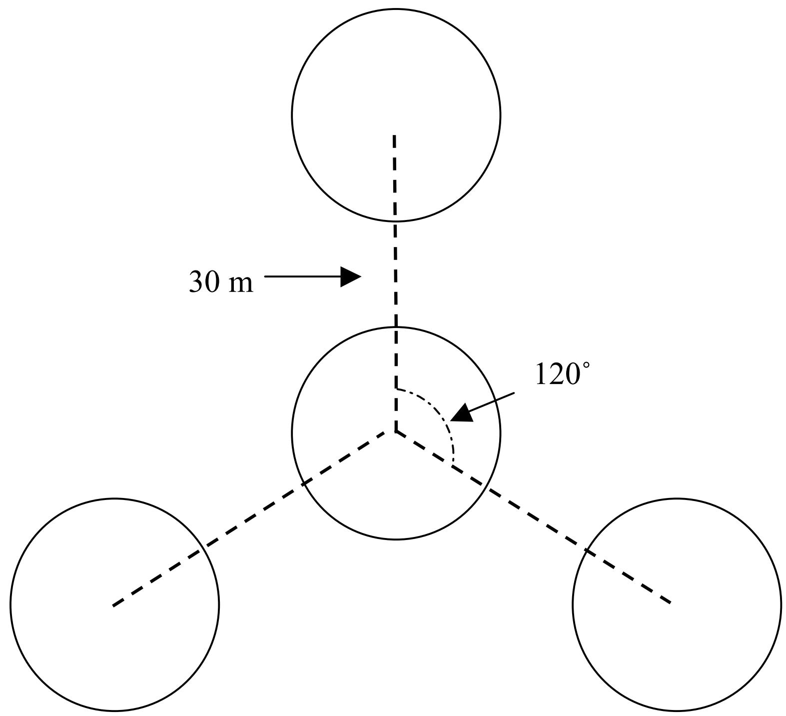

Figure 3.2. Vegetation sampling plots in a post-fire forest to sample characteristics of snags among three treatments of salvage logging in survey of woodpecker foraging in a post-fire forest, Deschutes National Forest, OR, 2005-2006. Each circle represents one sampling plot with 11.3 m radius.

Foraging Observations

We opportunistically located black-backed and hairy woodpeckers for foraging observations by walking through two randomly selected study stands each day. One observer surveyed each stand, looking and listening for birds between 0730 and 1030 from 15 May to 15 July, 2005 and 2006. Each stand was visited two to four times each year. For each species, we collected approximately equal numbers of observations in each salvage treatment, though the number of observations differed between species.

We assumed that observed woodpeckers represented independent samples during each day, but recognize that it is likely that individual birds were resampled during repeat visits to a stand. To minimize the probability of resampling the same bird in any given day, we did not sequentially record information collected from mated pairs of woodpeckers and we did not record observations of a given species of woodpecker within 150 m from a previous observation. If our presence noticeably affected the behavior of the woodpecker (e.g., alarm call or calling continually), we ended the observation.

Our observation of a woodpecker began when we detected it flying to a foraging substrate, or if initially observed foraging, when it flew to a new substrate. For each observation, we dictated into a hand held tape-recorder the species and sex of the bird, and the type of substrate being foraged upon (ground, down wood, snag, or stump). If the substrate was a snag, we noted the zone of the snag the woodpecker used (low bole: below mid-height of snag; upper bole: above mid-height of snag; branches). When the woodpecker flew off the snag, we ended the observation. We measured the diameter, estimated the percent bark cover, and counted beetle holes. If the substrate was downed wood, we estimated bark cover. If the substrate was ground or stump, we did not record other data. We only used data from the first substrate a woodpecker was observed using in our analysis to avoid the issue of sequential observations not being independent (Bell et al. 1990).

We calculated the means of diameter, percent bark, and index of density of beetle holes among all observations in 2005-06 within each stand for each woodpecker species. We estimated niche breadth values (variation in resources used for foraging) for where woodpeckers foraged on snags (zone) using Levins' (Levins 1968) formula:

$$B = \frac{1}{\sum p_i^2}$$

where B is niche breadth, and p_i is the proportion of observations occurring in the i^{th} zone of snags.

Statistical Analysis

Characteristics of Snags

We conducted statistical tests using SAS 9.1.3 (SAS Institute Inc. 2004). We used a mixed model with repeated measures on year to determine differences in diameter of snags, bark cover on snags, and number of beetle holes (collectively referred to as characteristics of snags) (PROC MIXED). We tested for differences of characteristics of snags among treatments with the fixed effects of salvage treatment, year, and the interaction between salvage treatment and year. The effect of interannual variation on characteristics of snags was not of primary interest, but a "year" term was used in the model to account for variance between years.

Woodpecker foraging

We used a repeated measures analysis of variance (ANOVA; PROC MIXED) to determine if selection of characteristics of snags differed between species and among salvage intensities. We examined the fixed effects of species, salvage treatment, and the interaction between species and salvage treatment on characteristics of snags. Because of sample size limitations, we combined observations across the two years by species and salvage intensity. We allowed variance to differ between woodpecker species. We selected a covariance structure from four possible structures (compound symmetry, unstructured covariance [1] or [2], and autoregressive covariance) for each species based on the smallest value of Akaike's information criterion corrected for small sample sizes (AIC_c). We ln transformed diameters to better meet model assumptions of normality. If the effect of salvage intensity was significant ($p \leq 0.05$), we made three pair-wise comparisons, adjusted with a Tukey test (Zar 1999).

We compared means of each snag characteristic selected for foraging to means of snag characteristics in each treatment of salvage with ANOVA. We assessed statistical significance of differences after adjusting the p-value with a Dunnett's adjustment ($\alpha=0.05$) for multiple comparisons of treatments to a single mean (Ramsey and Schafer 2002) for diameter and bark cover, and a Bonferonni adjustment

(α=0.0167) for multiple comparisons (Ramsey and Schafer 2002) between woodpecker species and treatments for density of beetles holes.

We used logistic regression to determine the probability of a woodpecker foraging on a snag as a function of zone of a snag (zone=high bole, low bole, or branches) and salvage treatment (PROC GENMOD) (Hoesmer and Lemeshow 1989). We used AIC_c to compare the relative likelihood of five candidate models of the probability of each woodpecker species foraging within a zone of a snag as a function of: (i) neither snag zone nor salvage intensity; (ii) snag zone; (iii) salvage intensity; (iv) the additive effects of snag zone and salvage intensity; and (v) the interaction between snag zone and salvage intensity (Table 3.1).

We calculated ΔAIC_c as the difference in AIC_c for a given model and the minimim AIC_c value of all models. Models with $\Delta AIC_c \leq 4.0$ are considered competing given the data (Burnham and Anderson 2004). We calculated AIC_c weights (w_i), which describe the weight of a model relative to the candidate set of model (Burnham and Anderson 2004). We calculated the relative importance of a variable based on the sum of w_i values of models that contained the variable of interest. To account for model uncertainty when one model was not clearly supported ($w_i \geq 0.90$) from the set of candidate models, we used model averaging to estimate parameter coefficients and the associated unconditional estimate of variance for a final model (Burnham and Anderson 2004). We determined the odds of a species of woodpecker foraging on a particular zone of a snag.

Table 3.1. Model selection results for five candidate models for the probability of a woodpecker using a zone of a snag. Models are ranked by ΔAIC_c (Δ_i) with model weight (w_i). K=number of parameters.

Model name	$QAIC_c$	Δ_i	w_i	K
Zone	204.257	0.000	0.659	3
Zone+Treatment	206.371	2.115	0.229	5
Zone*Treatment	208.797	4.541	0.068	9
Null	210.661	6.404	0.027	1
Treatment	211.501	7.244	0.018	3

Previous studies have found that the foraging ecology of these woodpeckers does not differ in burned forest (Harris 1982, Villard and Beninger 1993, Murphy and Lehnhausen 1998), and we predicted no differences in the foraging ecology between these species of woodpeckers in the unsalvaged intensity. We predicted that as snag densities decreased, the selection of snags by these species of woodpeckers would change. Thus, we predicted a significant interaction between species and treatment for characteristics of snags, and a significant interaction between zone and treatment for where foraging occurred on the snag.

RESULTS

Characteristics of snags

Mean diameter of snags (≥10 cm dbh) differed among treatments and depended on year ($F_{1,9}$=65.83, p<0.0001; Figure 3.3). Mean diameter of snags significantly differed among salvage treatments in 2006 ($F_{2,9}$=4.91, p=0.036) but not in 2005 ($F_{2,9}$=0.25, p=0.78). Mean diameter of snags increased between 2005 and 2006 in the heavy salvage treatment by 13.7 cm (95% confidence interval [CI]: 7.8 to 19.61) and in the moderate salvage treatment by 9.36 cm (95% CI: 3.45 to 15.28) due to the fuels treatment which removed snags <20.3 cm diameter.

Mean bark cover on snags did not significantly differ among salvage intensities ($F_{2,9}$=2.8, p=0.11). Bark cover on snags decreased by 9.6% (95% CI: 4.5 to 14.66) between 2005 and 2006 across all salvage treatments ($F_{1,9}$=18.7, p=0.002; Figure 3.3).

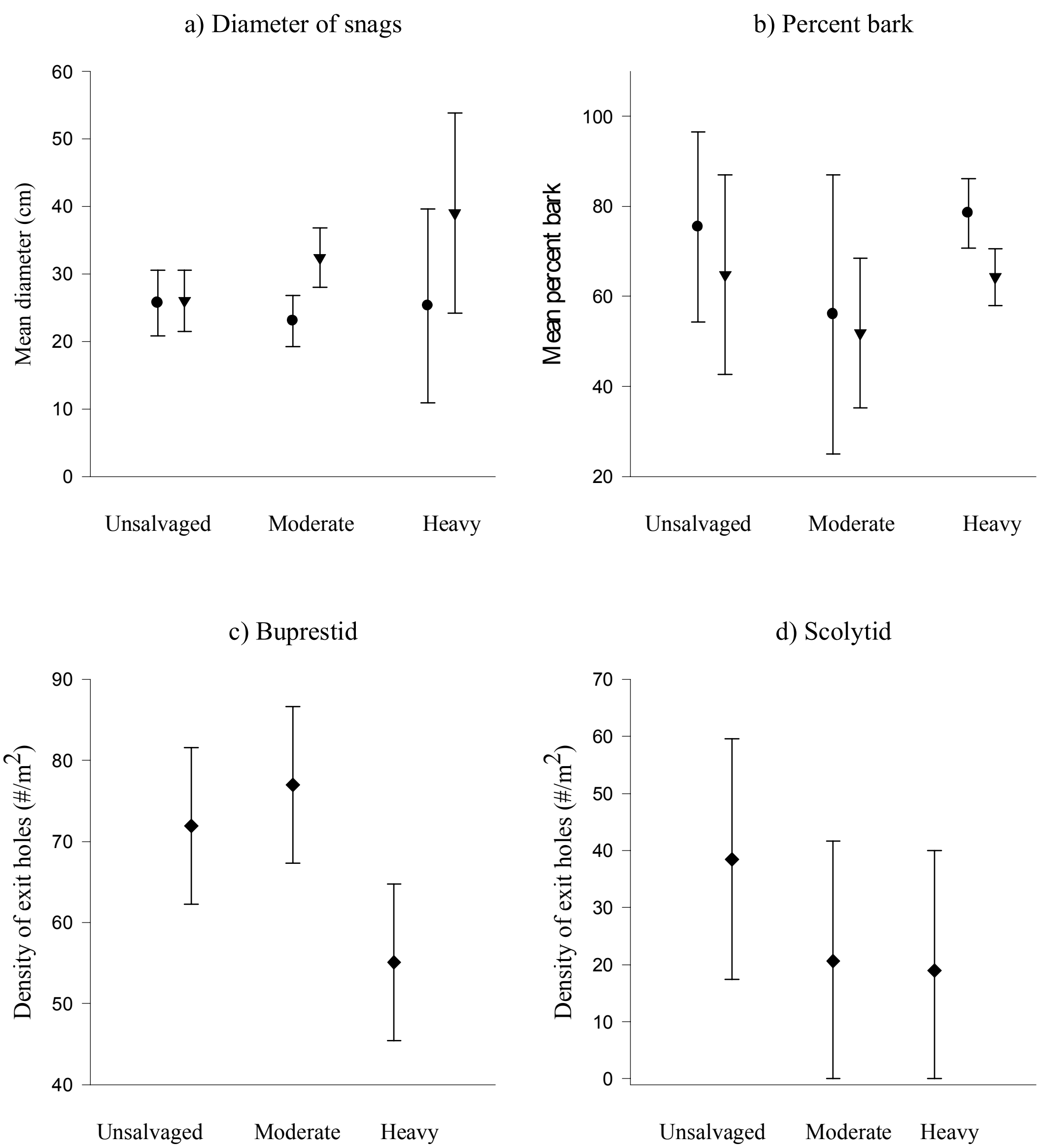

Figure 3.3. Mean values of snag characteristics in three treatments of salvage logging in a post-fire forest, Deschutes National Forest, OR, 2005-2006. a) Mean diameter of snags ≥10 cm; b) mean percent bark remaining on snags ≥10 cm; and number of c) Buprestid and d) Scolytid exit holes per m^2 counted at 1.4 m above the ground, in an 8 cm swath on snags. Mean value for each salvage treatment in year 2005 (●) and 2006 (▼) and 2005-2006 average (♦); error bars represent 95% confidence limits.

Densities of Scolytid holes did not significantly differ among treatments ($F_{2,9}$=1.35, p=0.31) or between years ($F_{1,9}$=0.76, p=0.41; Figure 3.3). Densities of Buprestid exit holes did not significantly differ between years ($F_{1,9}$=0.06, p=0.81), but significantly differed among salvage treatments ($F_{2,9}$=7.19, p=0.014; Figure 3.3). Snags in the moderate salvage treatment had 21.9 (95% CI: 5.0 to 38.7) more Buprestid holes per m^2 than did the heavy salvage treatment. Snags in the unsalvaged treatments had 16.8 (95% CI: -0.07 to 33.6) more Buprestid holes per m^2 than did the heavy salvage treatment.

Woodpecker Foraging

Each stand had at most one breeding pair of black-backed woodpeckers and one to three breeding pairs of hairy woodpeckers present. We recorded foraging observations of hairy woodpeckers in all stands in each year. We did not record any foraging observations of black-backed woodpeckers in one stand of moderate salvage in either 2005 or 2006. We recorded 55 foraging observations of black-backed woodpeckers; 54 (98.2%) of these observations were of birds foraging on snags (Table 3.2). We recorded 120 foraging observations of hairy woodpeckers; 111 (92.5%) of these observations were of birds foraging on snags and 6 (5%) of these observations were of birds foraging on downed wood (Table 3.2).

Our observation rate (number of observations per hour) of hairy woodpeckers was significantly greater than the observation rate of black-backed woodpeckers in the

Table 3.2. Number of observations of black-backed and hairy woodpeckers on different foraging substrates among three treatments of salvage logging in a post-fire forest, Deschutes National Forest, OR, 2005-2006.

Species	Stand Condition	Snag	Down wood	Ground	Stump	Total Observations
Black-backed woodpecker						
	Heavy	16	0	0	0	16
	Moderate	13	0	0	0	13
	Unsalvaged	25	0	1	0	26
	Combined	54	0	1	0	55
Hairy woodpecker						
	Heavy	34	4	1	1	40
	Moderate	40	1	0	1	42
	Unsalvaged	37	1	0	0	38
	Combined	111	6	1	2	120

heavy ($F_{1,18}$=7.05, p=0.016) and moderate salvage ($F_{1,18}$=11.7, p=0.003) treatments (Table 3.3).

We did not observe differences in mean diameter of snags selected for foraging between woodpecker species or among salvage treatments (Figure 3.4). Mean diameter of snags used for foraging was 51.4 cm (95% CI: 37.2 to 71.5) for black-backed woodpeckers, and 55.2 cm (95 % CI: 42.3 to 71.9) for hairy woodpeckers.

The mean diameter of snags selected for foraging by both species of woodpeckers significantly differed from mean diameters for each treatment of salvage in each year ($p<0.02$) except for the treatment of heavy salvage in 2006 (t_{29}=-2.43, p=0.11; Table 3.4). The lack of significant difference with the heavy salvage treatment in 2006 is likely the result of low variance in snag diameters present; the prescription for the heavy salvage included retaining larger snags (>50.8 cm) and the fuels treatment removed snags <20.3 cm.

We did not detect differences in bark cover on snags selected for foraging by woodpeckers among salvage treatments ($F_{2,9}$=0.68, p=0.53; Figure 3.4). On average, the black-backed woodpeckers foraged on snags that had 13.3% (95% CI: 4.9 to 21.7) more bark than did snags foraged on by hairy woodpeckers.

Black-backed woodpeckers selected snags that had significantly more bark cover than expected given availability in all treatments in 2006 ($p\leq0.0005$) and in the moderate in 2005 (t_{28}=4.61, p=0.0006; Table 3.5). Hairy woodpeckers only selected snags with significantly more bark cover than expected given availability the treatment of moderate salvage in 2006 (t_{28}=4.57, p=0.0006; Table 3.6).

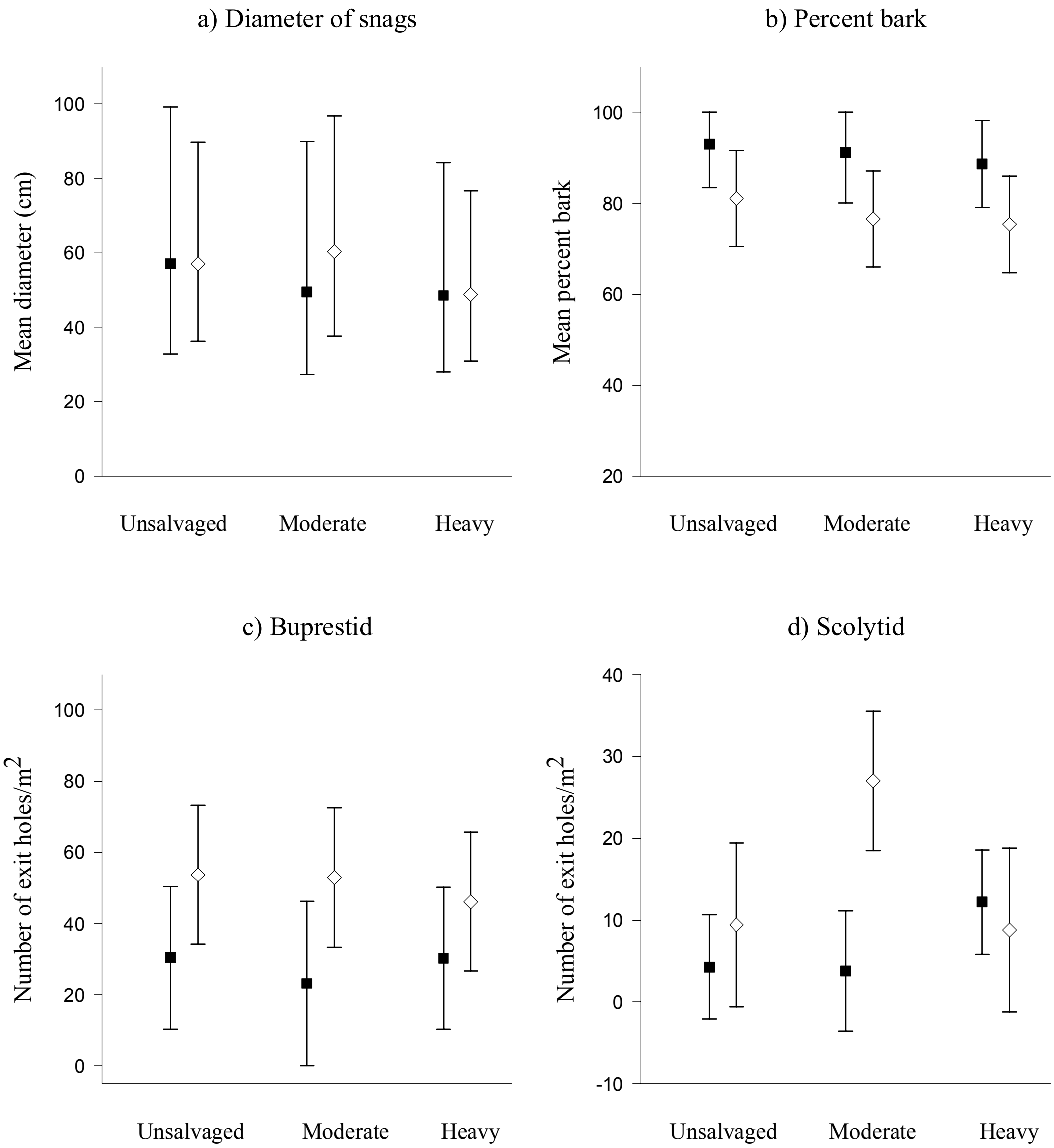

Figure 3.4. Mean values of snag characteristics selected for foraging by black-backed and hairy woodpeckers in three treatments of salvage logging in a post-fire forest, Deschutes National Forest, OR, 2005-2006. a) Median diameter of snags; b) mean percent bark remaining on snags; and number of c) Buprestid and d) Scolytid exit holes per m^2 counted at 1.4 m above the ground, in an 8 cm swath on snags. Mean value for the black-backed (■) and hairy woodpecker (◊) in each salvage treatment; error bars represent 95% confidence limits.

Table 3.3. Number of observations, hours, and observation rate for two species of woodpeckers among three treatments of salvage logging in a post-fire forest, Deschutes National Forest, OR, 2005-2006.

Species	Stand condition	Number of observations	Hours	Observation rate
Black-backed woodpecker				
	Unsalvaged	25	42	0.60
	Moderate	37	58.5	0.23
	Heavy	63	42	0.27
Hairy woodpecker				
	Unsalvaged	37	46.5	0.80
	Moderate	40	52.5	0.76
	Heavy	34	48	0.71

Table 3.4. Comparisons between mean diameters of snags selected for foraging by black-backed and hairy woodpeckers (woodpeckers) and mean diameters of snags available among three treatments of salvage logging in a post-fire forest, Deschutes National Forest, OR, 2005-2006. **Bold** indicates significant differences in diameter of snags ($p<0.05$ after Dunnett adjustment).

Group		Diameter (cm)		Difference from woodpecker mean			
Treatment	Year	Mean	95% CI	Mean	95% CI	DF	P
Woodpeckers	2005-2006	56.66	(49.21, 64.12)				
Unsalvaged	2005	25.68	(12.77, 38.59)	30.98	(10.63, 51.33)	29	**0.0012**
	2006	26.02	(13.10, 38.93)	30.65	(10,30, 50.99)	29	**0.0013**
Moderate	2005	23.05	(10.13, 35.96)	33.61	(13.27, 53.96)	29	**0.0004**
	2006	32.41	(19.5, 45.32)	24.25	(3.9, 44.6)	29	**0.0136**
Heavy	2005	25.27	(12.35, 38.18)	31.39	(11.05, 51.74)	29	**0.001**
	2006	38.97	(26.06, 51.88)	17.69	(-2.65, 38.04)	29	0.1121

Table 3.5. Comparisons between mean bark cover on snags selected for foraging by black-backed woodpecker and mean bark cover of snags available among three treatments of salvage logging in a post-fire forest, Deschutes National Forest, OR, 2005-2006. DF=degrees of freedom, **bold** indicates significant differences in diameter of snags ($p<0.05$ after Dunnett adjustment).

Group		Percent bark		Difference from black-backed woodpecker mean			
Treatment	Year	Mean	95% CI	Mean	95% CI	DF	P
Black-backed woodpecker	2005-06	90.93	(85.74, 96.13)				
Unsalvaged	2005	75.39	(61.02, 89.77)	15.54	(-5.83, 36.91)	28	0.26
	2006	64.83	(54.47, 75.19)	26.1	(9.90, 42.31)	28	**0.0005**
Moderate	2005	62.59	(49.63, 73.54)	29.35	(11.12, 47.58)	28	**0.0006**
	2006	50.48	(39.44, 61.52)	29.35	(23.39, 57.52)	28	**<0.0001**
Heavy	2005	78.46	(64.08, 92.83)	12.48	(-8.89, 33.84)	28	0.48
	2006	64.28	(53.92, 74.62)	26.65	(10.24, 42.86)	28	**0.0004**

Table 3.6. Comparisons between mean bark cover on snags selected for foraging by hairy woodpecker and mean bark cover of snags available among three treatments of salvage logging in a post-fire forest, Deschutes National Forest, OR, 2005-2006. DF=degrees of freedom, **bold** indicates significant differences in diameter of snags ($p<0.05$ after Dunnett adjustment).

Group		Percent bark		Difference from hairy woodpecker mean			
Treatment	Year	Mean	95% CI	Mean	95% CI	DF	P
Hairy woodpecker	2005-06	77.67	(72.53, 82.18)				
Unsalvaged	2005	75.39	(61.02, 89.77)	2.28	(-19.06, 23.62)	28	0.99
	2006	64.83	(54.47, 75.19)	12.84	(-3.33, 29.01)	28	0.2
Moderate	2005	62.59	(49.63, 73.54)	16.09	(-2.11, 34.29)	28	0.11
	2006	50.48	(39.44, 61.52)	27.19	(10.16, 44.23)	28	**0.0006**
Heavy	2005	78.46	(64.08, 92.83)	-0.78	(-22.12, 20.56)	28	1
	2006	64.28	(53.92, 74.62)	13.39	(-2.78, 29.56)	28	0.15

Hairy woodpeckers foraged on snags that had significantly greater densities of entrance and emergence holes of Buprestid than snags foraged on by black-backed woodpeckers ($\bar{x}$ difference=22.99, 95% CI: 6.52 to 39.47, $F_{1,8}$=10.35, p=0.012; Figure 3.4). Densities of holes of Buprestid on snags selected for foraging did not significantly differ among treatments for both species of woodpeckers ($F_{2,9}$=0.13, p=0.88). Woodpecker selection of snags with Scolytid holes depended on species and salvage treatment ($F_{2,8}$=7.44, p=0.015; Figure 3.4). This was due primarily to selection by hairy woodpeckers of snags with greater densities of Scolytid holes in the moderate treatment relative to other treatments.

Black-backed woodpeckers foraged on snags with significantly lesser densities of Buprestid holes than expected given availability among all treatments (unsalvaged: t_{19}=7.09, p<0.0001; moderate: t_{19}=7.87, p<0.0001; heavy: t_{19}=4.53, p=0.002). Hairy woodpeckers foraged on snags with significantly lesser densities of Buprestid holes than expected given availability in unsalvaged and moderate-salvage treatments (unsalvaged: t_{19}=2.82, p=0.03; moderate: t_{19}=3.51, p=0.006), but not in heavy- salvage treatment (t_{19}=0.55, p=0.93). Black-backed and hairy woodpeckers did not differentially select snags for Scolytid emergence and exit holes.

The variable of zone was in competive models ($\Delta AIC_c<4.0$) and had a relative weight of importance of 0.96, indicating that black-backed and hairy woodpeckers selected different zone on a snag for foraging (Table 3.1). The odds of black-backed woodpeckers foraging on the upper bole of a snag were 2.12 (95% CI: 0.63 to 7.12) times that of black-backed woodpeckers foraging on the branches. The odds of black-backed woodpeckers foraging on the lower bole of snags were 1.92 (95% CI: 0.81 to 4.55) times that of black-backed woodpeckers foraging on upper boles. The odds of black-backed woodpeckers foraging on the lower bole of snags were 4.08 (95% CI: 1.26 to 13.18) times that of black-backed woodpeckers foraging on the branches of a snag.

Hairy woodpeckers foraged on more zones of snags than did black-backed woodpeckers. Niche breadth (variation in resources used by species) of zone of snags used for foraging was smallest for both black-backed and hairy woodpeckers in the unsalvaged treatment. Niche breadth of black-backed woodpeckers increased with decreasing densities of snags, while niche breadth was greatest for hairy woodpeckers in the moderate salvage intensity (Table 3.7).

Among all treatments, we observed black-backed woodpeckers foraging predominantly on boles of snags (88.9% of total observations), and foraging on the lower bole 55.6% of the total number of observations (Fig. 3.5). Foraging by hairy woodpeckers was distributed more evenly among snag zones than foraging by black-backed woodpeckers. Among all treatments, 28.8% of our observations of hairy woodpecker were on branches, 38.7% on the high bole of snags, and 32.5% on the low bole of snags (Fig. 3.5).

DISCUSSION

Based on previous research of black-backed and hairy woodpecker foraging ecology in burned forests (Harris 1982, Villard and Beninger 1993, Murphy and Lehnhausen 1998), we predicted that the selection of foraging habitat by each species

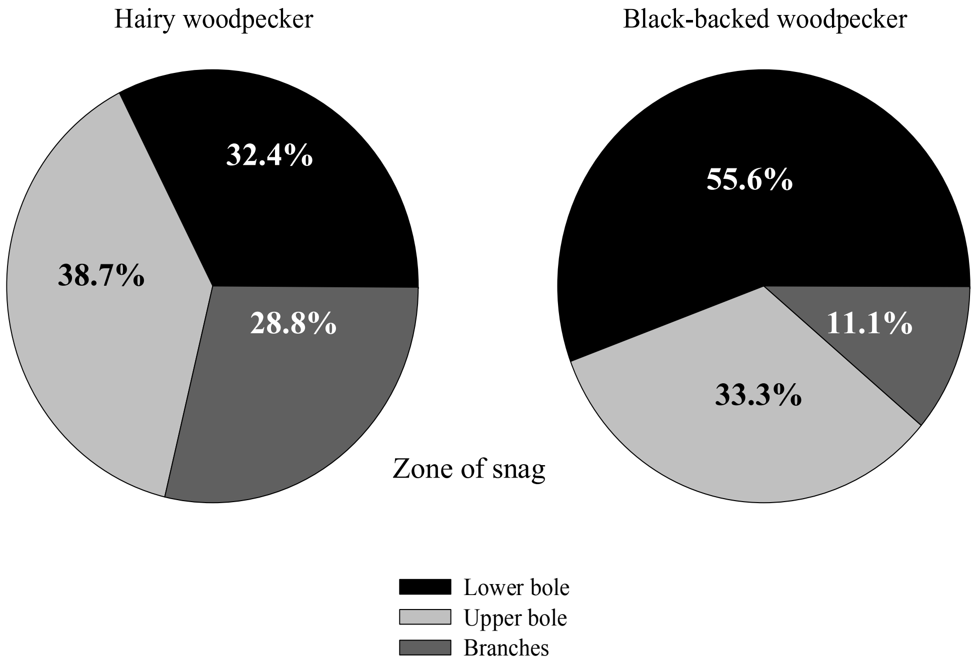

Figure 3.5. Percentage of observations of black-backed and hairy woodpeckers on zone of snags in a post-fire forest, Deschutes National Forest, OR, 2005-2006. Lower bole is mid-height of snag and below, and upper bole is mid-height of snag and above. Number of observations of black-backed woodpeckers (N=55) and hairy woodpeckers (N=120) are pooled across treatments and years.

Table 3.7. Estimated values of relative niche breadth of where two species of woodpeckers foraged on snags among three treatments of salvage logging in a post-fire forest, Deschutes National Forest, OR, 2005-2006.

Species	Unsalvaged	Moderate	Heavy
Black-backed woodpecker	2.02	2.09	2.72
Hairy woodpecker	2.69	2.90	2.82

would depend on the treatment of salvage. However, our results for diameter of snags, amount of bark cover, and densities of exit and emergence holes of Scolytid did not support this prediction. Our results indicate that the foraging ecology of black-backed and hairy woodpeckers did not differ among the treatments of salvage.

Our observations of black-backed woodpeckers foraging more on the lower bole of a snag than on the upper bole of snags in burned forests are consistent with previous findings (Harris 1982, Villard and Beninger 1993, Dudley 2005). While there was not strong evidence that the zone of the snags that woodpeckers foraged differed among treatments, black-backed woodpeckers foraged on a larger proportion of snags in the heavy salvage treatment. Dudley (2005) found similar differences in height at which black-backed woodpeckers foraged between burned and unburned forests. Unburned forests have lower densities of wood-boring beetles than burned forests (Saint-Germain et al. 2004), and though untested, it is assumed that salvaged forests have lower densities of beetles than burned forests, suggesting that black-backed woodpeckers use a larger proportion of each snag as prey resources decrease.

We found some evidence of habitat partitioning between black-backed and hairy woodpeckers. Black-backed woodpeckers selected snags for foraging that had significantly more bark remaining than those selected by hairy woodpeckers. Hairy woodpeckers selected snags that had greater densities of Burprestid holes than did black-backed woodpeckers. Yet, both woodpeckers foraged on snags of similar diameter size. The differences or similarities that we observed between species of woodpeckers were consistent across salvage treatments, suggesting that salvage logging is not influencing differential selection of snags between woodpecker species.

Our results suggest that woodpeckers selected larges snags for foraging among all treatments than expected given availability. Land managers and researchers have recognized the importance of snags to woodpeckers for nesting and foraging (Thomas et al. 1979, Parks et al. 1997). Woodpeckers select snags of larger diameter in green (nesting: Scott 1978, Thomas et al. 1979, Mannan et al. 1980, Zarnowitz and Manuwal 1985, Lundquist and Mariani 1991, Raphael and White 1984; foraging: Weikel and Hayes 1999) and burned forests (nesting: Raphael and White 1984, Hutto 1995, Hitchcox 1996, Saab and Dudley 1998, Lehmkuhl et al. 2003; foraging: Harris 1982, Raphael and White 1984, Hutto 1995, Caton 1996, Powell 2000) more than expected given availability of large snags. Policies regarding retention of larger trees and snags established for green forests (USDA and USDI 1994) are based primarily on the nesting requirements for cavity-nesting wildlife (Thomas et al. 1979), and these guidelines are generally applied to burned forests (Hutto 2006). In this study, the salvage prescriptions included retaining the largest snags (>91cm) within the salvaged stands, as well as maintaining large snags (>50.8 cm in the heavy and >35.6 cm in the moderate). Yet the woodpeckers selected snags of significantly larger diameter compared to average diameters of snags in each salvage treatment. Policies regarding retention of snags may need to be changed to adequately meet the habitat needs of species of birds that use burned forests, especially for species of birds that are relatively restricted to post-fire habitat (Hutto 2006). Recent studies suggest that woodpeckers in burned forests select nest sites that have higher densities of snags compared to random nest sites (Saab and Dudley 1998, Kotliar et al. 2002). Our results highlight the importance of large snags to woodpeckers for foraging. Retaining more large snags is crucial to maintain quality foraging habitat for woodpeckers.

Our results are suggestive of black-backed woodpeckers foraging on snags with more bark cover in 2006 than expected given availability among the salvage treatments. However, these results did not significantly differ, in part because of small sample sizes. While the observed difference in the bark cover on snags available compared to snags used for foraging is only suggestive, it may reflect selection of snags by black-backed woodpeckers that are less decayed relative to other snags in the treatments.

Black-backed woodpeckers forage on snags with high densities of prey compared to random snags (Harris 1982, Murphy and Lehnhausen 1998, Nappi et al. 2003). Less decayed snags support greater densities of beetle larvae than do well-decayed snags (Saint-Germain et al. 2004). Densities of beetle larvae decrease along a gradient of increasing height of snags (Hogstad 1977, Harris 1982), and larger diameter snags contain higher densities of wood-boring beetles (Nappi et al. 2003). Selection of large snags with more bark cover than expected given availability, and predominant foraging on the lower bole of snags by black-backed woodpeckers suggests selection of snags with greater abundances of prey.

However, we found that black-backed woodpeckers selected snags that had lesser densities of Buprestid holes than expected given availability of snags. This suggests that either the Buprestid and Scolytid holes we counted were not good indicators of abundances of beetle larvae, or black-backed woodpeckers were foraging on larvae of other beetle species. Larvae of Cerambycids are associated with some species of Scolytid larvae (Dahlsten and Stephen 1974, Stephen and Dahlsten 1976) in recently killed trees. The life cycle of Cerambycids ranges from 3 months to several years suggesting that these larvae may have been present in snags, but we did not record their presence due to a lack of exit holes. Diets of black-backed woodpeckers also include Cerambycid larvae (Bent 1939, Murphy and Lehnhausen 1998), and they may have been feeding on these larvae.

Retaining snags that support sufficient densities of prey maintains quality foraging habitat for woodpeckers. Bark and wood-boring beetles infest newly dead wood (Evans 1971, Hagle et al. 2003) and the larvae are a primary food source for black-backed and hairy woodpeckers (Beal 1911, Bent 1939, Harris 1982, Murphy and Lehnhausen 1998). As wood-boring beetles emerge, abundances of woodpeckers decrease, (Blackford 1955, Murphy and Lehnhausen 1998), presumably to the decrease in abundance of prey. Hard and large diameter snags are more likely to have greater densities of beetle larvae (Nappi et al. 2003, Saint-Germain et al. 2004), and thus provide foraging higher quality foraging habitat for black-backed and hairy woodpeckers than soft and small diameter snags.

Scope and limitations

This study was conducted on the eastside of the Cascade Mountains of Oregon and our results are applicable to ponderosa pine-Douglas-fir forests after fire and salvage logging in this region. To our knowledge, this is the first study to examine differences in the foraging ecology of black-backed and hairy woodpeckers after salvage logging, and applications to these woodpeckers in other regions are unclear. Our finding that black-backed and hairy woodpeckers selected snags of larger diameter more than expected given availability is consistent with other studies of these species in ponderosa pine-Douglas-fir forests after fire (Harris 1982, Raphael and White 1984, Hutto 1995, Caton 1996), and suggests that these results may be applicable to this forest type outside the immediate region.

Our study stands were small in comparison to the size of woodpecker territories. While we were unable to sample areas large enough to encompass black-backed and hairy woodpecker territories, we documented foraging within the salvaged and unsalvaged habitat that comprises a portion of the total territory, and demonstrated that both species were foraging in these areas of post-fire forests.

Management implications

The black-backed woodpecker is categorized as a sensitive species by many state agencies (USDI 2003, Oregon Natural Heritage Information Center 2004, Montana Natural Heritage Program and Montana Fish Wildlife and Parks 2006). Black-backed woodpeckers are closely associated with recent post-fire habitat (Hejl et al. 1995) and abundances decline two to four years post-fire (Harris 1982, Murphy and Lehnhausen 1998). The rarity of post-fire habitat due to fire suppression and ephemeral nature this habitat type, could impair the ability of populations of black-backed woodpeckers to persist throughout its geographic range. Management goals to maintain populations of black-backed woodpeckers should take into account the foraging needs as well as the nesting needs of the species. Though abundances of black-backed woodpeckers are lower in salvaged stands than unsalvaged stands (Caton 1996, Saab and Dudley 1998, Haggard and Gaines 2001, Hutto and Gallo 2006, this study chapter 2) they are not excluded from these stands. Providing foraging habitat in salvaged stands may be important for persistence of these species in burned forests where salvage logging occurs. Our results demonstrate that large diameter snags are important foraging resources to the black-backed woodpecker in burned and salvage logged habitat.

We contend that the selection by black-backed and hairy woodpeckers of large snags for foraging should be an important consideration when planning management prescriptions for salvage logging. Large snags that are not very decayed are often removed to recover economic value, but retention of these snags will provide long-term foraging habitat for woodpeckers and other wildlife habitat values. Additionally, hard, large-diameter snags persist longer in a habitat (Lehmkuhl et al. 2003, Russell et al. 2006). We recommend retaining high quality snags that are large in diameter and of low deterioration in forests that are salvage logged after fire to provide foraging habitat for black-backed and hairy woodpeckers.

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CHAPTER 4: CONCLUSIONS

The principal goal of our research was to determine the influence of salvage logging on species of birds that occur post-fire to better inform management decisions in regards to post-fire forests. We investigated the influences of two different intensities of salvage logging on densities and relative abundances of species of birds, the correlation between vegetation variables and densities or relative abundances of birds, and the use of snags for foraging by two species of woodpeckers.

Previous studies of the influences of salvage logging birds have focused primarily on cavity-nesting species, and half of the species of birds we analyzed are cavity-nesters. Cavity-nesters that respond positively to fire and foraged on snags (black-backed woodpecker, hairy woodpecker, and brown creeper) were more abundant in unsalvaged treatment than in either of the intensities of salvage logging. We did not find significant differences for two species of cavity-nesting birds (mountain bluebirds and house wrens) that are typically more abundant in burned forests than unburned forests. Remarkably, we did not find strong correlations between the densities of four taxa (hairy woodpecker, house wren, mountain bluebird, and *Tachycineta*) and density of snags >35 cm among the salvage treatments.

In addition to cavity-nesting species, we found salvage-logging significantly influenced the relative abundances or densities of four non-cavity nesting species. We found correlations between vegetation variables and densities of three of these species as well. Western wood-pewees are typically more abundant in burned forests, and our results suggest that salvage logging negatively impacts this species. We found greater densities of yellow-rumped warblers in the unsalvaged treatment compared to the salvage intensities, and a positive correlation between species density and density of snags >35 cm. Densities of ground and shrub nesters (dark-eyed juncos and fox sparrows) were lower in the unsalvaged treatment than in either of the salvage intensities. We found positive correlations between shrub volume and densities of fox sparrows and dark-eyed juncos, suggesting that these species may be responding more to an increase in shrubs, than to a decrease in snag density.

For species whose densities and relative abundances were greatest in the unsalvaged treatment (hairy woodpecker, black-backed woodpecker, western wood-pewee, brown creeper, and yellow-rumped warbler), densities and relative abundances did not differ between moderate and heavy intensities of salvage logging. This suggests that at these intensities of salvage logging (moderate, 30 snags/ha, and heavy, 5-6 snags/ha), the different levels of salvage did not mitigate the negative effects of salvage.

Use of snags for foraging by black-backed and hairy woodpeckers did not significantly differ among the treatments of salvage for the variables that we measured. Both species of woodpeckers selected snags of larger diameter than expected given the availability of large snags. Other studies that have found large snags are important foraging resources for many species of birds in green (Raphael and White 1984, Weikel and Hayes 1999) and burned forests (Harris 1982, Raphael and White 1984, Hutto 1995, Caton 1996), and our results for black-backed and hairy woodpeckers are consistent with these findings. Even though these species of woodpeckers have lower abundances in burned forests after salvage logging than unsalvaged forests, they are not excluded from salvaged areas (Caton 1996, Saab and Dudley 1998, Haggard and Gaines 2001, this study). Retaining large snags in salvaged forests will provide some foraging habitat for black-backed and hairy woodpeckers.

In sum, our results suggest that unsalvaged-burned forests support greater densities or relative abundances of some species of birds than salvage-logged forest after fire. Post-fire habitat is relatively limited across a landscape due to fire suppression decreasing the extent and severity of fire (Agee 1993). The low frequency of occurrence and the ephemeral nature of post-fire habitat necessitate reserving at least a portion of burned forests to remain unsalvaged. Our results indicate that non-cavity nesting species can be effected by salvage logging, in addition to cavity-nesting birds. Management policies should consider the response of non-cavity nesting species of birds to salvage logging. Our results suggest that the moderate intensity of salvage logging did not mitigate the negative impact for species of birds that had lower abundances in the heavy salvage treatment than in the unsalvaged treatment. In addition, our results suggest retention of large diameter snags in salvage areas provide important foraging habitat for black-backed and hairy woodpeckers.

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APPENDICES

APPENDIX A: MODELS FROM PROGRAM DISTANCE

Models used to generate estimates of density for six species and one genus in program DISTANCE v4.0 (Thomas et al. 2002) in post-fire forests with three treatments of salvage logging in Deschutes National Forest, OR, summers 2005-2006. Function is the shape of the detection probability curve that best fit the data. Detections of a given species were i) all pooled together (pool), ii) stratified by salvage treatment (treatment) or iii) stratified by year (year) to generate a detection function. Covariates (treatment, year or observer) were included for some models based on model selections results. Covariates allowed the detection function to shift along the x-axis, without changing the overall shape of the function.

Species	Function	Data stratified by	Covariate
Hairy woodpecker	Hazard-rate	Pool	Observer
Tachycineta	Hazard-rate	Year	
House wren	Hazard-rate	Pool	Year
Mountain bluebird	Hazard-rate	Pool	
Yellow-rumped warbler	Hazard-rate	Treatment	
Fox sparrow	Hazard-rate	Pool	
Dark-eyed junco	Hazard-rate	Pool	Year

APPENDIX B: SCIENTIFIC NAMES OF BIRD SPECIES

Number of detections of species of birds (with scientific name) in post-fire forests with three treatments of salvage logging in Deschutes National Forest, OR, summers 2005-2006. Detections are summed across all treatments within a year.

Species common name	Scientific name	2005	2006
Dark-eyed junco	*Junco hyemalis*	164	245
Mountain bluebird	*Sialia currucoides*	168	201
Yellow-rumped warbler	*Dendroica coronata*	161	111
Hairy woodpecker	*Picoides villosus*	123	129
Fox sparrow	*Passerella iliaca*	82	164
Tree swallow[a]	*Tachycineta bicolor*	55	106
Violet-green swallow[a]	*Tachycineta thalassina*		
Dusky flycatcher	*Empidonax oberholseri*	69	83
Black-backed woodpecker	*Picoides arcticus*	33	59
House wren	*Troglodytes aedon*	35	53
Chipping sparrow	*Spizella passerina*	39	47
White-breasted nuthatch	*Sitta carolinensis*	37	48
Red-breasted nuthatch	*Sitta canadensis*	68	11
Rock wren	*Salpinctes obsoletus*	38	41
American robin	*Turdus migratorius*	31	23
Western tanager	*Piranga ludoviciana*	33	20
Brown creeper	*Certhia americana*	29	20
Western wood-pewee	*Contopus sordidulus*	17	30
Mountain chickadee	*Poecile gambeli*	32	6
Northern flicker	*Colaptes auratus*	20	13
Olive-sided flycatcher	*Contopus cooperi*	23	9
Brown-headed cowbird	*Molothrus ater*	6	23
White-headed woodpecker	*Picoides albolvatus*	11	17
Townsend's solitaire	*Myadestes townsendi*	23	4
Clark's nutcracker	*Nucifraga columbiana*	15	0
Common nighthawk	*Chordeiles minor*	4	8
Lazuli bunting	*Passerina amoena*	2	6
Western bluebird	*Sialia mexicana*	4	2
American kestrel	*Falco sparverius*	0	5
Steller's jay	*Cyanocitta stelleri*	3	2
Common raven	*Corvus corax*	1	2
Lewis' woodpecker	*Melanerpes lewis*	0	1
Pilieated woodpecker	*Drycopus pileatus*	0	1
Black-headed grosbeak	*Pheucticus melanocephalus*	0	1

a Species combined to genus *Tachycineta*