INFLUENCE OF POSTFIRE SALVAGE LOGGING ON BLACK-BACKED WOODPECKER NEST-SITE SELECTION AND NEST SURVIVAL

by

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Christopher David Forristal

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TABLE OF CONTENTS

1. INTRODUCTION TO THESIS

LIST OF TABLES

LIST OF TABLES – CONTINUED

LIST OF FIGURES

ABSTRACT

Post-fire timber harvest practices (i.e. post-fire salvage logging) on public lands are a highly contentious issue in the western United States. Harvest of burned trees impacts a number of species, particularly those specialized for using post-wildfire habitats. We assessed the effects of post-fire salvage logging on black-backed woodpecker (Picoides arcticus) nest-site selection and nest survival within burned, mixed conifer forests of south-central Oregon. Multiple treatment and control plots were surveyed two years pre-logging (2003-04) and two years post-logging (2005-06). Our objectives were to (a) examine the effects of salvage logging on black-backed woodpecker nest site selection and nest survival at coarse and fine spatial scales (b) elucidate additional habitat and abiotic factors predicting black-back nest occurrence and survival, and (c) determine if those habitat covariates influencing nest site selection coincide with those influencing nest survival. A total of 210 black-backed woodpecker nests were monitored during the four year postfire period. Postfire salvage logging did not significantly reduce snag numbers or diameters within treatment units. Based upon our best nest-site selection model, black-backed woodpecker nest locations were different from non-nest points in habitat characteristics at both fine and coarse spatial scales, with variables related to surrounding snag density being the strongest predictors. Black-backed woodpeckers exhibited high overall nest survival (78.5%; 95% CL = 0.6996, 0.8495). Nest survival models containing temporal predictors (i.e. Julian date) received more support than those related to salvage harvest or other habitat features. Factors influencing black-backed woodpecker nest-site selection were not same as those affecting nest survival, suggesting a lack of adaptive nest-site choice in terms of nest survival. Our results correspond with past studies outlining the importance of high-density snag areas for woodpecker nesting. Maintaining complete snag species composition and high snag densities will help conserve black-backed woodpecker nesting habitat in the early years following stand-replacement wildfire.

CHAPTER ONE

INTRODUCTION TO THESIS

Background Information

Wildfire was historically a major influential factor in shaping the structure of coniferous forests in western North America. As the primary method of large-scale disturbance in this region, fire is intrinsically tied to patterns of vegetation succession and composition in these forested ecosystems. More than 50 years of fire suppression on public lands has resulted in altered fire regimes in lower elevation western coniferous forests. Current fire regimes in ponderosa pine and mixed coniferous forests are unlike those that occurred over the last few centuries, resulting in conditions favoring higher-intensity, stand replacement fires (Arno and Brown 1991, Covington et al. 1997, Schoennagel et al. 2004). As natural disturbance processes are altered or interrupted, a host of species that evolved with wildfire face potential consequences to their populations (Hutto 1995). Species specialized for early post-fire forests may be especially sensitive to changes in fire regimes and increased levels of postfire timber management activities (Hutto 1995, Murphy and Lehnhausen 1998, Saab and Dudley 1998).

Due to their high dispersal capabilities, birds are among the first and most abundant vertebrate groups found in recently burned forests. Among birds, woodpeckers in particular use postfire environments (for breeding, foraging, etc.) at greater densities than green, unburned forest (Hutto 1995, Murphy and Lehnhausen 1998, Kotliar et al. 2002, Saab et al. 2005, Smucker et al. 2005). A recent literature review characterizing avian abundances in burned and unburned forests of North America found cavity-nesting bird species consistently more plentiful in burns, especially woodpeckers (Saab et al. 2005). Several post-fire investigations have concluded that burned forest habitats favor woodpeckers through increased nesting opportunities (snags), increased availability of insect prey, and reduced nest predation (Blackford 1955, Koplin 1969, Bock et al. 1978, Lowe et al. 1978, Raphael and White 1984, Hutto 1995, Powell 2000, Saab and Vierling 2001, Saab et al. 2007).

Woodpeckers, specifically primary cavity nesters (those that excavate new cavities annually), are known to play an important role in supporting numerous living components of the forest community. The cavities created by excavators provide microhabitats for a large suite of organisms, ranging from fungi to mammals (Bednarz et al. 2004, Farris et al. 2004, Jackson and Jackson 2004, Martin et al. 2004). Past research has proposed that woodpeckers play a role in regulating timber-dwelling beetle populations and may lessen the severity of their outbreaks (Koplin 1972, Fayt et al. 2005). Studies have characterized primary cavity nesters as keystone species in some systems, whose members generate the base of a “nest web” consisting of interdependent groups producing and benefiting from nest-cavity resources (Ripper 2002, Martin et al. 2004, Saab et al. 2004). In British Columbia, Martin et al. (2004) described a cavity nest web of 22 different species, with Northern Flickers being the keystone excavator constructing most cavity resources. Thus, the presence, absence, or decline of primary excavators may influence large assemblages of forest community members.

Black-backed woodpeckers are both primary cavity nesters and very closely associated with recently burned forests (Hutto 1995, Murphy and Lehnhausen 1998, Dixon and Saab 2000, Hoyt and Hannon 2002, Smucker et al. 2005). In a review of 11 studies, 8 reported this species to be significantly more abundant in burned forest than in green counterparts (Kotliar et al. 2002). Hutto's (1995) analysis found black-backed woodpeckers to be the third most habitat-specialized bird species out of 77 examined in western coniferous forests. These woodpeckers will appear in a burned forest almost immediately following a fire and remain in the habitat for 2-5 yrs before declining in numbers (Koplin 1969, Bock and Lynch 1970, Bock et al. 1978, Taylor and Barmore 1980, Apfelbaum and Haney 1981, Bull et al. 1986, Murphy and Lehnhausen 1998, Dixon and Saab 2000). Black-back nest locations are consistently surrounded by higher snag densities compared to other woodpecker nests and random plots within the same study areas (Saab and Dudley 1998, Saab et al. 2002). Black-backed woodpeckers' strong preference for early burned seral forests and high snag densities indicate this species to be particularly sensitive to salvage logging activities, which tend to target these same areas for harvest (Hutto 1995, Murphy and Lehnhausen 1998, Saab and Dudley 1998, Kotliar et al. 2002, Morissette et al. 2002, Saab et al. 2002, Saab et al. 2007)

Postfire timber harvest practices on public lands are a highly contentious issue in the western United States. Plans for salvage logging are often challenged in court, with plaintiffs frequently citing the detrimental effects of salvage harvest on wildlife populations (McIver and Starr 2001, Beschta et al. 2004, Nappi et al. 2004, Lindenmayer and Noss 2006). Despite this controversy, few studies have investigated the connection between burned tree removal and its influence on wildlife reproduction. The primary objective of this study was to assess the hypothesis that salvage timber harvest negatively influences black-backed woodpecker (*Picoides arcticus*) nest survival and nest-site selection within burned, mixed conifer forests. We examined black-backed woodpecker nest-site selection and nest survival in unlogged and salvage logged study units for four years postfire. This research focuses on a little-known, sensitive species and its relationship to salvage logging using a before-after control-impact experimental approach.

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CHAPTER TWO

FACTORS AFFECTING NEST-SITE SELECTION AND NEST SURVIVAL OF BLACK-BACKED WOODPECKERS IN BURNED MIXED CONIFEROUS FOREST

Introduction

Habitat selection during the breeding season can have strong consequences for individual fitness and subsequently affect population growth. Choice of nesting site in birds can influence a number of vital rates, including adult survival and productivity. Nest-site selection is hypothesized to be a hierarchical process, whereby individuals assess habitat quality across multiple spatial scales and choose nest sites that maximize their own reproduction and survival (Hutto 1985, Martin 1998, Jones 2001). In selecting a breeding site, birds must balance their own survival with survival of their offspring. Non-random habitat selection can be shaped by a variety of selective pressures, one of which is nest predation. As the primary cause of reproductive failure in birds, nest predation has the potential to strongly influence patterns of nest-site selection (Wiens 1985, Martin 1993, 1998). Understanding the factors shaping habitat selection and its connection to reproductive performance is important for conservation of rare or threatened species. Because abundance of a species is not always correlated with habitat quality (esp. in the case of anthropogenic habitat alteration), using density estimates can misinform management decisions (Van Horne 1983, Vickery et al. 1992, Bock and Jones 2004). Managers attempting to identify high-quality habitat for conservation or mitigate impacts of land-use activities would benefit from information regarding spatial variation in both habitat preference and fitness (Clark and Shutler 1999, Bailey and Thompson 2007, Aldridge and Boyce 2008).

Black-backed woodpeckers are known as an early postfire specialist and demonstrate a strong habitat preference for recently burned coniferous forests (Hutto 1995, Murphy and Lehnhausen 1998, Hoyt and Hannon 2002, Smucker et al. 2005, Hutto 2008). Black-backed woodpeckers preferentially nest in and forage on dead and dying trees, a resource which presumably becomes super-abundant in the first years after a moderate to severe wildfire. Throughout its range, black-backed woodpeckers favor areas of high snag densities for both nesting and foraging (Murphy and Lehnhausen 1998, Dixon and Saab 2000, Hoyt and Hannon 2002, Smucker et al. 2005, Hanson and North 2008, Saab et al. 2009). As a snag-dependent species, black-backed woodpeckers may be especially intolerant to removal of snags by postfire salvage harvest (Hutto 1995, Murphy and Lehnhausen 1998, Saab and Dudley 1998, Kotliar et al. 2002, Morissette et al. 2002, Saab et al. 2002, Saab et al. 2007). While the link between black-backed woodpeckers and burned forest is well documented, studies examining the relationship between this habitat selection behavior, postfire snag removal, and any measures of reproductive output are rare (but see Hitchcox 1996, Saab et al. 2007).

A number of studies characterizing the changes in bird communities in response to postfire timber harvest have found evidence for negative effects on black-backed woodpeckers (Harris 1982, Caton 1996, Hitchcox 1996, Morissette et al. 2002, Hutto and Gallo 2006, Schwab et al. 2006, Koivula and Schmiegelow 2007, Saab et al. 2007). However, these studies often compared abundance data and their results were typically based on relatively small sample sizes. Using local abundance or density estimates to make inferences about habitat quality for black-backed woodpeckers is problematic, as they are considered a highly irruptive species and their distribution across the forest landscape is not uniform (Van Horne 1983, Dixon and Saab 2000). Additionally, bird abundance data is typically gathered through point-count methods, which likely underestimate abundance of species that do not regularly sing and that have large home ranges, like woodpeckers (Martin and Eadie 1999, Saab et al. 2005, Smucker et al. 2005). Low species abundance combined with low detection probability may result in occupied, high-quality habitat to be identified as unoccupied and poor quality. Because post-wildfire environments appear to be critical habitats for black-backed woodpeckers, factors affecting its demography are likely to impact local populations and should be of greater conservation concern.

Few studies have examined changes in bird habitat quality brought about by salvage logging through demographic information (but see Hitchcox 1996, Hutto and Gallo 2006, Saab et al. 2007), even though abundance and demographic performance may not be coupled (Van Horne 1983, Vickery et al. 1992, Bock and Jones 2004). Woodpecker nest survival is hypothesized to increase after recent wildfires because of increases in nesting and foraging substrates, and likely reductions in nest predators (Saab and Vierling 2001, Saab et al. 2004, Saab et al. 2007), especially small mammals (Fisher and Wilkinson 2005). Postfire salvage logging could negatively affect black-backed woodpecker nest-site selection and nest survival through a reduction in suitable nest snags, food resources, or by creating forest structural changes that increase predation risk (Schwab et al. 2006, Saab et al. 2007). A number of potential “cues” may assist an individual in determining where to nest, including vegetation structure, food resources, personal or conspecific reproductive performance, and predator abundance. Anthropogenic habitat alterations can decouple the cues that animals typically use to associate habitat quality with fitness, resulting in nonideal habitat selection (Dwernychuk and Boag 1972, Gates and Gysel 1978, Orians and Wittenberger 1991, Arlt and Part 2007). Salvage-logged landscapes represent a novel habitat with potentially conflicting habitat quality cues for black-backed woodpeckers. Birds may avoid salvage logged areas because they superficially appear more like "old" burns with low snag densities and few remaining large snags. Increased amounts of downed wood caused by logging activities could suggest higher nest predator (e.g. small mammal) densities (Fisher and Wilkinson 2005, Converse et al. 2006). Black-backed woodpeckers could bypass salvage-logged areas, associating older burns with higher nest predation and reduced food, even though abundant wood boring and bark beetle larva likely reside in newly burned residual snags.

Green, unburned forest serves as a source habitat for nest predators to recolonize burned areas (Fisher and Wilkinson 2005). Nest predation may increase as time since wildfire increases. With time since fire, recolonization of small mammalian and reptilian nest predators into burned forests could increase nest predation starting at the outer burn edges and moving towards the interior of the burns. Shape and size of the burned patch, combined with fire severity, likely plays a role in influencing the timing and extent of predator recolonization and ensuing nest predation rates.

In southwest Idaho and northwest Montana, black-backed woodpecker nest densities were higher in unlogged vs. salvaged logged units, although small sample sizes made inferences difficult (Hitchcox 1996, Hutto and Gallo 2006, Saab et al. 2007). Saab et al. (2007) found little evidence for a difference in black-backed woodpecker nest survival between salvage logging treatments of differing harvest intensities and unlogged control sites, however small sample sizes (n=4 in logged units) did not allow for a strong comparison. In contrast, hairy woodpeckers (*Picoides villosus*), a primary cavity nester with similar feeding habits, had lower nest survival 1-4 years postfire in salvage logged sites verses those left unharvested (Hitchcox 1996, Saab et al. 2007). The influence of salvage harvest on nest survival has been mixed or non-significant for other cavity nesters. Post-logging effects on nest survival would indicate a potential mechanism through which salvage logging influences reproduction and population growth of this sensitive species.

Research indicates that black-backed woodpeckers select nest sites based upon habitat information at coarse (1 km) and fine spatial scales. Black-backed woodpeckers in burned ponderosa pine forest of western Idaho chose larger diameter nest trees, higher snag densities, larger conifer patch areas, and greater proportions of moderate-high prefire crown closure within 1 kilometer of the nest than that available on the landscape (Saab et al. 2002, Russell et al. 2007, Saab et al. 2009). Other studies have confirmed black-backed woodpecker's propensity for nesting within dense snag stands, although the spatial scale at which this preference functions is unknown (Harris 1982, Hitchcox 1996, Hutto and Gallo 2006, Vierling et al. 2008). Data suggest that black-backed woodpeckers perceive high snag densities as quality habitat because snags represent both nesting and food resources. The large home range and territory size of black-backed woodpeckers implies that they are capable of assessing habitat differences (e.g. snag densities) over a large spatial scale, particularly prior to the breeding season (Dudley and Saab 2007, Saab et al. 2009).

Our objectives were to (a) examine the effects of salvage logging on black-backed woodpecker nest site selection and nest survival at coarse and fine spatial scales (b) elucidate additional habitat and abiotic factors predicting black-back nest occurrence and survival, and (c) determine if those habitat covariates influencing nest site selection coincide with those influencing nest survival.

We predicted that black-backed woodpeckers would avoid nesting in areas affected by salvage logging at the plot (0.4 ha), patch (unit), and landscape (500m, 1km) scales. We hypothesized that changes in forest structure due to salvage logging, such as a reduction in snags for nesting and foraging, an influx of downed woody debris, and more edge habitat, would reduce nest survival of those woodpeckers that choose to nest in logged areas.

We also predicted black-backed woodpeckers would select nest sites with higher snag densities (SnagHa), larger diameter surrounding snags (SnagDBHPlot), higher plot and landscape-level prefire crown closure (PlotCC, cc500m, cc1k), higher plot and landscape-level burn severity (plotDNBR, dNBR500m, dNBR1k), and greater proportions of high snag density area (Burn500m, Burn1k).

Study units used in this work were selected to be the best black-backed habitat available based upon previous research. Moderate-high prefire crown closure and med-high fire severity characterized all study units. Thus, the scope of inference from our research is limited to this hypothesized high-quality, highly preferred postfire habitat.

Methods

Study Area

This research was conducted in the Fremont-Winema National Forest of south-central Oregon. The Fremont-Winema occupies 480,000 hectares of mostly coniferous forests and intermittent scab-rock flats. Dominant tree species in the study area consist of ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), and white fir (*Abies concolor*). Over the study period (2003-2006), average monthly precipitation during the during the breeding season (April – July) varied from 10 to 62 mm, and daily maximum/minimum temperatures ranged from -10°C to 37°C, respectively (SNOTEL weather station, Silver Creek, OR). Cattle grazing activities are prevalent and widespread throughout the forest. Prior to European settlement, the natural fire regime was most likely one of frequent, low-intensity burns (Agee 1993).

In late summer of 2002, the Toolbox and Silver fires burned approximately 34,398 hectares at elevation ranges from 1,500 to 1,800 meters. Both fires were mixed-severity, stand-replacement burns that consumed the forest in a non-uniform pattern across the landscape. Resulting forest areas were characterized by patches of completely charred trees next to relatively green, unburned woodland resulting in a burned/green mosaic. Land ownership within the fire boundaries included private, state, BLM, and Forest Service properties. Most private properties containing merchantable timber were immediately logged postfire.

Study Units

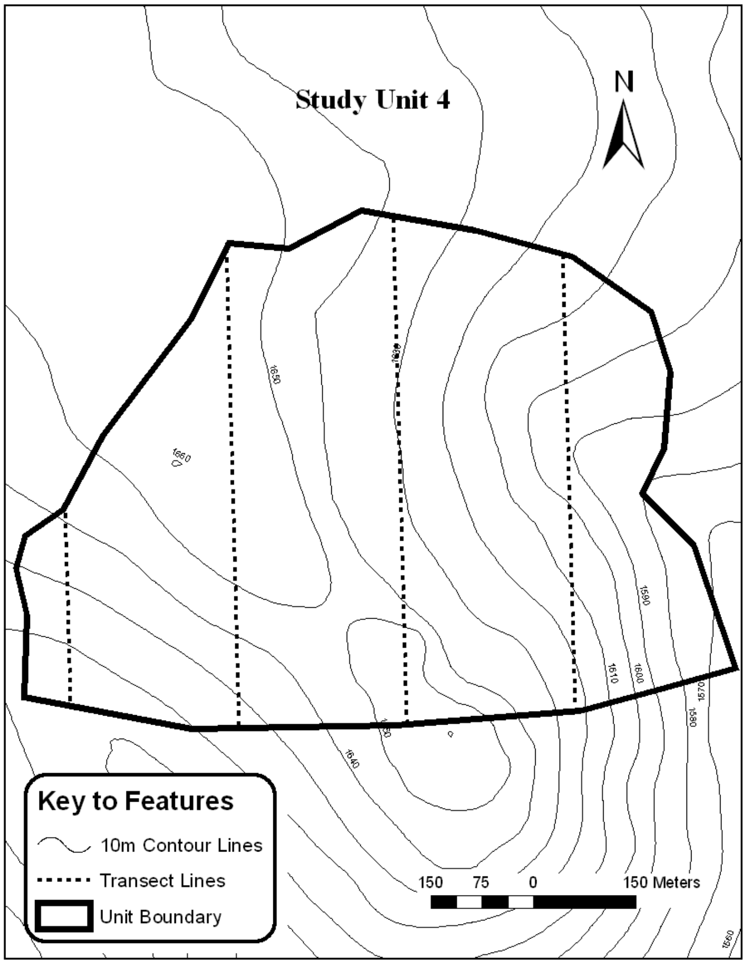
Study units were selected *a priori* to be high quality black-backed woodpecker habitat based upon previous work (Saab et al. 2002, Russell et al. 2007, Vierling et al. 2008). Remotely-sensed vegetation and fire severity characteristics were utilized to detect forested study units that contained high postfire snag densities, an important habitat feature that is characteristic of black-blacked woodpecker nesting sites (Saab and Dudley 1998, Johnson et al. 2000, Saab et al. 2002, Russell et al. 2007, Saab et al. 2009). Study units within the Toolbox and Silver fires were selected using pre-fire and post-fire Landsat TM imagery in conjunction with 2003 outlined plans for salvage logging sale units. Relatively contiguous areas containing high postfire vegetation mortality (50%) combined with high pre-fire canopy cover (>50%) were identified with remote sensing tools. Because the black-backed woodpecker is considered a Sensitive Species in the Critical subcategory within Oregon (Oregon Dept. Fish and Wildlife) and a Sensitive Species by the USDA Forest Service (Regions 1, 2, 9), the highest quality areas (in terms of high snag densities) were set aside as unlogged control units to prevent further harm to the species and protect against litigation. For comparison against unlogged units, treatment study units were selected to contain the highest pre-harvest snag densities of all areas slated for logging. Other than unlogged reserve areas selected for black-backed woodpeckers, treatment areas contained the highest snag densities of those available.

A total of 12 study units were created in 2003 (8 unlogged, 4 logged). An additional treatment unit was added in 2004 when logging plans were changed to only partially log one of the original treatment units. A lack of large continuous harvest units containing habitat features similar to unlogged units limited the number of suitable treatment units. Study units ranged in size from 111 to 24 ha (average 60.2 ± 8.4 SD), totaling approximately 781 ha. A number of small burn patches (9 units, range 2-11 ha) were also set aside as unlogged reserve areas for Lewis's woodpecker (*Melanerpes lewis*). Nest survival data for black-backed woodpecker nests associated with Lewis's units were included in analysis. Control units were left unlogged, whereas treatments were salvage logged 2 years post-fire during the late summer and fall of 2004. Treatment sites were logged with a minimum retention of 25 snags/hectare of various diameters. Diameters of designated "leave" trees represented the range of pre-treatment tree and snag diameters. The resulting prescription was clumps of approximately 100 leave snags every 4 hectares, although actual harvest intensity varied among treatment units and often left more (especially small <23 cm dbh) standing snags. Despite being set aside as reserves, salvage logging occurred inside several of the Lewis's areas. Lewis's woodpecker units were considered a treatment unit if >50% was logged.

Nest Searching and Monitoring

Black-backed woodpecker nests were located within units using systematic searching and playback surveys along belt transects (0.4 x 1.0 km) during May and early June (Figure 2.1) (Dudley and Saab 2003). All transects in all units were surveyed once a year in calm, dry weather conditions, and survey effort (hours) was similar among years. Adjacent transects were generally not surveyed in the same week to avoid missing nests because of weather conditions or late nest initiation timing. Playback surveys consisted of 30 seconds of black-backed calling and drumming followed by 30 seconds of silence, repeated 3 times every 200 meters along the transect line. Including Lewis's woodpecker units, total area surveyed each year was approximately 840 hectares. This technique provides a relatively complete census of nest cavities (but see Russell et al. 2009). Nest cavities from the previous year were also visited to determine current use and detect potential returning pairs. Birds were audibly or visibly detected and followed back to cavities, where the location was marked via a Trimble GeoExplorer 3 GPS unit and a flagged bearing tree >10 m distant. A cavity was not considered to contain an active nest until it was found to contain eggs or young.

Figure 2.1: Example study unit with north-south belt transects used for surveying.



Nests were monitored approximately every 3-4 days (average 3.45, range 1-11 days) using an electronic camera mounted to a telescoping pole (TreeTop II; Sandpiper Technologies, Inc.) except cavities over 14 m high or those blocked by thick branches, which were monitored using visual observations of adult or nestling behavior. Reproductive data, including time, date, nest stage, and cavity contents (i.e. counts of eggs or young), were recorded each visit until the nest failed or fledged ≥1 young. As little time as possible was spent at the nest tree when cavity viewing, and observations were often <30 seconds due to low cavity heights. We avoided camera use when potential nest predators were present (e.g. squirrels, *Glaucomys sabrinus*, ravens, *Corvus corax*) and varied our paths to and from the nest tree. Black-backed woodpecker nestlings were never observed prematurely fledging ("force fledging") as a result of our activity at the nest.

Because cavities were rarely found during egg-laying, initiation dates (first day an egg was laid) and nest ages were established by backdating from hatch or fledging dates using averaged estimates contained in the literature. Assumed lengths of nest stages were: one egg laid a day, 13 days for incubation, and 25 days for nestlings (Dixon and Saab 2000). These estimates generally matched up well with observed nesting chronology in our study area. If a nest was found during the nestling period and failed prior to fledging, nestling development was used to estimate age and backdated to initiation date.

Nest fate was determined successful if the cavity was observed empty at the time of expected fledging, there was no sign of predation in or around the nest tree, and previous nest visits had shown the nestlings to be exhibiting pre-fledging signs (e.g. large size, advanced feather development, adult-like vocalizations, head protruding from cavity entrance, etc.). Age of young was also used to determine fledging status if a transition date (egg laying or hatching) had been previously observed. Fledglings were rarely detected and thus did not serve as reliable indicators of nest fate. Newly fledged black-backed young are capable of extensive movements with their family groups (J. Dudley *personal communication*). Unless the time between nest visits was one day or fledglings were directly observed, the fledge date was recorded as the midway point between the last active visit and the next inactive check (Dudley and Saab 2003). Nests were identified as failed when we observed dead nestlings or the cavity was empty before the nestlings were developed enough to fledge. We attempted to determine cause of nest failure, but were unable to discern this in many cases. Naturally abandoned, depredated, and usurped nests were all recorded as unsuccessful. If a nest was potentially abandoned due to researcher activity (n=2), the last observation interval was excluded from nest survival analysis.

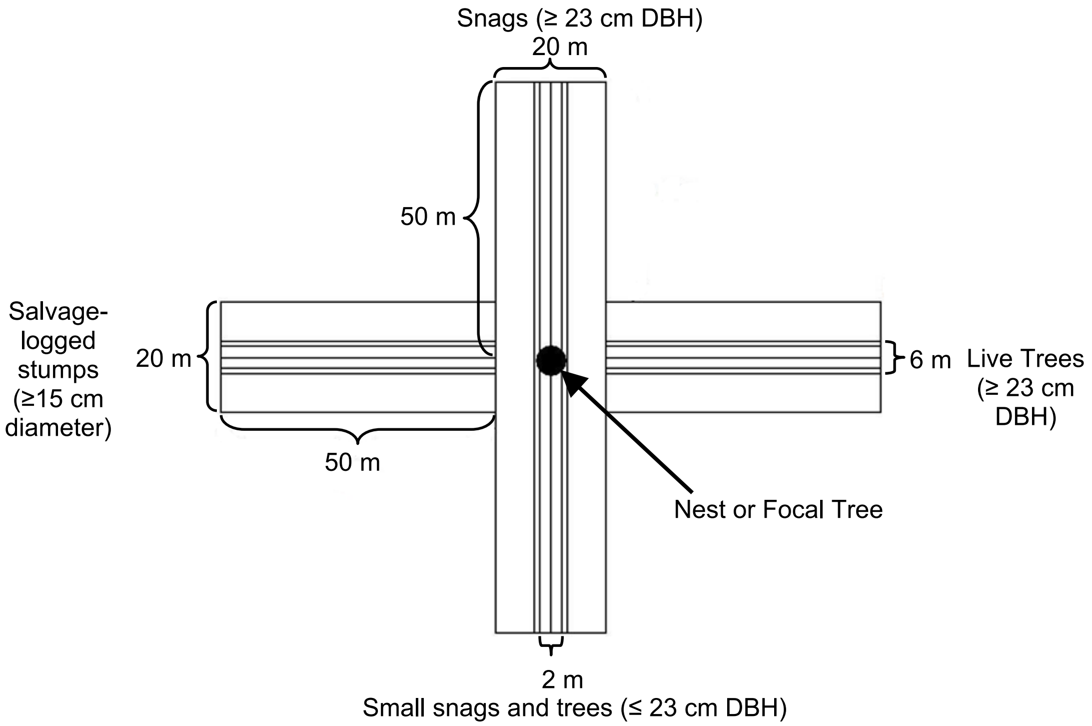
Non-nest Points

Random non-nest points were generated within study units (except Lewis's units) using a Geographic Information System (GIS) and random point generator. Within-year random points were proportionally distributed across study units based on unit size and located >100 meters apart to prevent overlapping vegetation plots. Forty random plots were measured in 2003-2004 (pre-treatment period) and a new set of forty-seven in 2005-2006 (post-treatment period). Seven additional plots were added in the post-treatment period to account for the new study unit added in 2004. The overall number of random plots was limited by logistics and time constraints. Once the randomly generated coordinates were reached in the field, the nearest available tree (snag or live tree ≥15 cm dbh, minimum diameter of nest tree, see Table 3.1) was selected as the focal tree and centered in the vegetation plot (see Figure 2.2). Available focal trees were rarely more than five meters from the generated coordinates. Random plots were measured each year and averages of their habitat conditions for the two year period (pre-treatment period, post-treatment period) were used in data analysis. Habitat variables such as snag density change very little in the first few years after wildfire (Russell et al. 2006), so using the average between two years should still be a reasonable reflection of the vegetation structure.

Habitat Measurements

Detailed vegetation surveys were conducted at all nest and randomly selected non-nest trees (collectively referred to as a focal tree). Focal tree characteristics recorded included tree species, condition (live or dead), dbh, and tree height. Cavity height and cavity orientation were also characterized at nest trees. Surrounding vegetation were recorded through four rectangular plots centered on the nest tree (Figure 2.2) and oriented in the four cardinal directions (USDA 2004). Total vegetation plot area was approximately 0.4 ha. East and West-oriented plots were offset 10 meters away from the nest tree to prevent double sampling of habitat features. While all rectangular sampling plots were 50 m long, the width of the sampling belt varied depending upon the vegetation characteristic being measured (see Figure 2.2). Snags were defined as having no green needles and both snags and live trees had to be >1.37 m in height and ≥23cm dbh to be sampled at this scale. For each large snag and live tree on the plot, we recorded species, height, decay class, and cavity status. Snags, stumps, and live trees were all converted to densities per hectare to ease direct comparison and model interpretation. Small dead and live trees <23 cm dbh and >1.37 cm in height were tallied into dbh classes (0 to < 2.5, 2.5 to < 5, 5 to < 8, 8 to < 13, 13 to < 15, 15 to < 23) and sampled at a plot width of only 2 m. This vegetation sampling protocol was originally developed for green forests and designed to sample habitat features rare on the landscape (i.e. snags) (Bate et al. 1999). It was implemented here for direct comparison to other vegetation sampling efforts being conducted throughout ponderosa pine ecosystems in the western United States (USDA 2004).

Figure 2.2. Belt transect vegetation sampling plot



Remote sensing tools were also used to characterize habitat variables at the plot and landscape (500 m, 1 kilometer radius) scales surrounding nest and non-nest points. We decided to include remotely-sensed measures as they facilitate large-scale wildlife habitat analysis and are readily accessible to forest and wildlife managers. Prefire crown closure and differenced normalized burn ratio (ΔNBR) layers were first generalized using the median value in a moving 3 x 3 pixel window (Booth and Oldfield 1989). ΔNBR is a continuous variable derived using pre- and postfire Landsat TM images and is the best remote sensing tool currently available for classifying burn severity (Brewer et al. 2005, Cocke et al. 2005, Epting et al. 2005, Key and Benson 2006). The generalized pixel value for pre-fire crown closure and ΔNBR score were recorded at all nests. In addition, the prefire crown closure layer was reclassified into low (<40%), moderate (>40% - 70%), and high (>70%) categories (Johnson et al. 2000, Saab et al. 2002) and the ΔNBR layer was reclassified into unburned (-999 to 99), low severity (100 to 269), and moderate-high severity (270 to 1057) (Key and Benson 2006, Russell et al. 2006, Russell et al. 2007). Once reclassified, these layers were used to calculate area proportions of categorized habitat data within 500 meter and 1 kilometer radii of nest trees. To further characterize high-quality (high snag density) habitats using remote sensing tools, we then created additional layers using overlapping areas of moderate-high prefire crown closure and moderate-high burn severity (Burn500m, Burn1k). Amount of salvage logged area was also quantified at these two landscape scales. Forest Service personnel provided GIS maps of salvage harvest units on federal lands. Burned, forested private land falling within the landscape scale buffers was classified as logged immediately postfire (2002) and verified using postfire high-resolution digital aerial photography. Thus, some logging was present at the landscape scale prior to the 2004 logging treatments.

Nest-site Selection Analysis

Relationships between nest-site selection and habitat covariates were examined with logistic regression in a case-control design where nests were considered cases and non-nest point were considered controls. Biologically defensible *a priori* models hypothesizing the effects of covariates on nest-site selection were constructed based upon previous studies of nest-site selection and nest survival. Using the nest-quality hypothesis, we predicted that habitat characteristics shaping nest-site selection would also play a role in influencing nest survival (one component of fitness) (Martin 1998). Hence, many of our *a priori* nest-site selection models were similar to those used in the previous nest survival analysis.

Nest-site selection was analyzed with logistic regression in program R (glm, family=binomial) (R Development Core Team 2006). Potential correlations between covariates were inspected using Pearson correlation coefficients (Appendix C). Highly correlated variables ($|r| \geq 0.6$) were not included in the same models (Neter et al. 1996). Models were assessed with an information-theoretic approach (Anderson et al. 2000, Burnham and Anderson 2002). Competing models were evaluated through Aikaike's Information Criterion (Akaike 1973) corrected for small sample size (AIC_c) (Hurvich and Tsai 1989). Ranking ΔAIC_c and models weights then facilitated detection of the model or models best suited for inference (Burnham and Anderson 2002). Goodness-of-fit for global models was examined using the le Cessie-van Houwelingen method (1991). This test statistic is more appropriate for logistic regression models containing continuous covariates than other GOF tests (Hosmer et al. 1997).

Nest Survival Analysis

Relationships between nest survival and habitat and abiotic covariates were examined with generalized non-linear mixed models (PROC NLMIXED; SAS Institute, Inc. 2000), as described by Dinsmore et al. (2002), Stephens (2003), Shaffer (2004), and Rotella et al. (2004). An advantage of this statistical method over traditional Mayfield estimates is the ability to include numerous covariates that may be important predictors of the survival model, such as habitat, age of nest, observer effects, or weather covariates, as well as potential random effects (Rotella et al. 2000, Dinsmore et al. 2002, Rotella et al. 2007). Biologically defensible *a priori* models hypothesizing the effects of covariates on daily nest survival (DSR) were evaluated with an information-theoretic approach (Anderson et al. 2000, Burnham and Anderson 2002). Potential correlations between covariates were inspected using Pearson correlation coefficients (Appendix C). Highly correlated variables were not included in the same models to avoid issues with multicollinearity (Neter et al. 1996). Competing models were evaluated through Aikaike’s Information Criterion (Akaike 1973) corrected for small sample size (AIC_c). Ranking ΔAIC and weight values then facilitated detection of the model or models best suited for inference (Burnham and Anderson 2002).

Variables and Predictions

The variables used in our survival and nest-site selection models can be divided into five categories: nest, plot, patch, landscape, and abiotic. See Appendix A for a list of variables and descriptions.

1) Nest-scale hypotheses.

a) Height of the nest cavity (NestHt) was the only nest tree characteristic hypothesized to affect DSR. We predicted a positive relationship between nest cavity height and nest survival because nest predators may have more difficulty locating and accessing higher nests (Martin and Li 1992). Fisher and Wiebe (2006) found support for increased survival in higher nests in northern flickers (*Colaptes auratus*), another primary cavity nester. Other studies have found positive or no effects of cavity height on nest success (see Fisher and Wiebe 2006 for a full review).

b) Nest tree diameter (Dbh) was predicted to positively influence nest-site selection, with larger snags being selected compared to non-nest snags. Saab et al. (2009) observed black-backed woodpeckers favored increasing snag diameters for nest trees. Nest tree diameter was not included in nest survival models as there is little evidence to support an effect of cavity tree diameter on DSR.

2) Plot-scale hypotheses. Both field-collected and remotely-sensed habitat variables were used to assess changes in DSR at an approximate 50 meter radius around the nest tree. Snag density (SnagHa), ΔNBR (plotDNBR), crown closure (PlotCC), average dbh of surrounding snags (SngDBHplot), and salvage-logged stump density (LogStumpHa) were hypothesized as influential factors on nest-site selection and daily nest survival at this scale. Justification of our predictions is as follows:

a) Nest survival will benefit from increasing snag densities (SnagHa) through decreasing predator search efficiency (Martin and Li 1992, Chalfoun and Martin 2007), elevating food resources for adults and young, and increase nest cavity vigilance by reducing foraging time and distance traveled by adults. Saab et al. (2002) and Russell et al. (2007) demonstrated black-backed woodpecker's nest site preference for high snag densities at both the plot and landscape scales; therefore we predicted the same response. Evolutionary theory would predict that this habitat selection behavior should be adaptive and confer fitness benefits upon the individual.

b) Increasing values of ΔNBR (PlotDNBR) indicate increasing burn severity, thus we predict a positive relationship between ΔNBR, nest-site selection and daily nest survival. Higher burn severity should result in higher snag densities and lower numbers of ground nest predators.

c) We predict increasing daily nest survival and selection of nest sites with increasing values of prefire crown closure at the plot scale (PlotCC). Prefire crown closure has found to be a strong predictor of postfire black-backed woodpecker nesting habitat (Saab et al. 2002, Russell et al. 2007). If nest survival is a driver of nest-site habitat selection, nest survival may increase with higher prefire crown closure.

d) Increasing average dbh of surrounding snags (SngDBHplot) indicate larger snags and concordantly more food in the form of wood-boring (Cerambycidae and Buprestidae) and bark (Scolytidae) beetles. Past studies suggest that black-backs and beetle prey preferentially forage on larger diameter snags (Villard and Beninger 1993, Murphy and Lehnhausen 1998, Powell 2000, Nappi et al. 2003). Larger snags could provide more concealment and structural complexity around the cavity tree, thus lowering predator search ability (Martin 1993). This association leads us to predict a positive relationship between snag diameters, nest-site selection and DSR.

e) Salvage-logged stump density (LogStumpHa) is a direct, plot-scale test of our primary hypothesis regarding postfire salvage logging. We predict a negative relationship with more stumps because increasing stump density should indicate reduced snags available for nesting, foraging, and nest concealment. Residual snags in logged areas should generally be of lower quality in terms of size and structural integrity as logging typically targets the largest, straightest snags. Harvest intensity appeared to differ among logged units; this variable attempts to quantify that difference around the immediate nest area.

3) Patch-scale hypothesis. (LogUnit) is a categorical variable indicating whether the nest is associated with a logged treatment unit or unlogged control unit. Modeled on its own, this categorical variable tested for a difference in nest-site selection or nest survival between control and treatment units independent of the logging time period. Our primary hypothesis was modeled using an interaction term (LogPer) representing pre- and post-logging periods (1-2 years vs. 3-4 years) to test for an effect of salvage logging at a larger scale than the 50 m radius around the nest. It directly compares the effects of salvage logging using our before-after control-impact (BACI) study design. We predicted a negative coefficient for the after- LogPer*LogUnit interaction term.

4) Landscape-scale hypotheses. Habitat variables can affect nest survival at multiple spatial scales and in a hierarchical manner (Stephens et al. 2004, Ibarzabal and Desrochers 2005, Stephens et al. 2005). Because black-backed woodpeckers and their nest predators/competitors were not restricted to our study unit boundaries, we created

nest-site selection and nest survival models including habitat variables at 500 m and 1 km radii from the nest trees. These distances were chosen to approximate territory size in our study area (based upon observed nest densities) and for direct comparison to past studies investigating this species where territories were found to be larger (Saab et al. 2002, Dudley 2006).

a) The amount of logged area in hectares was calculated at both landscape scales and modeled separately to avoid problems with multicollinearity. We hypothesized lower nest survival and negative nest-site selection odds-ratios with increasing area of salvage logging due to reduced foraging substrates.

b) The proportion of area containing med-high prefire crown closure (40-100%) within 500 meters and 1 kilometer radius of the nest was calculated (cc500m and cc1k). Similarly, proportion of moderate-high fire severity (ΔNBR 270-1200) was calculated for both spatial scales (dNBR500m and dNBR1k). Variables calculated at the 500 meter radius were not used in the same models as those from the 1 kilometer radius (variables were highly correlated with each other at 500m and 1km). We predicted a positive interaction term (coefficient) between dNBR and prefire crown closure, where increasing values resulted in increased odds of nest placement and higher nest survival. We reasoned that within the burn mosaic, med-high prefire crown closure would only provide high quality habitat if it was associated with moderate-high fire severity. Amount of logged area was included as an additive effect in models containing this interaction to account for habitat lost.

c) The proportion of area containing unlogged med-high prefire crown closure (40-100%) with overlapping moderate-high fire severity (ΔNBR 270-1200) was calculated for both spatial scales (Burn500m and Burn1k). These overlapping areas should represent patches of increased snag abundance and high quality woodpecker foraging habitat. Increased values were predicted to have a positive influence on nest-site selection and nest survival.

5) Abiotic covariate hypotheses. A number of recent studies have found strong evidence for effects of weather, year, or initiation date on nest survival rates of cavity-nesting birds (Newlon 2005, Fisher and Wiebe 2006, Mahon and Martin 2006, Bonnot et al. 2008). Abiotic variables were not used in any nest-site selection models.

a) We expect a negative relationship with daily average temperature (AveTemp) because warmer weather may accelerate adult wood-boring beetle emergence and prematurely deplete larval beetle resources during nestling provisioning (Annila 1969, Salonen 1973, Post 1984). Hot weather, particularly later in the nesting season, may create unfavorable cavity temperatures for developing nestlings. Studies of cavity-nesting birds have found evidence for effects of weather on nest survival, however the direction and magnitude differed among species (Pasinelli 2001, Dawson et al. 2005, Newlon 2005).

b) Year was modeled two different ways in our analysis. First, year was modeled as a year after fire, linear time-trend influence on nest survival (YrPostfire). We predicted nest survival would decrease as year postfire increased. As year postfire increases, nest predators should increase and beetle numbers drop, thus limiting food resources and raising the probability of nest failure. Second, calendar year was modeled as a categorical predictor using 3 dummy variables (2004, 2005, 2006), allowing nest survival to differ completely from year to year over the study period. Using year as a categorical predictor models an alternative hypothesis that annual fluctuations in unmeasured variables (e.g. nest predator communities, beetle prey densities) influence nest survival non-linearly.

c) Calendar day (JDate) can influence nest survival through numerous mechanisms. Patterns of food or predator abundance (i.e. squirrel litter emergence) could be tied to season cycles or photoperiod. Fisher and Wiebe (2006) related a significant quadratic date effect on northern flicker DSR to complex seasonal patterns of squirrel foraging tactics and cavity kleptoparasitism (Kappes 1997). We predict a similar quadratic relationship with DSR, as causes of nest failure are likely to be similar in our study area.

d) Nest age (Age) was hypothesized to influence daily survival rate through changes in behavior of adults and young. Nest detectability increases post-hatching, as adults make more frequent trips to the cavity and young begin begging (Russell et al. 2009). By late in the nestling stage, we could hear begging nestlings >200m from the nest tree. However, as parental investment in young increases with age, adults may intensify nest defense and vigilance behaviors to counteract amplified cavity detectability (Montgomerie and Weatherhead 1988, Carrillo and Aparicio 2001, Pavel and Bures 2001, Leech et al. 2006). Nest age was modeled to have either a linear or quadratic relationship with DSR.

Nest-Site Selection Model Construction

Biologically relevant *a priori* models were constructed and grouped into suites based upon their respective predictor categories. Because we had no hypotheses about how our habitat variables at multiple spatial scales would combine to influence nest-site selection and we wished to compare model results with those from the nest survival analysis, covariates from different model suites were not mixed in any *a priori* models. When a variable was hypothesized to have particularly strong effects, it was used in both single and multiple predictor models. The nest/plot and landscape model suites included a global model containing all of the predictors used in that model suite.

Exploratory models were constructed *post hoc* after examining within-suite model selection results, beta estimates, and 95% confidence intervals. Covariates whose confidence intervals did not overlap zero were considered further in exploratory additive models and possible interaction terms. Exploratory models were not regulated to a single spatial scale or category; rather all potentially significant covariates were used in biologically reasonable combinations.

Odds ratios were used for interpretation of parameter estimates, as predicted probabilities are inappropriate in case-control studies (Keating and Cherry 2004). We estimated adjusted odds ratios by holding all other covariates constant except one. Adjusted odds ratios express the odds of an event given a unit *x* change in your covariate of choice. We attempted to choose biologically relevant unit changes when creating odds ratios. The unit change for each selected model's covariate is given in Tables 3.3 and 3.5.

Nest Survival Model Construction

Biologically relevant *a priori* models were constructed and grouped into suites based upon their respective predictor categories (see Table 2.1). Because we had no hypotheses about how abiotic and habitat variables at multiple spatial scales would combine to influence DSR, covariates from different model suites were not mixed in any *a priori* models. When a variable was hypothesized to have particularly strong effects, it was used in both single and multiple predictor models. Each model suite contained a null model (assumes constant DSR) and, when appropriate, a global model containing all of the predictors used in that model suite (excluding interaction terms). Inclusion of a null model allowed us to assess whether any abiotic or habitat covariates were explaining more variation in our data than a simple constant survival model with no covariates. The goodness-of-fit of our best-performing and global models from each suite was examined using techniques outlined by Sturdivant et al. (2007).

In addition to investigating the effects of various habitat and abiotic predictors on DSR, we also checked to see if our nest monitoring activities negatively influenced nest survival (Rotella et al. 2000). We built models testing for both an observation effect and a cavity-viewing camera effect on nest daily survival rate for the day after the nest was visited. The observation effect did not distinguish whether we used the camera to monitor the nest contents or not. We ran these models on only the 2003 data, the first year of the study. In this year, nests were monitored with the camera every other visit. In 2004 through 2006, cameras were used for almost every nest check, except for those nests where the cavity was too high to reach for viewing. Thus, our ability to detect a significant effect of camera viewing on DSR would have been highest in 2003 and not confounded with cavity height.

Exploratory models were constructed *post hoc* after examining within-suite model selection results, beta estimates, and 95% confidence intervals. Variables whose parameter estimate confidence intervals did not overlap zero were considered further in exploratory additive models and interaction terms. Exploratory models were not constrained to a single spatial scale or category; rather all potentially significant covariates were used in biologically reasonable combinations.

Table 2.1. *A priori* models representing predictions of the response of black-backed woodpecker nest daily survival rate (DSR) to covariates within burned, mixed coniferous forests of south-central Oregon, USA.

Model Suite	Model Structure
Nest	$B_0 + B_1$(NestHt)
Plot	$B_0 + B_1$(SnagHa)
	$B_0 + B_1$(SngDBHPlot)
	$B_0 + B_1$(PlotDNBR)
	$B_0 + B_1$(PlotCC)
	$B_0 + B_1$(LogStumpHa)
	$B_0 + B_1$(SnagHa) + B_2(SngDBHPlot) + B_3(PlotDNBR) + B_4(LogStumpHa)
	$B_0 + B_1$(SnagHa) + B_2(SngDBHPlot) + B_3(PlotCC) + B_4(LogStumpHa)
	$B_0 + B_1$(PlotDNBR) + B_2(PlotCC) + B_3(PlotDNBR)*(PlotCC)
	Global (all predictors excluding interactions)
Patch	$B_0 + B_1$(LogUnit)
	$B_0 + B_1$(LogUnit) + B_2(LogPer) + B_3(LogUnit)*(LogPer)
Landscape	$B_0 + B_1$(LogArea500m)
	$B_0 + B_1$(LogArea1k)
	$B_0 + B_1$(LogArea500m) + B_2(CC500m) + B_3(DNBR500m) + B_4(CC500m)*(DNBR500m)
	$B_0 + B_1$(LogArea500m) + B_2(Burn500m)
	$B_0 + B_1$(LogArea1k) + B_2(CC1k) + B_3(DNBR1k) + B_4(CC1k)*(DNBR1k)
	$B_0 + B_1$(LogArea1k) + B_2(Burn1k)
	Global (all predictors excluding interactions)
Abiotic	$B_0 + B_1$(JDate)
	$B_0 + B_1$(JDate) + B_2(JDate)^2
	$B_0 + B_1$(Age)
	$B_0 + B_1$(YrPostfire)
	$B_0 + B_1$(2004) + B_2(2005) + B_3(2006)
	$B_0 + B_1$(AveTemp)
	Global (all predictors excluding YrPostfire)

Results

Nest Summary

A total of 210 black-backed woodpecker nests were located and monitored from 2003-2006. We recorded 32, 68, 63, and 47 nests in 2003-2006, respectively. Out of the total nest sample, 132 nests were inside or within 50 meters of the study units while 78 were outside these boundaries. Densities of nests were generally higher in control units than in treatment units, both before and after salvage logging (Figure 2.3). Three cavities were reused by black-backs in consecutive years and were included in the analysis as independent samples. With the exception of one nest that was in a live tree, snags were used exclusively as nest trees. Lodgepole pine (*Pinus contorta*) and ponderosa pine (*Pinus ponderosa*) made up 90% of all selected nest tree species (Figure 2.4). Black-backed woodpeckers gradually switched from nesting primarily in lodgepole pine to ponderosa pine as year postfire increased (2.2). Average nest tree diameter remained consistent until year four, when it increased (Figure 2.3). Nest height varied annually (Figure 2.5). All nest cavities were classified as constructed by black-backed woodpeckers.

From the sample of 210 nests, 3 nests were excluded from survival analysis due to unknown nesting chronology and the final intervals of 2 nest records were censored due to suspected researcher-caused abandonment. Of the nests with complete end fates, 180 survived and 25 failed (apparent nest success = 88%). As birds were not individually marked, definitive renesting attempts were never observed. In one instance of early nest failure, new cavity location (~40 meters from the failed cavity) and nest initiation timing did suggest a renesting attempt. Previous year's cavities were only reused in subsequent years 3 times by black-back pairs over the course of the study and most nest cavities showed obvious signs of being excavated the same year as occupation.

Average length of the full nesting cycle was 40 days ± 1.7 (1 SD, range 33-46). Clutch size, initiation date, and fledging date varied from year to year and did not demonstrate any clear trends (Table 2.2). Average number of fledglings produced per successful nest appeared to decrease slightly as year postfire increased from 2003-2006 (Table 2.2). We found 48% of nest cavities before or during incubation and 52% during the nestling period. Causes of nest failures were largely undetermined, but Least Chipmunks (*Tamias minimus*) and a tree squirrel (unknown spp.) were observed in recently failed nest cavities. Secondary cavity-nesting species exhibiting nest usurping behavior at black-backed woodpecker cavities were tree swallows (*Tachycineta bicolor*), house wrens (*Troglodytes aedon*), mountain bluebirds (*Sialia currucoides*), and European starlings (*Sturnus vulgaris*).

Habitat Summary

Box-and-Whisker plots (Tukey 1977) detailing characteristics of continuous habitat variables used for modeling nest-site selection and nest survival are provided in Appendix B. Basic summary statistics for pooled within-unit nests, random non-nest, and all other nests are shown in Table 2.3. Postfire snag densities of random plots within control units were generally higher than those in treatment units, both before and after logging (Appendix B). Salvage logging in treatment units decreased snag density and average diameter of snags on the plot, but only slightly for both. Plot-level fire severity

(Δ dNBR) at non-nests was generally higher in treatment units than in controls. The amount of logged area around non-nest points at landscape scales increased after salvage logging; larger logged areas were associated with treatment units compared to non-nests in control units. Proportion of high snag density habitat at landscape scales decreased significantly after logging in treatment units.

Pearson product-moment correlation coefficients, histograms, and x-y scatter plots of continuous variables are presented in Appendix C. Variables are grouped by their respective *a priori* model suite.

Table 2.2. Number of nests monitored, number of failed nests, average clutch size, number of fledglings per successful nest, and average initiation and fledging dates for black-backed woodpecker nests in burned, mixed coniferous forest of south-central Oregon, USA. 2003-2006. Means are followed by 1 SE (*n*, range). SE for initiation and fledge date is indicated in days.

Year	Number of monitored nests	Number of failed nests	Clutch Size	Initiation Date	Fledge Date	Number of Young per Successful Nest
2003	32	4	3.6 ± 0.45 (11, 1-5)	8 May ± 3 (10 April – 25 June)	14 June ± 1 (31 May – 29 June)	2.9 ± 0.18 (28, 1-5)
2004	68	4	3.4 ± 0.19 (30, 1-5)	4 May ± 1 (10 April – 31 May)	13 June ± 1 (20 May – 10 July)	2.6 ± 0.08 (63, 1-4)
2005	63	9	3.5 ± 0.16 (39, 2-5)	12 May ± 1 (27 April – 6 June)	20 June ± 1 (8 June – 12 July)	2.2 ± 0.10 (51, 1-4)
2006	47	8	3.9 ± 0.08 (20, 3-4)	10 May ± 1 (28 April – 8 June)	18 June ± 1 (6 June – 13 July)	2.2 ± 0.11 (38, 1-3)
Overall	210	25	3.6 ± 0.09	8 May ± 1	16 June ± 1	2.4 ± 0.06

Table 2.3. Summary statistics of habitat attributes recorded at black-backed woodpecker nest sites and random non-nest points in burned, mixed coniferous forest of south-central Oregon, USA. 2003-2006. Means are followed by 1 SD (range).

	Within-unit nests (n = 132)	Random sites (n = 87)	All other nests (n = 78)
Nest/Plot scale			
Dbh of nest or non-nest focal snag (cm)	27.7± 0.8 (15 - 73)	34.1± 2.2 (15 - 95)	32.2± 1.3 (16 - 76)
Snags/ha	123.3± 5.1 (17.5 - 295)	89.8± 6 (16.3 - 228.8)	105.4± 6.3 (12.5 - 257.5)
Dbh of Nest Plot Snags	33.2± 0.5 (24.8 - 51.5)	32.7± 0.6 (22.9 - 48.1)	33.6± 0.6 (24.6 - 46.1)
Logged stumps/ha	10± 2.6 (0 - 167.5)	11.5± 3.6 (0 - 165)	14.7± 4.5 (0 - 217.5)
Burn severity (ΔNBR)	567.4± 14.6 (109.8 - 982.9)	476± 22.2 (60.2 - 923.6)	480.8± 15.9 (169.7 - 725.6)
Prefire crown closure (%)	53.5± 1.2 (0 - 79)	54.6± 1.7 (0 - 82)	47.2± 1.5 (7 - 72)
Landscape scale			
dNBR500m (% area)	74.4± 1.8 (24.3 - 99.5)	71.1± 2.7 (9.2 - 100)	69.8± 2.2 (28.1 - 100)
dNBR1k (% area)	63.8± 1.8 (12.4 - 92.3)	63.2± 2.4 (13.5 - 92)	60.9± 1.9 (22.8 - 88.2)
Logged area 500m (ha)	21.7± 2.5 (0 - 131.3)	18± 2.2 (0 - 75.5)	20.6± 2.9 (0 - 97.4)
Logged area 1k (ha)	92.9± 7.3 (0 - 338.5)	77.2± 7.7 (0 - 242)	79.3± 8.9 (0 - 278.8)
Burn500m (% area)	47.7± 2 (0.7 - 89.9)	39.9± 2.8 (0 - 84.6)	42.1± 2.3 (4.8 - 81.5)
Burn1k (% area)	35.9± 1.4 (0.7 - 68.3)	29.7± 1.9 (0.7 - 65.2)	34.3± 1.9 (4.1 - 68.4)
Prefire crown closure 500m (% area)	65.7± 1.4 (15.2 - 94.2)	70.5± 1.6 (20.2 - 98.3)	59.2± 2.4 (13.5 - 97)
Prefire crown closure 1k (% area)	57.6± 1 (26.3 - 88.1)	61.2± 1.2 (26.4 - 89.9)	54.7± 2 (13.9 - 86.5)

Figure 2.3. Black-backed woodpecker nest densities by year postfire and study unit type over four years since wildfire in burned, mixed coniferous forest of south-central Oregon, USA. 2003-2006. Whiskers indicate ±1 standard error.

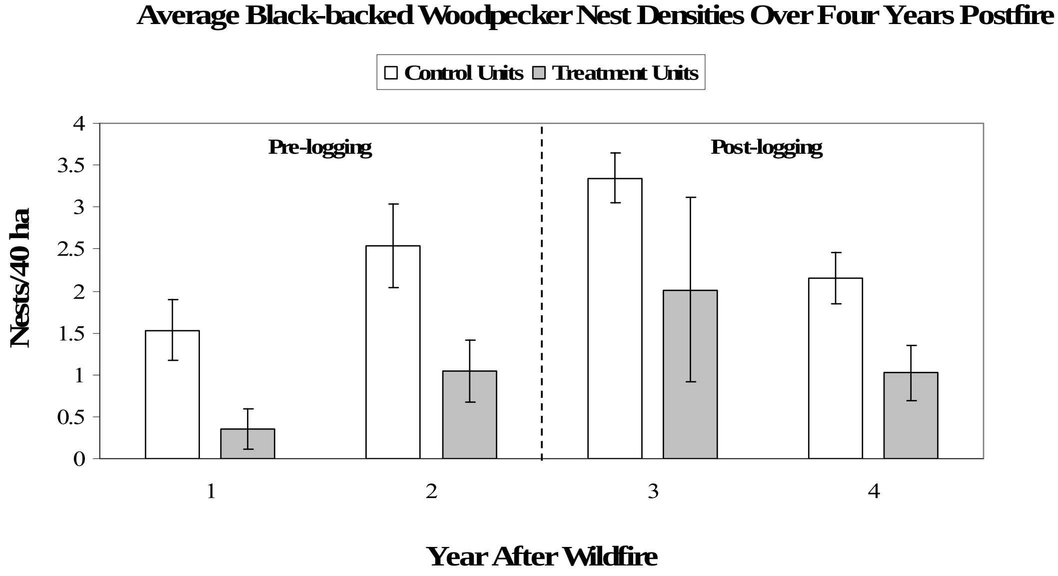


Figure 2.4. Black-backed woodpecker nest tree species by year postfire over four years since wildfire in burned, mixed coniferous forest of south-central Oregon, USA. 2003-2006. Annual nest sample sizes are indicated above each group of bars.

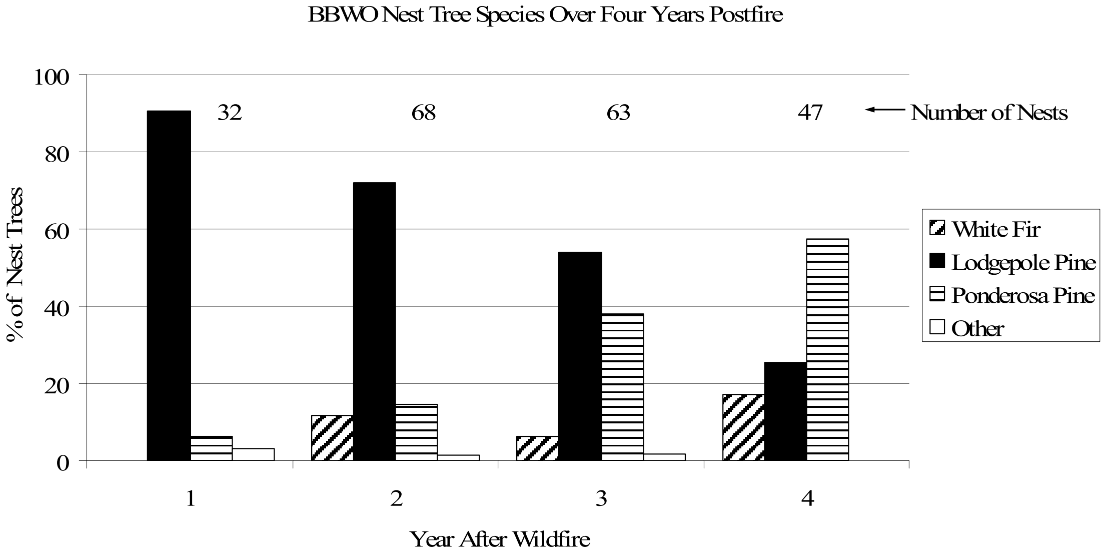


Figure 2.5. Black-backed woodpecker nest tree diameter by year postfire over four years since wildfire in burned, mixed coniferous forest of south-central Oregon, USA, 2003-2006. Annual nest sample sizes and 95% confidence intervals are indicated on each bar.

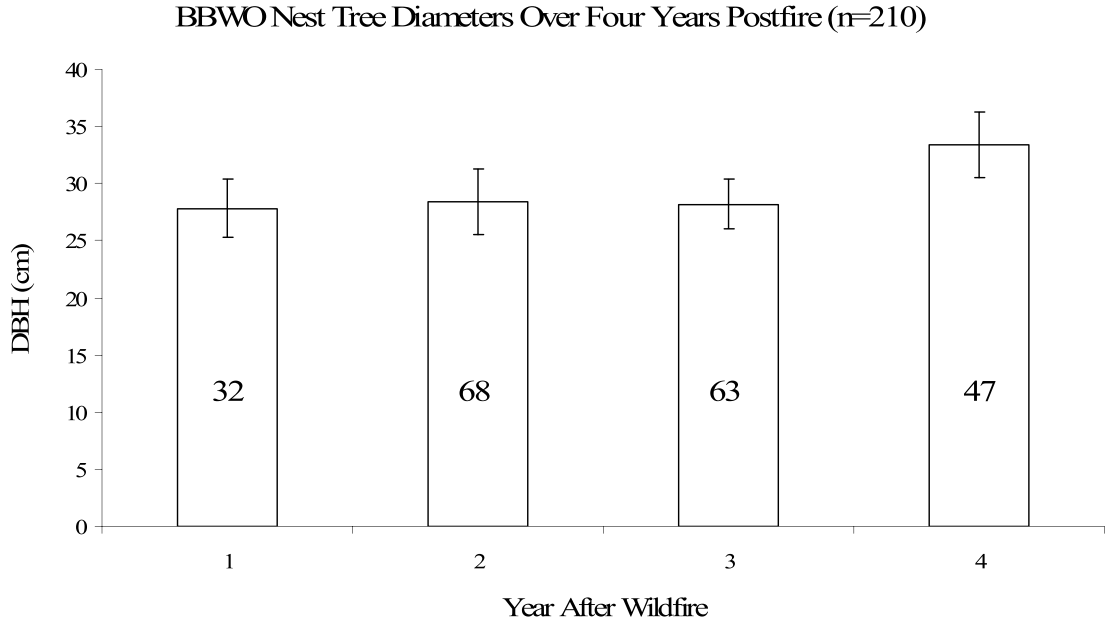
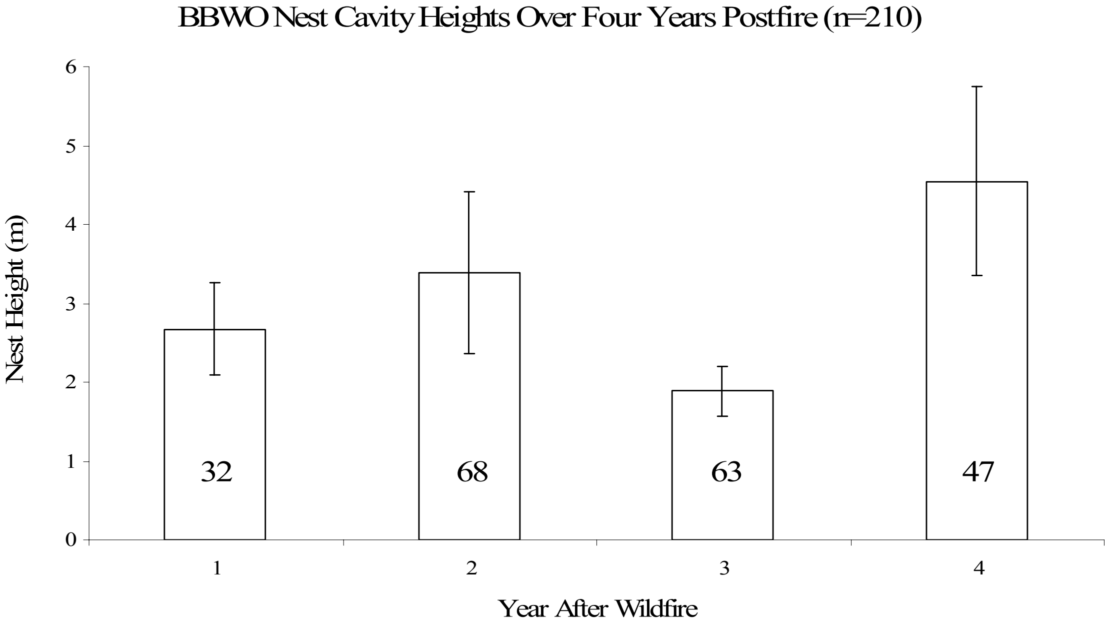


Figure 2.6. Black-backed woodpecker nest cavity height by year postfire over four years since wildfire in burned, mixed coniferous forest of south-central Oregon, USA, 2003-2006. Annual nest sample sizes and 95% confidence intervals are indicated on each bar.



Nest-site Selection

Fourteen *a priori* models were evaluated for nest-site selection of black-backed woodpeckers (Table 2.4). The le Cessie-van Houwelingen goodness-of-fit test (1991) on global models indicated adequate fit. Model selection uncertainty was moderate, with the nest and landscape scale model suites each having two closely competing models. The most parsimonious nest-site selection model at the nest/plot scale consisted of the additive effects nest tree dbh, snag density, average snag diameter, prefire crown closure, and logged stump density. A closely competing second-ranked model included the same variables, with the exception of prefire crown closure, which was replaced by burn severity. At the landscape scale, the two top models differed both in their spatial extent and their predictive variables.

The influence of logging on nest-site selection was most evident on the plot scale but largely inconclusive on the landscape scale. At the plot scale, snag density was the strongest predictor of nest-site selection (odds ratio = 1.983; 95% CL = 1.485, 2.713), with the odds of a nest occurrence nearly doubling for every 50 additional snags over 23 cm dbh, strong evidence that this species prefers nesting areas of high snag densities. A unit change of 50 snags was chosen for odds ratio calculation because this was the average number of salvage logged stumps for all plots that contained at least one stump. In contrast, our measure of salvage harvest intensity at the plot scale (logged stump density), received little support within the model suite (Table 2.4). Snag density and stump density were not strongly correlated (Pearson's correlation coefficient = -0.294), thus explaining how this potential contradiction in effects could occur. A test of our BACI study design with the LogUnit*LogPeriod interaction did not perform well compared to the single LogUnit predictor (Table 2.4). The odds ratio for the single LogUnit model was significant (Table 2.5); suggesting black-backed woodpeckers were approximately 44% more likely to select nests in control units over non-nest points in treatment units, regardless of whether the unit had yet been logged. None of the logging models in the patch suite, however, were well supported compared to habitat variables at the nest or plot spatial scale (Table 2.4). At the landscape scale, amount of logged area had a positive relationship with nest occurrence, which is contrary to our predictions of less logging around nest sites. This landscape result is not consistent with nest-site selection of high snag densities at the plot scale, suggesting that black-backed woodpeckers are selecting nest sites based on habitat conditions at smaller spatial scales in this study area.

A number of habitat variables at several spatial scales showed significant relationships with nest-site selection. In addition to snag density, nest tree dbh (odds<1) had significant odds ratios at the nest/plot scale. For trees large enough to support a cavity (≥15 cm dbh), woodpeckers chose smaller diameter snags. Every 5 cm increase in tree diameter decreased the odds of a black-backed woodpecker nesting in it by 15%. Similar to past studies, these data indicate increased odds of black-backed woodpecker nest occurrence with increases in snag density.

At the landscape scale, covariates quantifying habitat within 500 meters and one kilometer demonstrated relationships with black-backed woodpecker nest-site selection. Within one kilometer of the site, a 10% increase in the proportion of heavily treed burned forest (overlapping areas of med/high prefire canopy closure and moderate/high burn severity) increased the odds of a nest by 28%. Amount of logged area within 500 meters and 1 kilometer positively influenced the likelihood of nest occurrence, although only slightly. Increasing proportions of medium-high prefire crown closure within 500 meters negatively affected the odds of nesting whereas areas of high and moderate burn severity was in the second best model, but did not have significant odds ratios (Table 2.5). The interaction between these two variables did receive some support; as the combined interaction value increased, so did the odds of a black-backed nest. These data imply that densely forested areas only resulted in increased odds of nesting if they coincided with increasing areas of med-high burn severity.

Based upon *a priori* model selection results and examination of individual variable performance in single-predictor models, eight exploratory models were constructed and evaluated (Table 2.6). Exploratory combination of spatial scales improved the performance of the model in comparison to within-suite *a priori* models. The best supported exploratory model improved AIC_c by 9.43 points from the top *a priori* model. This model included nest tree dbh, snag density, plot-level burn severity, and 1 kilometer landscape-scale burned habitat, prefire crown closure, and logged area (Table 2.7). Odds ratios indicated that black-backs selected nest sites in smaller snags, higher snag densities, larger burned areas, less area of med-high prefire crown closure, and more logged area.

Habitat differences selected by nesting black-backed woodpeckers outside of the study units were different enough to cause shifts in model selection results. With all nest sites included, model selection results changed slightly. The top *a priori* model in the nest scale model suite gained support ($w_i = 0.92$) and the two next lower models switched ranks. In the landscape scale suite, the top ranked and second ranked models switched places, with the new top model well supported ($w_i = 0.98$, $\Delta AIC_c = 8.18$). Because we did not measure non-nest available habitat in these areas, these additional nests were not included in further analysis.

Table 2.4. Model selection results for *a priori* nest-site selection logistic regression models of black-backed woodpeckers in burned, mixed coniferous forests of south-central Oregon. Within each suite, models are ranked from most supported to least supported based upon the scaled AIC$_c$ value ($\Delta AIC_{c\ suite}$). K is the number of parameters in the model, AIC$_c$ is Akaike's Information Criterion for small sample size, $w_{i\ suite}$ is the Akaike weight within the model suite, $w_{i\ set}$ is the Akaike weight for all models, and $\Delta AIC_{c\ set}$ refers to the scaled AIC$_c$ value for all models within the table.

Suite	Model	k	AIC_c	ΔAIC_c suite	$w_{i\ suite}$	$\Delta AIC_{c\ set}$	$w_{i\ set}$
Nest/Plot	Dbh + SnagHa + SngDBHPlot + PlotCC + LogStumpHa	6	274.04	0	0.68	0	0.67
	Dbh + SnagHa + SngDBHPlot + PlotDNBR + LogStumpHa	6	275.73	1.69	0.29	1.69	0.29
	SnagHa	2	280.77	6.73	0.02	6.73	0.02
	PlotDNBR * PlotCC	4	282.79	8.75	0.01	8.75	0.01
	PlotDNBR	2	285.93	11.89	0	11.89	0
	Dbh	2	288.09	14.05	0	14.05	0
	SngDBHPlot	2	297.93	23.89	0	23.89	0
	PlotCC	2	298.08	24.03	0	24.04	0
	LogStumpHa	2	298.22	24.18	0	24.18	0
Patch	LogUnit	2	290.74	0	0.88	16.70	0
	LogUnit*LogPeriod	4	294.78	4.04	0.12	20.74	0
Landscape	LogArea1k + Burn1k	3	289.59	0	0.46	15.55	0
	LogArea500m + cc500m + dNBR500m + cc500m * dNBR500m	5	290.23	0.64	0.34	16.19	0
	LogArea500m + Burn500m	3	291.78	2.19	0.15	17.74	0
	LogArea1k + cc1k + dNBR1k + cc1k * dNBR1k	5	295.97	6.39	0.02	21.93	0
	LogArea1k	2	296.24	6.65	0.02	22.20	0
	LogArea500m	2	297.19	7.60	0.01	23.15	0

Table 2.5. Parameter estimates, standard errors, and odds ratios from the best supported *a priori* nest-site selection models predicting black-backed woodpecker nest occurrence. Odds ratios for the predictors LogUnit and LogPeriod represent the odds of a nest being selected in a control unit vs. treatment unit. Continuous variable odds ratios represent the odds of a nest site selected for every unit change (indicated in the "Unit Change" column). Confidence limits that do not contain 1 are indicated in bold.

					Odds Ratio		
Suite	Coefficient	Parameter Estimate	Standard Error	Unit Change	Odds Ratio Estimate	95% Profile Likelihood Confidence Limits	
Nest/Plot	(Intercept)	-0.836	1.034				
	Dbh	**-0.032**	**0.012**	**5**	**0.850**	**0.749**	**0.952**
	SnagHa	**0.013**	**0.003**	**50**	**1.918**	**1.424**	**2.649**
	SngDBHPlot	0.057	0.032	5	1.329	0.978	1.839
	PlotCC	-0.020	0.011	10%	0.815	0.649	1.014
	LogStumpHa	0.006	0.005	50	1.378	0.850	2.335
	(Intercept)	-1.034	1.016				
	Dbh	**-0.036**	**0.012**	**5**	**0.833**	**0.735**	**0.932**
	SnagHa	**0.008**	**0.003**	**50**	**1.520**	**1.091**	**2.162**
	SngDBHPlot	0.028	0.033	5	1.149	0.837	1.592
	PlotDNBR	0.001	0.001	100	1.143	0.934	1.404
	LogStumpHa	0.004	0.005	50	1.208	0.745	2.035
Patch	(Intercept)	0.674	0.170				
	LogUnit (C vs. T)	**-0.828**	**0.302**	**1**	**0.437**	**0.241**	**0.787**
	(Intercept)	0.654	0.242				
	LogUnit	-0.895	0.470	1	0.409	0.160	1.021
	LogPeriod	0.039	0.341	1	1.040	0.532	2.033
	LogUnit:LogPeriod	0.102	0.615	1	1.107	0.332	3.731
Landscape	(Intercept)	-0.723	0.384				
	LogArea1k	**0.004**	**0.002**	**10 ha**	**1.039**	**1.001**	**1.082**
	Burn1k	**0.025**	**0.009**	**10%**	**1.283**	**1.086**	**1.528**
	(Intercept)	7.135	3.248				
	LogArea500m	0.006	0.006	10%	1.066	0.952	1.201
	cc500m	**-0.121**	**0.051**	**10%**	**0.299**	**0.103**	**0.761**
	dNBR500m	-0.063	0.042	10%	0.532	0.226	1.171
	cc500m:dNBR500m	0.001	0.001	10%	1.012	1.000	1.025

Table 2.6. Model selection results for exploratory nest-site selection logistic regression models of black-backed woodpeckers in burned, mixed coniferous forests of south-central Oregon. Models are ranked from most supported to least supported based upon the scaled AIC$_c$ value (ΔAICc). K is the number of parameters in the model, AIC$_c$ is Akaike's Information Criterion for small sample size, w_i is the Akaike weight, and Likelihood corresponds to the relative support of the model given the data.

Model	k	AICc	ΔAICc	w_i	Likelihood
Dbh + SnagHa + PlotDNBR + Burn1k + cc1k + LogArea1k	7	264.61	0.00	0.68	1.00
Dbh + SnagHa + PlotDNBR + LogUnit + Burn1k + cc1k + LogArea1k	8	266.53	1.92	0.26	0.38
Dbh + SnagHa + PlotDNBR + LogUnit + Burn500m + LogArea500m	7	272.00	7.39	0.02	0.03
Dbh + SnagHa + PlotDNBR + Burn500m + LogArea500m	6	272.47	7.86	0.01	0.02
Dbh + SnagHa + PlotDNBR	4	272.59	7.98	0.01	0.02
LogUnit + Dbh + SnagHa + PlotDNBR	5	273.47	8.86	0.01	0.02
Burn1k + cc1k + LogArea1k	4	276.80	12.19	0.00	0.00
LogUnit + Burn1k + cc1k + LogArea1k	5	278.53	13.91	0.00	0.00

Table 2.7. Parameter estimates, standard errors, and odds ratios from the best supported exploratory nest-site selection models predicting black-backed woodpecker nest occurrence in burned, mixed coniferous forests of south-central Oregon, 2003-2006. Continuous variable odds ratios represent the odds of a nest site selected for every unit change (indicated in the "Unit Change" column).

				Odds Ratio		
Coefficient	Parameter Estimate	Standard Error	Unit Change	Odds Ratio Estimate	95% Profile Likelihood Confidence Limits	
(Intercept)	1.363	1.071				
Dbh	**-0.034**	**0.012**	**5**	**0.845**	**0.745**	**0.945**
SnagHa	**0.008**	**0.003**	**50**	**1.488**	**1.075**	**2.100**
PlotDNBR	0.000	0.001	100	1.005	0.808	1.248
Burn1k	**0.037**	**0.011**	**10%**	**1.454**	**1.169**	**1.832**
cc1k	**-0.041**	**0.016**	**10%**	**0.665**	**0.475**	**0.910**
LogArea1k	**0.004**	**0.002**	**10 ha**	**1.045**	**1.003**	**1.092**

Nest Survival

Goodness-of-fit assessments for the best supported and global models within each suite indicated adequate fit in all cases (Sturdivant et al. 2007). Models investigating possible observer or nest viewing effects did not receive support compared to the null, constant survival model.

The null model of nest survival assumes constant survival and provides an overall estimate comparable to the Mayfield method. Estimated daily nest survival based upon this model was 0.9940 ± 0.2006 SE (95% CL = 0.9911, 0.9960). Exponentiating daily survival rate by the average number of days in the full nesting period yields an overall estimate of nest success $0.9940^{40} = 0.7855$ (95% CL = 0.6996, 0.8495). While this estimate is useful for comparisons with previous black-backed woodpecker work, current methods allow for more rigorous assessment of multiple habitat and time-varying covariates in relation to DSR. For our data set, models containing a habitat and temporal predictor received more support than the null model of constant nest survival.

Models containing logging covariates at the plot and landscape scales were not supported within their respective suites (Table 2.9), however we were unable to successfully model the effect of logging at the patch scale due to a lack of nest failures within the treatment units in the pre-logging period. As an alternative, Table 2.9 presents Mayfield-equivalent daily nest survival estimates and their associated confidence limits taken from nests grouped by unit type and logging period. Although daily nest survival appears to be higher in the treatment units, the drop in DSR from pre to post-logging periods in the logged units was double the change observed in the unlogged units over the same time frame. The larger decrease in DSR for nests in logged units is biologically irrelevant, however, as it equates to <0.001 percentage change in overall nest survival.

With the exception of average snag diameter at the nest plot scale, models containing habitat covariates at any spatial scale received little or no support from our data (Table 2.9). Average diameter of plot snags (SngDBHPlot) ranked slightly above the null model, but was within two ΔAIC_c units, indicating the constant survival model was also well supported (Burnham and Anderson 2002). Contrary to our hypothesis, the parameter estimate for the SngDBHPlot covariate was negative (-0.068 ± 0.035 SE), suggesting that daily nest survival decreased as diameters of snags on the plot became larger. The 95% confidence interval for SngDBHPlot did slightly overlap zero (-0.135, 0.00009) though, implying lack of precision around this estimate. The constant nest survival model ranked above all other habitat models and the confidence limits for all other habitat coefficients included zero.

Of our *a priori* models, the temporal effect of date (JDate) was the most parsimonious in explaining daily survival rate. The coefficient estimate for Julian date was negative ($\hat{\beta}_{\mathrm{JDate}}$ = -0.051 ± 0.015 SE; 95% CL = -0.081, -0.021), indicating that later dates through the nesting season coincided with decreasing DSR (Table 2.12). The relationship between estimated daily nest survival rate and date is demonstrated in Figure 2.7. Using this model, each elapsed day increases the odds of nest failure by 0.05. Thus, nests initiated on April 30th would have an overall nest success of 90.5% (95% CL = 84.4%, 96.7%), whereas nests initiated on May 20th and June 9th had success rates of 76.1% (95% CL = 68.4%, 83.9%) and 47.5% (95% CL = 22.5%, 72.5%), respectively. Few nests, however, initiated during the month of June (Figure 2.8). The quadratic form of Julian date contributed very little additional explanatory power (ΔAICc = 1.991). The model containing average daily temperature also received more support than the null model, and its coefficient estimate was significantly negative ($\hat{\beta}_{\text{AveTemp}}$ = -0.120; 95% CL = -0.208, -0.032), however it did not perform as well as Julian date (ΔAICc = 3.433).

We examined Julian date, average daily temperature, and average snag diameter on the plot scale in exploratory analysis (Table 2.10). Model selection procedures found the model containing date and average snag diameter to receive the most support, although there was some model selection uncertainty. A second competing model (ΔAICc = 0.864) incorporating an additive effect of average daily temperature was ranked near the top model. Closer investigation revealed average daily temperature was correlated with Julian date (Pearson Corr. = 0.414, $p < 0.0001$) and confidence limits for daily average temperature's coefficient shifted to bound zero (95% CL = -0.163, 0.039) in this second competing model. This evidence, in combination with model selection results from *a priori* and exploratory analysis, suggests that Julian date and average daily temperature were explaining much of the same variation in the data.

Comparison of the most supported *a priori* and exploratory models showed the exploratory model containing a temporal effect of date and plot-scale average snag diameter to be the best performing model of those assessed (Table 2.11). The logistic equation for this model was:

$$\text{logit(DSR)} = 15.745 - 0.051\ (\text{Julian Date}) - 0.0742\ (\text{SngDBHPlot})$$

According to this model, increasing Julian date and plot average snag diameter resulted in decreasing daily nest survival of black-backed woodpeckers (Figure 2.9).

Table 2.8. Model selection results for *a priori* daily survival rate models of black-backed woodpeckers in burned, mixed coniferous forests of south-central Oregon. Within each suite, models are ranked from most supported to least supported based upon the scaled AIC_c value ($\Delta AIC_{c\ suite}$). K is the number of parameters in the model, AIC_c is Akaike's Information Criterion for small sample size, w_i is the Akaike weight, and $\Delta AIC_{c\ set}$ refers to the scaled AIC_c value for all models within the table.

Suite	Model	k	AIC_c	$\Delta AIC_{c\ suite}$	$w_{i\ suite}$	$\Delta AIC_{c\ set}$	$w_{i\ set}$
Nest	Null	1	243.21	0	0.66	8.67	0.01
	NestHt	2	244.51	1.30	0.34	9.96	0
Plot	SngDBHplot	2	241.73	0	0.42	7.18	0.01
	Null	1	243.21	1.49	0.20	8.67	0.01
	PlotDNBR	2	244.92	3.19	0.09	10.37	0
	LogStumpHa	2	245.17	3.44	0.08	10.63	0
	SnagDensity	2	245.17	3.45	0.08	10.63	0
	PlotCC	2	245.19	3.46	0.07	10.65	0
	SnagHa+SngDBHPlot+ PlotCC+LogStumpHa	5	247.25	5.52	0.03	12.71	0
	SnagHa+SngDBHPlot+ PlotDNBR+LogStumpHa	5	247.37	5.64	0.03	12.82	0
	PlotDNBR*PlotCC	4	248.49	6.76	0.01	13.95	0
	Global	6	249.00	7.28	0.01	14.46	0
Landscape	Null	1	243.21	0	0.43	8.67	0.01
	LogArea1k	2	244.59	1.38	0.21	8.05	0.01
	LogArea500m	2	245.16	1.95	0.16	7.18	0.01
	LogArea1k + Burn1k	3	246.34	3.12	0.09	4.02	0.06
	LogArea500m + Burn500m	3	246.98	3.77	0.07	3.77	0.07
	LogArea500m + CC500m*dNBR500m	5	248.56	5.35	0.03	4.55	0.05
	LogArea1k + CC1k*dNBR1k	5	249.82	6.61	0.02	5.45	0.03
	Global	9	255.05	11.84	0	9.97	0
Abiotic	JDate	2	234.54	0	0.62	0	0.45
	$JDate^2$	3	236.54	1.99	0.23	1.99	0.17
	AveTemp	2	237.98	3.43	0.11	3.43	0.08
	Global	8	242.32	7.77	0.01	7.77	0.01
	Null	1	243.21	8.67	0.01	8.67	0.01
	YrPostfire	2	244.01	9.46	0.01	9.46	0
	CalYear	4	244.36	9.82	0.01	9.82	0
	Age	2	245.08	10.54	0	10.54	0

Figure 2.7. Estimated black-backed woodpecker daily nest survival rate (DSR) versus date; taken from the best-supported *a priori* model. Dashed lines signify 95% confidence intervals.

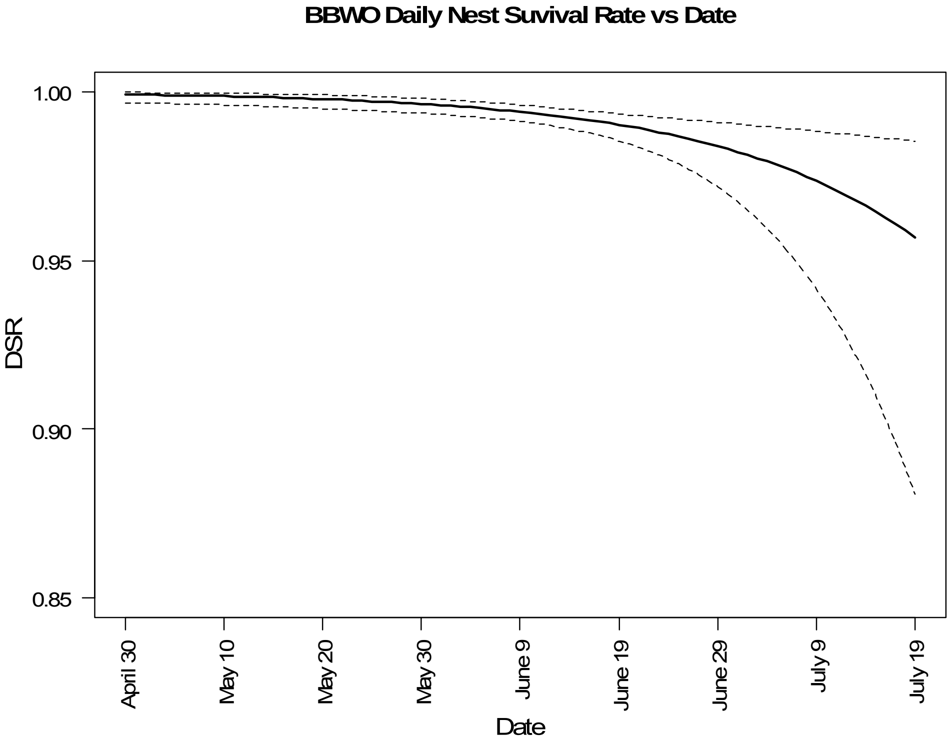


Figure 2.8. Frequency distribution of black-backed woodpecker nest initiation dates in burned, mixed coniferous forest, south-central Oregon, USA, 2003-2006.

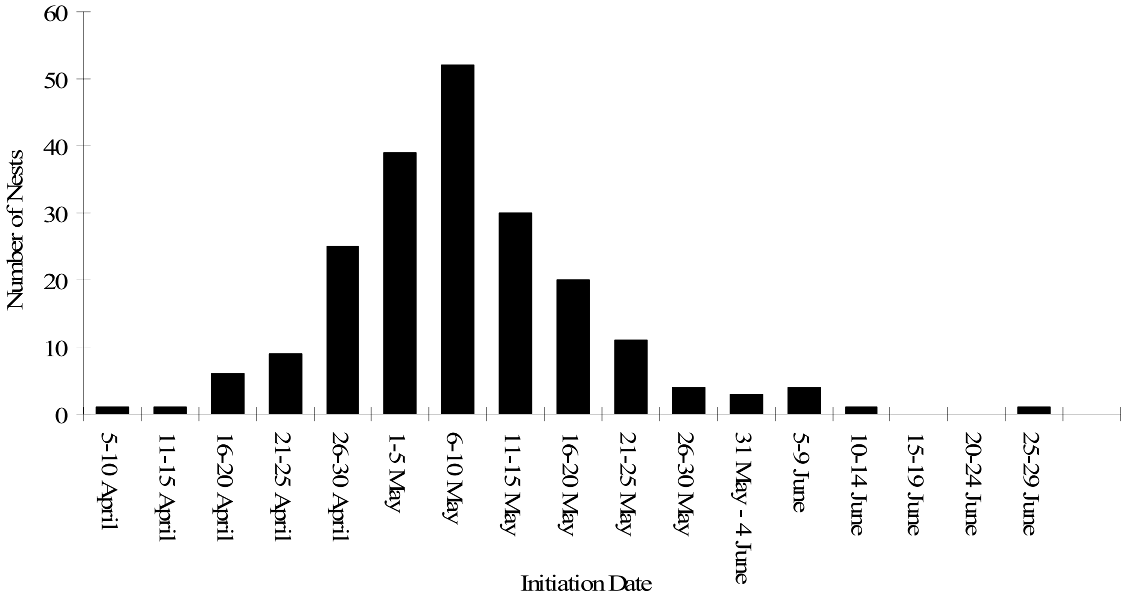


Table 2.9. Mayfield-equivalent daily nest survival estimates and their 95% confidence limits for black-backed woodpecker nests grouped by logging period and treatment type. Change in DSR quantifies the absolute change in daily survival estimates from pre-logging to post-logging years in control and treatment units, respectively.

	Control Units	Treatment Units
Pre-logging Period	0.9943 (0.9886 - 0.9971)	1.0 (1.0)
Post-logging Period	0.9916 (0.9855 - 0.9951)	0.9947 (0.9859 - 0.9980)
Change in DSR	-0.002715	-0.00533

Table 2.10. Exploratory models and model selection results from *post hoc* predictions of the response of black-backed woodpecker nest daily survival rate (DSR) to covariates within burned, mixed coniferous forests of south-central Oregon, USA. A constant survival model (Null) was included for comparison.

Model	k	AICc	ΔAICc	w_i	Likelihood
JDate + SngDBHPlot	3	232.739	0	0.451	1
JDate + AveTemp + SngDBHPlot	4	233.603	0.864	0.293	0.649
JDate + AveTemp	3	235.097	2.358	0.139	0.308
JDate*AveTemp	4	236.844	4.104	0.058	0.128
AveTemp + SngDBHPlot	3	236.897	4.158	0.056	0.125
Null	1	243.212	10.473	0.002	0.005

Table 2.11. Model selection results for combined *a priori* and exploratory nest daily survival rate models of black-backed woodpeckers in burned, mixed coniferous forests of south-central Oregon. Models are ranked from most supported to least supported based upon the scaled AIC_c value (ΔAICc). Prediction is whether the model was *a priori* or exploratory (exp), K is the number of parameters in the model, AIC_c is Akaike's Information Criterion for small sample size, w_i is the Akaike weight, and Likelihood corresponds to the relative support of the model given the data.

Prediction	Model	k	AICc	ΔAICc	w_i	Likelihood
exp	JDate + SngDBHPlot	3	232.739	0	0.43	1
exp	JDate + AveTemp + SngDBHPlot	4	233.603	0.864	0.279	0.649
a priori	JDate	2	234.544	1.804	0.175	0.406
exp	JDate*AveTemp	4	236.844	4.104	0.055	0.128
exp	AveTemp + SngDBHPlot	3	236.897	4.158	0.054	0.125
a priori	SngDBHPlot	2	241.727	8.988	0.005	0.011
n/a	Null	1	243.212	10.473	0.002	0.005

Figure 2.9. Estimated black-backed woodpecker daily nest survival rate (DSR) versus Julian date at small, median, and large average snag diameter sizes within nest plots; taken from the best-supported exploratory model. Dashed lines signify 95% confidence intervals.

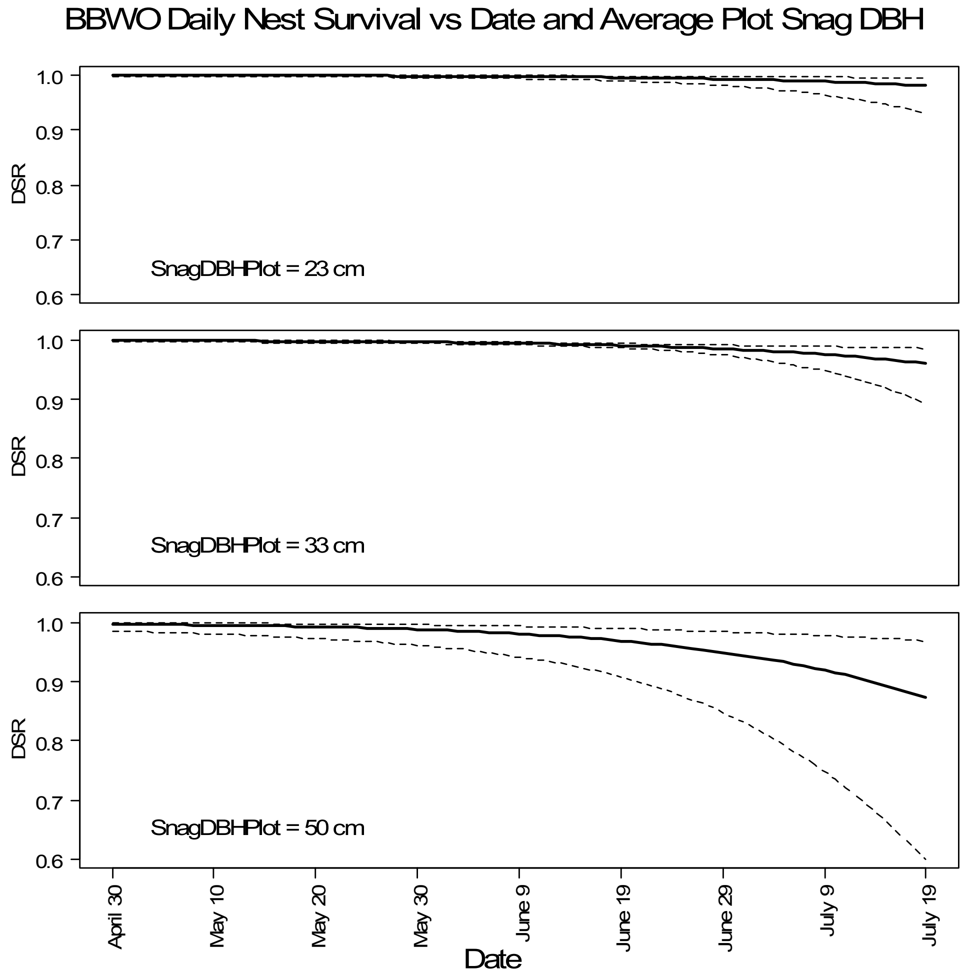


Table 2.12. Parameter Estimates for the best supported *a priori* and exploratory models of daily survival rate for black-backed woodpecker nests in burned, mixed coniferous forests of south-central Oregon.

Model	Parameter	Estimate	SE	95% confidence limits lower	upper
a priori	intercept	13.1789	2.514	8.2457	18.1120
	Julian date	-0.05085	0.015	-0.08104	-0.02067
Exploratory	intercept	15.7449	2.7629	10.3243	21.1654
	Julian date	-0.05051	0.01477	-0.07949	-0.02153
	SngDBHPlot	-0.07417	0.03639	-0.1456	-0.00277

Discussion

Black-backed woodpeckers nested in high numbers and with high nesting success in early postfire forests of south-central Oregon. Even among cavity nesters, which are known to have above-average nest survival, black-backed woodpeckers in this study experienced comparatively higher rates of success (Martin and Li 1992). Nest densities were among the highest ever observed for this species. Few studies have investigated nest survival of cavity-nesting birds, particularly since the advent of more advanced, less constraining nest survival modeling techniques (but see Fisher and Wiebe 2006, Mahon and Martin 2006, Etterson et al. 2007, Saab et al. 2007). Studies of woodpeckers have also been limited by low sample sizes due to the large home ranges they often occupy. The inability of past statistical techniques to model multiple continuous and time-varying covariates, combined with small samples inherent to woodpecker investigations, left previous researchers with few options in examining the influence of habitat and abiotic variables on DSR. This unique study presents results from a nest-site selection and nest survival modeling effort incorporating multiple spatial scales on a relatively large sample size of black-backed woodpecker nests. Using these newer techniques, we found an abiotic and a fine-scale habitat covariate to be important predictors of nesting success, whereas a number of different fine and landscape-scale variables explained nest-site selection.

The factors affecting nest-site selection were not the same as those influencing nest survival, suggesting that black-backed woodpecker breeding site choice was not adaptive or under strong selection pressure through nest failure (Clark and Shutler 1999) in burned forests of Oregon. Black-backed woodpecker nest-site selection was determined by habitat features at both fine and coarse spatial scales while nest survival was primarily influenced by date. However, low variation in habitat features and few black-backed woodpecker nest failures reduced our ability to detect vegetation characteristics affecting nest survival. As nest survival of woodpeckers was quite high, other demographic rates influencing nest site choice (e.g. juvenile survival) may be under more intense natural selection. Habitat selection of black-backed woodpeckers occurred at multiple spatial scales and consequences on other fitness components may be scale-dependent (Chalfoun and Martin 2007).

Similar to past studies, we found black-backed woodpeckers selected areas of high snag densities in close proximity to its nest (Kimmey 1955, Harris 1982, Hitchcox 1996, Bull et al. 1997, Bonnot 2006, Hutto and Gallo 2006, Russell et al. 2007, Vierling et al. 2008, Saab et al. 2009). Because snags play roles as both food and nesting resources in black-backed woodpecker habitat use, it remains difficult to partition out the exact cue or cues signaling it to nest in a particular location. Black-backed nest-site selection, especially its selection of dense snag areas, may be driven primarily by prey abundance rather than nest predation or nest tree limitations (Powell 2000, Bonnot 2006). The results of our nest survival and nest-site selection analyses would partially support this hypothesis. Nest survival models containing habitat variables did not perform well, thus providing evidence that nest site choice was not being shaped by vegetation differences between successful and unsuccessful nests. Nest densities were generally higher in units containing higher snag densities, but nest survival was comparable in control and treatment units. In an ideal free distribution pattern, woodpeckers choosing sites based upon relative snag densities could explain these nesting density differences, with little resulting variation in fitness (Fretwell and Lucas 1970, Clark and Shutler 1999). Nest survival is only one component of fitness and other demographic parameters (e.g. adult or juvenile survival) affected by surrounding habitat characteristics may be influencing patterns in breeding site selection.

Contrary to our hypotheses, variables relating salvage logging to nest-site selection and DSR received little support. Generally, treatment units had higher nest survival than control units, both before and after salvage harvest (although both had very high survival). Similarly, birds appeared to prefer control units, both before and after logging. Differences in snag abundance likely played an important role in shaping this difference in preference. Indeed, pre-harvest densities of large diameter (≥23cm dbh) snags in control units averaged 101 ±10.17 SE versus 73 ±13.01 (SE) snags per ha in treatment units. While salvage logging occurred in all treatment units, the severity and spatial extent of logging varied from unit to unit. "Leave" snags were marked within treatment units, but loggers were free to choose which unmarked snags they wished to harvest or ignore. For instance, most lodgepole pine was left unharvested due to its high postfire decomposition rate, smaller diameters, and low commercial value. Examination of snag densities at non-nest plots within treatment units showed only a slight reduction in snags after logging took place (Appendix B). Thus, all post-logging units retained snag densities greater than that originally prescribed and may have still served as quality black-backed habitat. Additionally, average diameter of non-nest plot snags located in treatment units was not significantly reduced after logging (Appendix B). The importance of plot-scale snag abundance in our nest-site selection models and the lower nest densities in treatment units suggests that birds may be sensitive to salvage logging activities. While this is indirect evidence supporting our hypothesis, it is an important consideration for managers attempting to conserve nesting habitat while still permitting salvage logging on burned landscapes.

Although past studies have identified a number of habitat variables at the plot and landscape scales to be strong predictors of black-backed woodpecker nest occurrence, we found little evidence that these same factors influenced nest survival. Few of the habitat covariates we considered in this study received support in our nest survival models. The only habitat covariate to demonstrate a significant relationship with DSR was the average diameter of snags within the plot, and this influence was negative; opposite of our prediction and contrary to the literature regarding nest-site selection (Johnson et al. 2000, Saab et al. 2002, Hutto and Gallo 2006, Saab et al. 2009). This discrepancy could be explained in a number of ways. Larger snags and associated downed wood may provide habitat for mammalian nest predators. Similarly, secondary cavity nesters could be attracted to these areas for increased foraging/nesting opportunities and consequently lower black-backed woodpecker nest survival through usurpation activity. It is important to note that the snag diameter measurements creating this covariate were only taken from snags ≥23 cm dbh, thus this covariate does not represent all of the snags found within a nest plot and the form of this relationship could be different if smaller snags were considered. Size data from smaller (<23 cm dbh) snags were not included because individual diameters were not recorded and these snags were sampled at a smaller spatial extent within the vegetation plot (Figure 2.2).

Diameter of the nest tree was an important factor in nest-site selection; however, contrary to previous research, black-backed woodpeckers on average nested in smaller diameter snags than random, non-nest snags. This can be partially accounted for by the pattern we observed in nest tree species' selection. Lodgepole pines were preferentially selected as nest trees in the earlier postfire years, with a gradual shift over to ponderosa pine by year four postfire (Figure 2.4). First, lodgepole pines rarely reach diameters comparable to ponderosa pine and other potential nest tree species. Additionally, burned lodgepole trees decay more quickly than other trees present in the study area and would have been easier to excavate (Kimmey 1955, Bull et al. 1997) . Lastly, a lodgepole pine vegetation component was virtually absent from the previous studies. Several studies have found black-backed woodpeckers to nest at the smaller range of tree diameters compared to other primary cavity nesting birds (Caton 1996, Hoffman 1997, Saab et al. 2002, Hutto and Gallo 2006, Saab et al. 2009). Potential nest snags appeared to be quite abundant in our study units, both at the smaller and larger spatial scales, although we did not examine a number of specific nest tree characteristics that could influence a single tree's selection (i.e. heart rot, snag hardness, bark retention, etc.).

While models containing snag density at the plot scale were strongly supported, our models using direct measures of logging and treatment effects did not meet our predictions. Odds ratios of the LogUnit covariate indicated that black-backs were significantly more likely to nest in the control units, even during the two years prior to logging of the treatment units. Because the highest-quality units (in terms of snag densities) were set-aside as controls at the beginning of the study, this result is not surprising. Hutto and Gallo (2006) attained similar results while examining black-backed woodpecker nest densities in salvage logged and control units that differed in pre-harvest snag abundance. Initial differences in habitat quality could explain the significance of the LogUnit covariate and the difficulty of detecting a logging treatment effect.

Amount of logged area (in hectares) at the 1km landscape scale showed a weak relationship with nest-site selection, as the lower confidence interval was close to one. Opposite of our prediction, the odds ratio estimate for this covariate was positive. This implies that increasing logged area within a one kilometer radius results in greater odds of black-backed nest occurrence. This result runs counter to all published literature regarding black-backed woodpeckers and salvage logging. Perhaps habitat quality in our logged study units was still high enough to negate habitat assessment or avoidance at the broader one kilometer spatial scale. An alternate possibility is that salvage logging outside of study units was not severe enough to trigger any avoidance cues, or, conversely, it was more intense in the landscape surrounding our treatment plots and birds were pushed into logged plots that contained reduced, but still higher, snag densities than surrounding habitat. For example, Forest Service personnel enacted "fuels reduction" activities in many previously salvaged logged areas surrounding our study units, resulting in every residual snag under 20cm dbh being turned into slash except those marked as leave (25 per ha).

Like Russell et. al (2007) and Saab et. al (2002, 2007, 2009), we found prefire canopy closure at the landscape (1 km) scale to be an important predictor of nest occurrence. Unlike those studies, however, we found the relationship to be a negative one rather than positive – as proportion of med-high prefire canopy closure increased, the odds of a nest decreased. A number of factors could account for this discrepancy. First, as mentioned earlier, our numerous, small study units were not made up of as large contiguous burned area found in other studies, thus more of our landscape scale analysis radii included habitat features not standardized during the study design (especially burn patchiness). Large amounts of med-high prefire crown closure may exist around the outside of the study area, but much of it may be unburned. Green, unburned forest could serve as source habitat for nest predators and deter woodpeckers from nesting near it (Rusch and Reeder 1978, Saab et al. 2004, Fisher and Wilkinson 2005). Second, a number of our control units (with higher nest densities; see Figure 2.3) had meadows, clearings, or old clearcuts adjoining them that would have been classified as little or no canopy closure. Again, if habitat quality was high, birds may chose breeding sites at a different spatial scale as in other habitats. Compared to most previous studies (Hitchcox 1996, Haggard and Gaines 2001, Hutto and Gallo 2006, Saab et al. 2007, Vierling et al. 2008), our control units had considerably higher black-backed nest densities, suggesting that habitat quality was quite high and could support more individuals in a smaller area. Black-backed woodpecker nest-site selection may have been operating at a finer spatial scale than in previous studies. Abundance alone does not always indicate habitat quality, though, and other demographic parameters should be examined to determine true quality (Van Horne 1983, Vickery et al. 1992, Wheatley et al. 2002, Bock and Jones 2004). In this study, high nest survival was found in areas of both higher and lower black-backed woodpecker nest densities.

A landscape-level (1 km) covariate that demonstrated a strong relationship with the odds of nest occurrence was the area proportion of overlapping med-high prefire crown closure and moderate-high burn severity. By combining these two remotely-sensed covariates, these data suggest we more accurately characterized areas with high snag densities. These same areas may also reflect higher food abundance and reduced predation through a temporarily limited predator community (Saab and Vierling 2001, Hoyt and Hannon 2002, Saab et al. 2004). Rather than using prefire crown closure alone as a surrogate for postfire snag density, we were able to delineate moderate-high pre-fire crown closure areas that also experienced fire severe enough to create snags. It is important to note, however, that these type of data collected by Landsat TM satellites are in 30m x 30m pixels and may be too coarse to pinpoint exact nesting locations (but see Russell et al. 2007, Saab et al. 2009). Despite fine-scale limitations, combining these readily available remotely-sensed data may be a useful tool for managers wishing to quickly identify potential high-snag postfire habitats for conservation and planning purposes (Russell et al. 2007).

Nest survival could have remained unaffected by salvage logging because harvest activities reduced nest predator abundance, however, the response of small mammals to time since wildfire and postfire salvage logging is not well understood and may reflect complex, species-specific habitat needs (Fisher and Wilkinson 2005, Converse et al. 2006). Similar to previous studies, sample sizes of nests in logged units were considerably lower than those in unlogged areas, thus hindering our ability to detect significant logging effects (Caton 1996, Hutto and Gallo 2006, Saab et al. 2007). Finally, black-backed woodpeckers may respond negatively to postfire salvage logging through other demographic parameters, such as number of fledglings produced, adult and juvenile survival, etc. Future research should be directed towards these areas of study.

Nest survival of black-backed woodpeckers in south-central Oregon was comparable to rates observed in burned ponderosa pine forests of central Idaho (Saab et al. 2007) and higher than those found in beetle killed forests (Goggans et al. 1989, Bonnot et al. 2008). DSR estimates for black-backed woodpeckers in unburned forests are non-existent, probably due to extremely low densities of nesting birds in this habitat type. Hutto (1995), Murphy and Lehnhausen (1998), and others have hypothesized that recently burned forests likely serve as population sources for black-backed woodpeckers, whereas green forests potentially function as sinks. While we did not measure nest predators directly, nest predation was a rare occurrence, thus backing up the idea that stand-replacement fire reduces ground predators and increases nest success in the short-term (Saab and Vierling 2001, Saab et al. 2004, Saab et al. 2007). The high nest densities and reproductive success achieved by black-backed woodpeckers in our study supports previous research suggesting recent burns to be high-quality breeding habitat.

The abiotic effect of date was the best supported single predictor of black-backed woodpecker nest survival, with DSR decreasing as the nesting season progressed. While we predicted a quadratic, nonlinear effect of date similar to Fisher and Wiebe (2006), the quadratic model did not receive additional support compared to the linear form (Δ AIC$_c$ = 1.99). Adding a single predictor with absolutely no explanatory power into a model would change the model exactly two Δ AIC$_c$ points. Other recent cavity-nester studies have demonstrated that temporal factors influenced nest success (Newlon 2005, Bonnot 2006, Fisher and Wiebe 2006, Mahon and Martin 2006, Saab et al. 2007). For instance, Bonnot et al. (2008) found the effects of date and nest age to be the strongest predictors of black-backed nest survival in beetle-killed forests within the Black Hills, SD.

Comparable to our findings, increasing dates resulted in lower DSR, however Bonnot et al. (2008) showed this effect was combined with increasing survival as nests aged. We found no such relationship with nest age, despite having a much larger sample size. Date of nest initiation can be a significant predictor of nest survival in woodpeckers (Newlon 2005, Fisher and Wiebe 2006), however we chose not to use this covariate because a large percentage of nests initiating prior to the start of our nest monitoring effort (Figure 2.9). By using Julian date rather than initiation date, we maintained inference over the time period when nest survival data were actually collected.

The two primary causes of nest failure we observed were predation and usurpation, both of which could be influenced by time of year. Later calendar dates may correspond with increased nest predation pressure through elevated predator abundance or seasonal prey switching (Grant et al. 2005, Bonnot 2006, Fisher and Wiebe 2006). As black-backed woodpeckers nested relatively early compared to most secondary cavity nesters in our study area, increasing calendar date likely intensified resource competition for cavities and ensuing usurpation pressure. Indeed, we often observed secondary cavity nesters (i.e. mountain bluebirds) initiate nesting within woodpecker cavities immediately after they were vacated. In 2005 and 2006, 85% and 87% of black-backed woodpecker cavities still intact from the previous breeding season showed evidence of use by other vertebrates. These data suggest that competition/preference for black-backed woodpecker cavities was high and increasing breeding season overlap with other cavity nesters later in the year likely resulted in elevated usurpation rates. Whereas Fisher and Wiebe (2006) observed a seasonal “pulse” of northern flicker nest failures caused by European starlings, we found no such pattern. Starlings were largely absent from our study units and do not exhibit as an extensive breeding timing overlap with black-backed woodpeckers. Through predation and usurpation pressures, black-backed woodpeckers face selection to nest earlier in the season, however very early nesters likely encounter temperature and food-related limitations that could also cause nest failure. Because we were not surveying or nest monitoring at the time these earliest egg-laying occurred, we can only speculate on the early season selective pressures experienced by nesting black-backed woodpeckers.

Despite our relatively large sample size of nests for this species, the lack of nest failures and low variability in habitat covariates made identification of strong DSR predictors unlikely. These data suggest that black-backed woodpeckers in early postfire forests are able to select "safe" nest sites in a habitat that already lacks many common nest predators. Selecting study units representing "ideal" black-backed woodpecker habitat likely contributed to low within and among-habitat variability and resulting high nest survival. Black-backed woodpeckers nesting in burn peripheries or adjacent unburned forest may experience lower DSR, however this study focused on black-backed woodpecker nest survival and salvage logging effects in the best habitat available.

Avian habitat selection is a complex process that likely incorporates hierarchical assessment of habitat quality at multiple spatial scales (Hutto 1985, Jones 2001). Similar to past studies, we found some evidence that black-backed woodpecker nest-site selection is influenced by habitat features at different spatial scales. Like nest survival, our ability to detect strong habitat preferences was hindered by the lack of broad variation in habitat within study units. The most significant habitat variability, the difference in pre-logging snag density between control and treatment units, likely served as an obstacle in elucidating the relationship between salvage logging and nest-site selection. Varying logging intensities within and between treatment units also may have interfered with our ability to reveal a logging effect. Future research should focus on standardizing habitat features between replicates and treatment-control pairs, as well as logging intensity, when designing and carrying out field experiments related to the ecological effects of postfire salvage logging.

Management Implications

The high nesting densities in our study units and results from nest-site selection modeling suggests that remotely-sensed pre-fire crown closure and fire severity data can be effective tools for identifying areas that attract breeding black-backed woodpeckers. These remotely-sensed data were used to select the best habitat available to black-backed woodpeckers within the burn perimeters. Based upon previous research, our study units were hypothesized to be high-quality and highly preferred by black-backed woodpeckers. Salvage logging effects on black-backed woodpeckers may vary in habitats of different suitability. Thus, inference from this study should only be extended to high crown closure, mixed-conifer forests after stand-replacement fire.

Black-backed woodpeckers showed changing preferences for nest snag characteristics over time, thus retaining the full range of snag species and diameters should be a component of maintaining black-backed nest habitat. Snag density at the plot scale (0.4 hectares) was the most important predictor of nest-site occurrence, with increasing snag numbers favoring black-backs. Our results imply that management activities severely reducing the number of large (≥23 cm dbh) snags will decrease the odds of a black-backed woodpecker nest. Preserving clumps of snags in salvage-harvested areas may attract nesting birds, as long as residual snag densities on the larger landscape provide adequate food supplies for adults and nestlings. As harvest intensity was fairly light in this study, the level of logging triggering black-backed nest avoidance (if such a threshold exists) remains unknown and requires further study.

Managers wishing to conserve post-wildfire nesting habitat for black-backed woodpeckers should make use of tools that identify snags on the landscape. Few techniques exist that reliably detect or quantify snags at a landscape scale. Our data suggest that delineating areas of overlapping med-high prefire crown closure and moderate-high burn severity (ΔNBR) could be an effective surrogate for outlining high-density snag locations. We recommend this method be used during future identification of high-quality postfire habitat for black-backed woodpeckers.

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APPENDICES

APPENDIX A

DESCRIPTION OF VARIABLES USED IN MODELS

Appendix A: Description of variables used in nest survival and nest-site selection modeling. Variable is the variable name in the model, Type indicates whether it was a continuous or categorical predictor, and Analysis describes the variable's use in nest survival analysis (survival), nest-site selection analysis (NSS), or both.

Model Suite	Variable	Type	Analysis	Description
Nest/Plot	NestHt	Continuous	Survival	Height (m) of the nest cavity to the ground
	Dbh	Continuous	NSS	Diameter at breast height (1.37 m) of the nest tree or snag
	SnagHa	Continuous	Both	Number of snags ≥23 cm dbh per hectare
	PlotDNBR	Continuous	Both	ΔNBR of the generalized 30x30 m pixel containing the nest or non-nest point
	PlotCC	Continuous	Both	Prefire crown closure value of the generalized 30x30 m pixel containing the nest or non-nest point
	SngDBHPlot	Continuous	Both	Average dbh of all snags ≥23 cm dbh located within the 0.4 ha sampling plot
	LogStumpHa	Continuous	Both	Number of salvage-logged stumps ≥15 cm at the cut (approximately 20-40 cm in height) per hectare
Patch	LogUnit	Categorical	Both	Nest or non-nest point was associated with a logged unit or not (0=unlogged, 1=logged)
	LogPer	Categorical	Both	Indicates the two-year pre- and post-logging time periods (0=pre-logging 2003-2004, 1=post-logging 2005-2006)
Landscape	LogArea500m	Continuous	Both	Amount of postfire salvage-logged area (in hectares) within a 500 m radius of the nest or non-nest point
	cc500m	Continuous	Both	Percentage of area containing med-high prefire crown closure (40-100%) within a 500 m radius of the nest or non-nest point
	dNBR500m	Continuous	Both	Percentage of area containing moderate-high ΔNBR (270-1200) within a 500 m radius of the nest or non-nest point

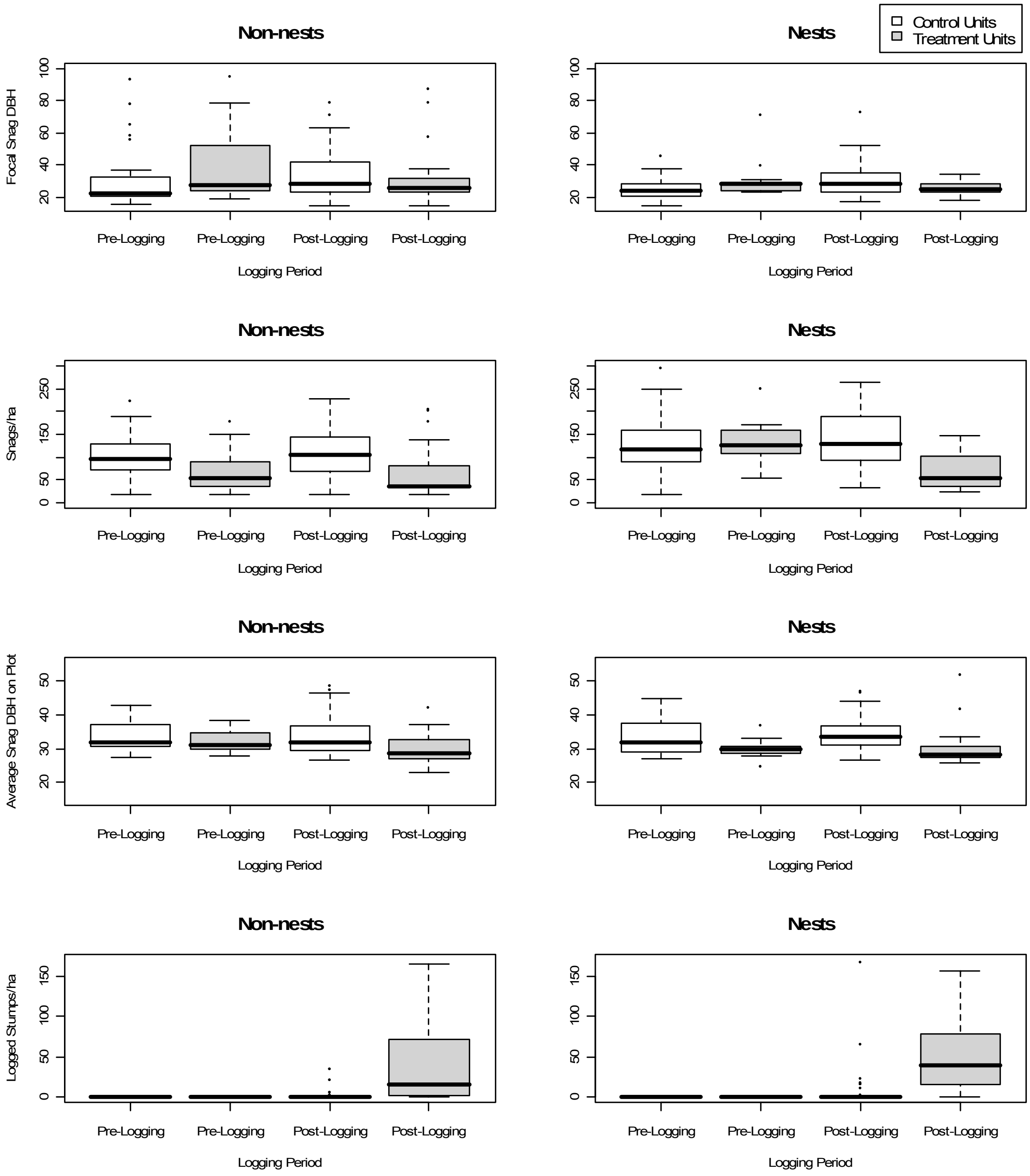
Appendix A (continued): Description of variables used in nest survival and nest-site selection modeling. Variable is the variable name in the model, Type indicates whether it was a continuous or categorical predictor, and Analysis describes the variable's use in nest survival analysis (survival), nest-site selection analysis (NSS), or both.

Model Suite	Variable	Type	Analysis	Description
Landscape (cont.)	Burn500m	Continuous	Both	Percentage of area containing overlapping med-high prefire crown closure and moderate-high ΔNBR within a 500 m radius of the nest or non-nest point
	LogArea1k	Continuous	Both	Amount of postfire salvage-logged area (in hectares) within a 1 km radius of the nest or non-nest point
	cc1k	Continuous	Both	Percentage of area containing med-high prefire crown closure (40-100%) within a 1 km radius of the nest or non-nest point
	dNBR1k	Continuous	Both	Percentage of area containing moderate-high ΔNBR (270-1200) within a 1 km radius of the nest or non-nest point
	Burn1k	Continuous	Both	Percentage of area containing overlapping med-high prefire crown closure and moderate-high ΔNBR within a 1 km radius of the nest or non-nest point
Abiotic	AveTemp	Continuous	Survival	Average daily temperature averaged over all the days in the respective monitoring interval, taken from Silver Creek snotel site located in one study unit
	YrPostfire	Continuous	Survival	Year after wildfire (1-4)
	Year	Categorical	Survival	2003 is used as the reference category. Dummy variables for 2004, 2005, and 2006
	Jdate	Continuous	Survival	Julian date of nest visit
	Age	Continuous	Survival	Age of nest from first first day of egg laying

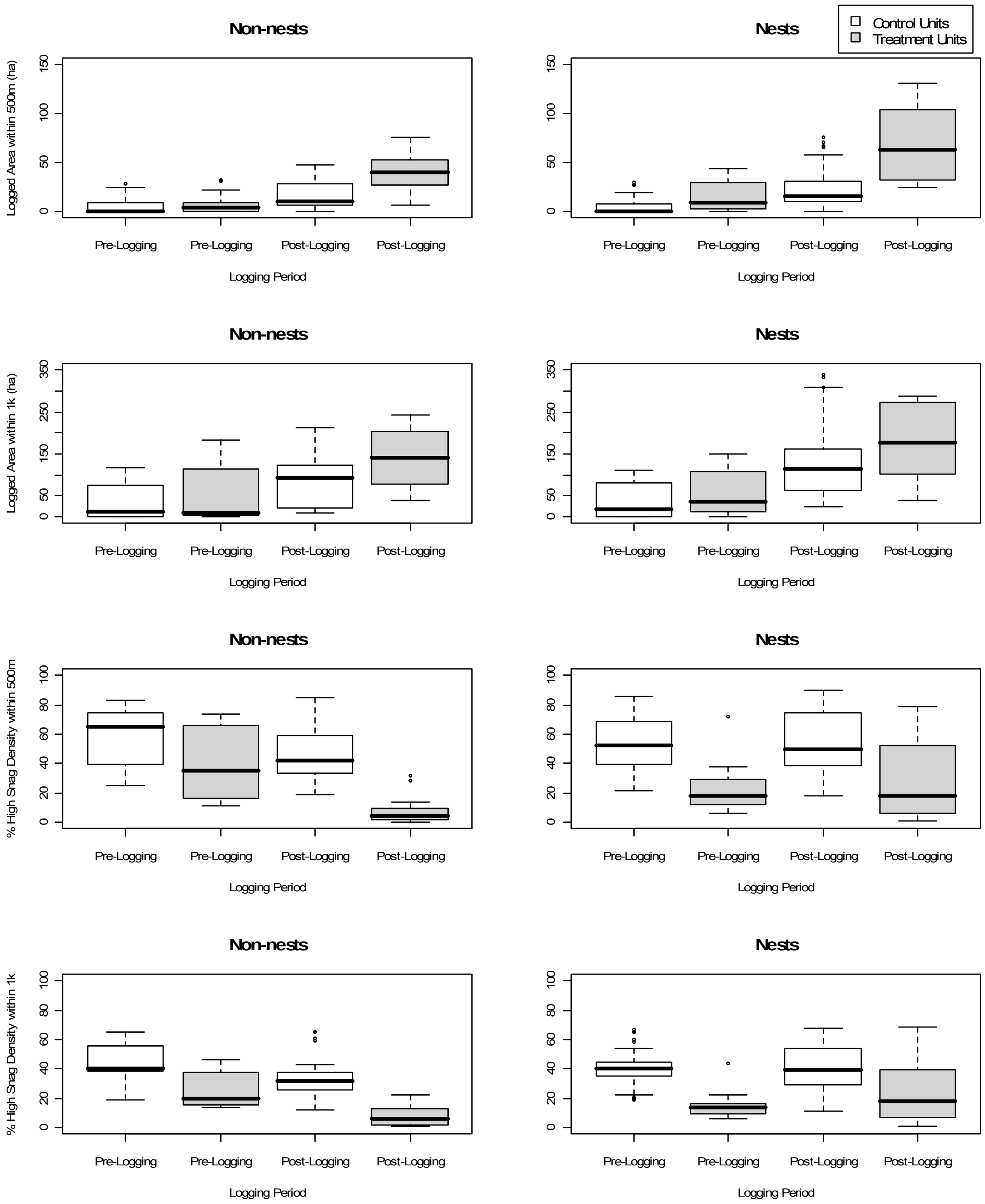
APPENDIX B

BOX AND WHISKER PLOTS

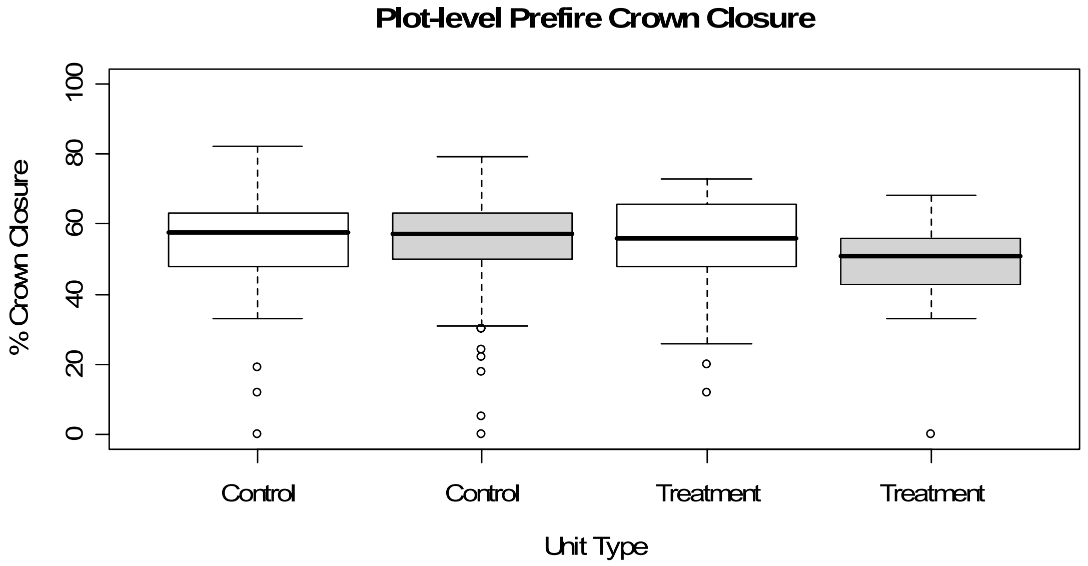
Appendix B: Box and Whisker plots of nest/patch suite habitat variables used in nest-site selection models. Random, non-nest habitat data are in the left column of plots and nest data in the right column of plots. Within each plot, data are separated by control and treatment unit, as well as pre-logging and post-logging time periods. The upper and lower edges of each rectangle indicate the 25% and 75% quantiles, respectively. Medians are shown by a dark horizontal line within each rectangle. Whiskers indicate 1.5 times the 25% and 75% quantiles. Points shown above or below a whisker are >1.5 times the closest whisker.



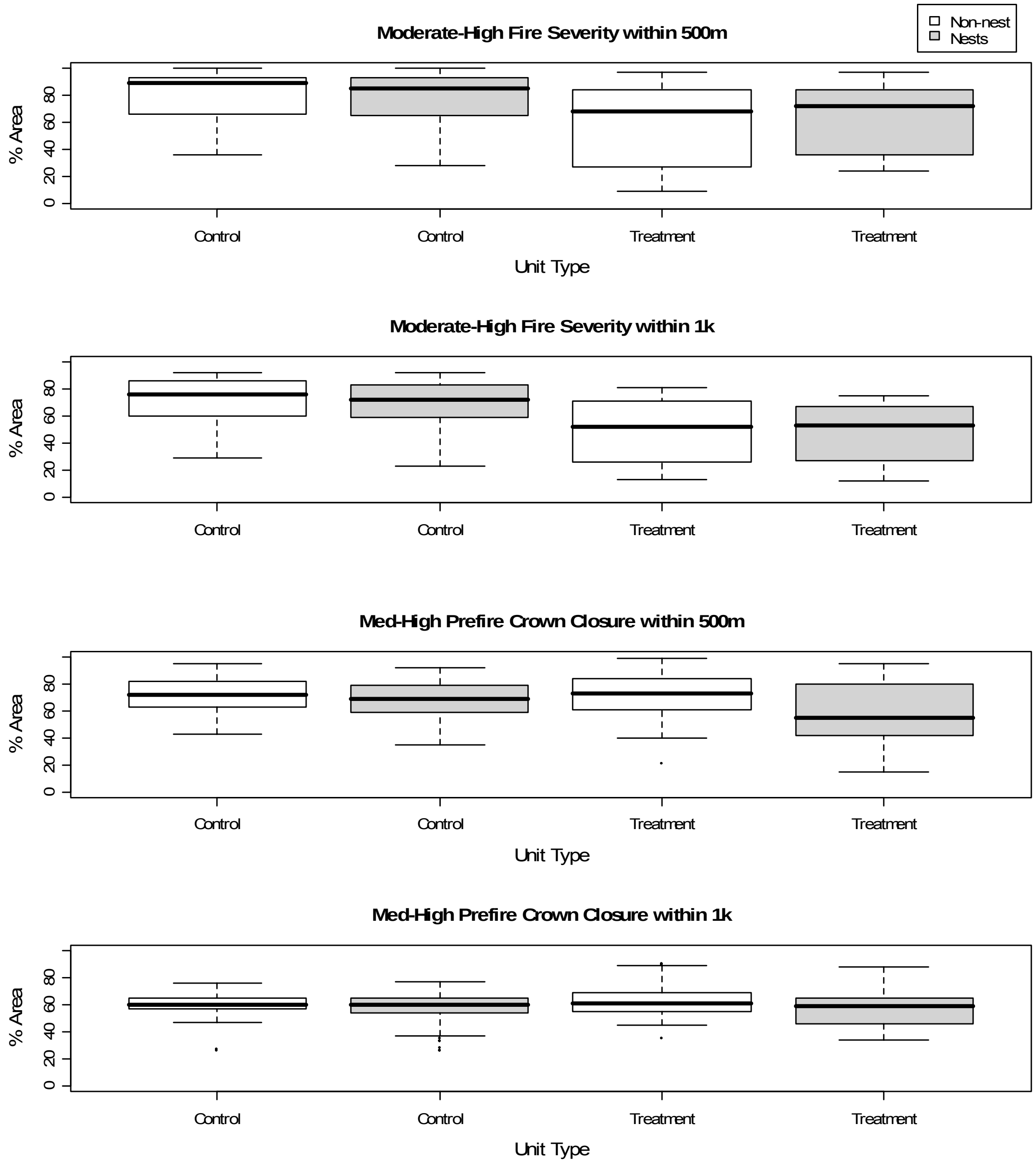
Appendix B (continued): Box and Whisker plots of landscape suite habitat variables used in nest-site selection models. Random, non-nest habitat data are in the left column of plots and nest data in the right column of plots. Within each plot, data are separated by control and treatment unit, as well as pre-logging and post-logging time periods. The upper and lower edges of each rectangle indicate the 25% and 75% quantiles, respectively. Medians are shown by a dark horizontal line within each rectangle. Whiskers indicate 1.5 times the 25% and 75% quantiles. Points shown above or below a whisker are >1.5 times the closest whisker.



Appendix B (continued): Box and Whisker plots of additional nest/plot suite habitat variables used in nest-site selection models. Within each plot, data are separated by non-nest (white box) and nest (gray box). The upper and lower edges of each rectangle indicate the 25% and 75% quantiles, respectively. Medians are shown by a dark horizontal line within each rectangle. Whiskers indicate 1.5 times the 25% and 75% quantiles. Points shown above or below a whisker are >1.5 times the closest whisker.



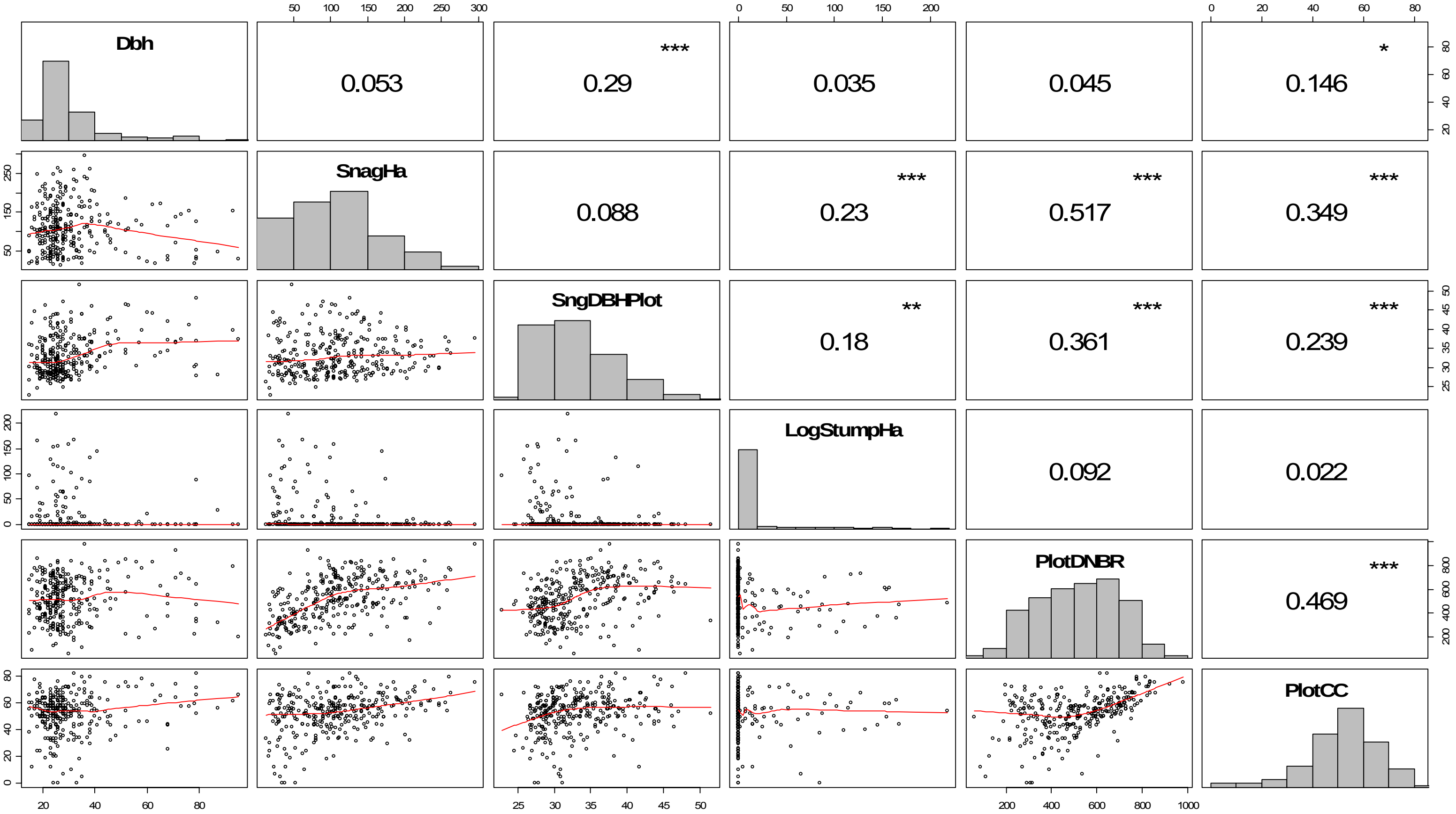
Appendix B (continued): Box and Whisker plots of landscape suite habitat variables used in nest-site selection models. Random, non-nest habitat data are in the left column of plots and nest data in the right column of plots. Within each plot, data are separated by non-nest (white box) and nest (gray box). The upper and lower edges of each rectangle indicate the 25% and 75% quantiles, respectively. Medians are shown by a dark horizontal line within each rectangle. Whiskers indicate 1.5 times the 25% and 75% quantiles. Points shown above or below a whisker are >1.5 times the closest whisker.



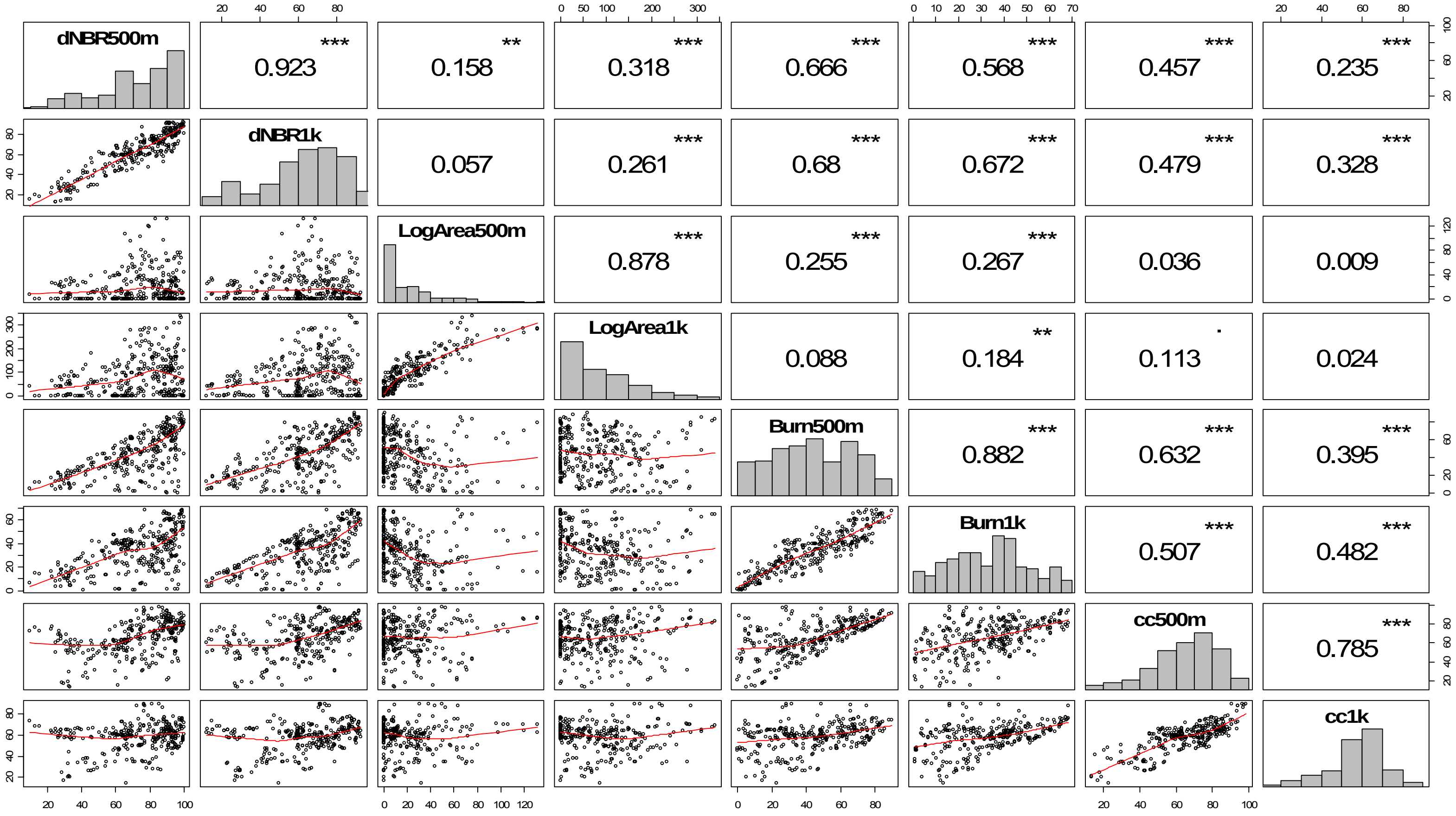
APPENDIX C

HISTOGRAMS, PEARSON ABSOLUTE CORRELATION COEFFICIENTS, AND X-Y SCATTER PLOTS

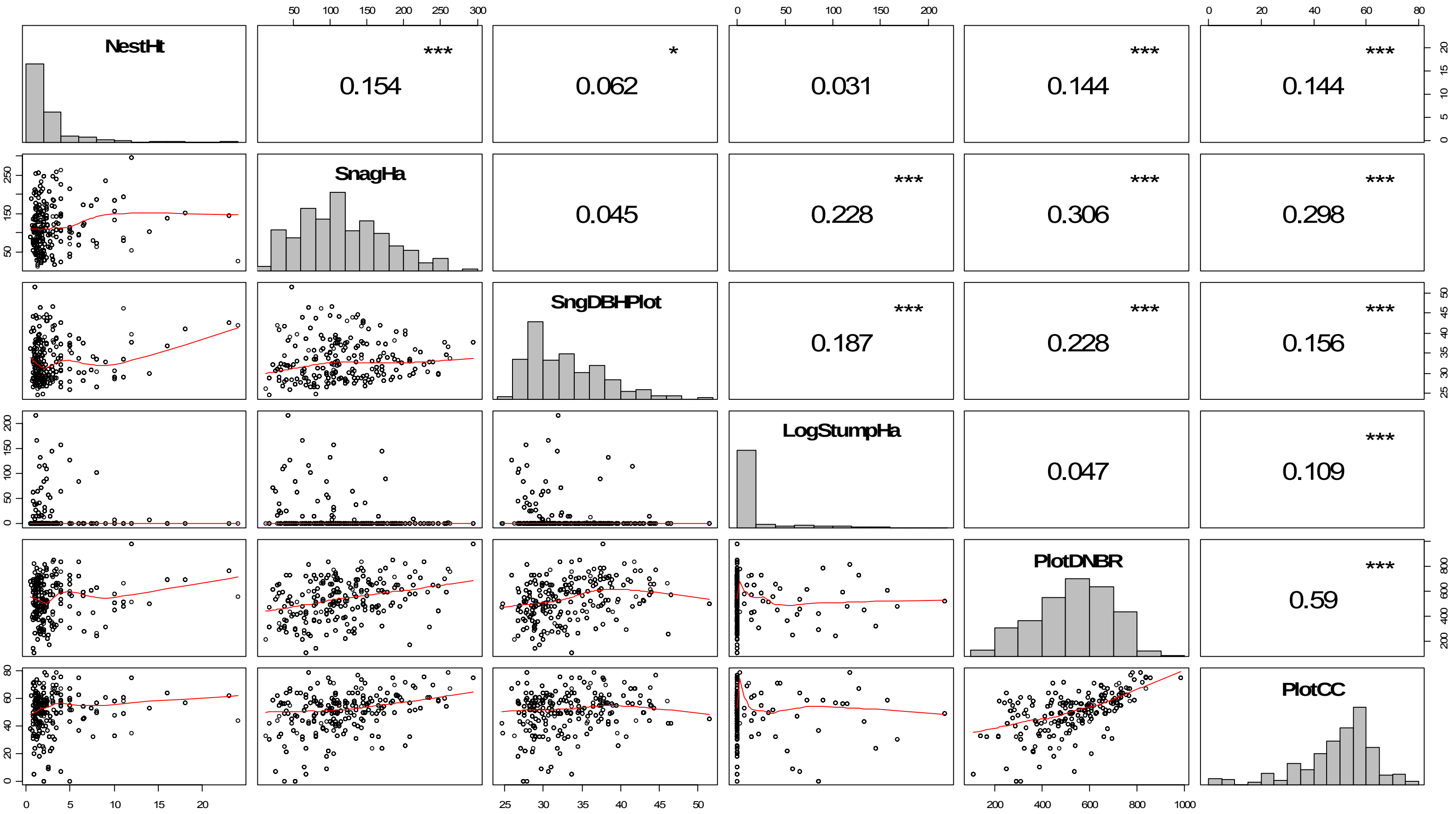
Appendix C: Histograms, Pearson absolute correlation coefficients, and x-y scatter plots of nest/plot scale habitat variables used in nest-site selection models. Histograms and the variable name are situated on the diagonal. Pearson absolute correlation coefficients are found above the diagonal (*** = p<0.001, ** = p<0.01, * = p<0.05). X-y scatter plots are located below the diagonal and contain a smoothing line.



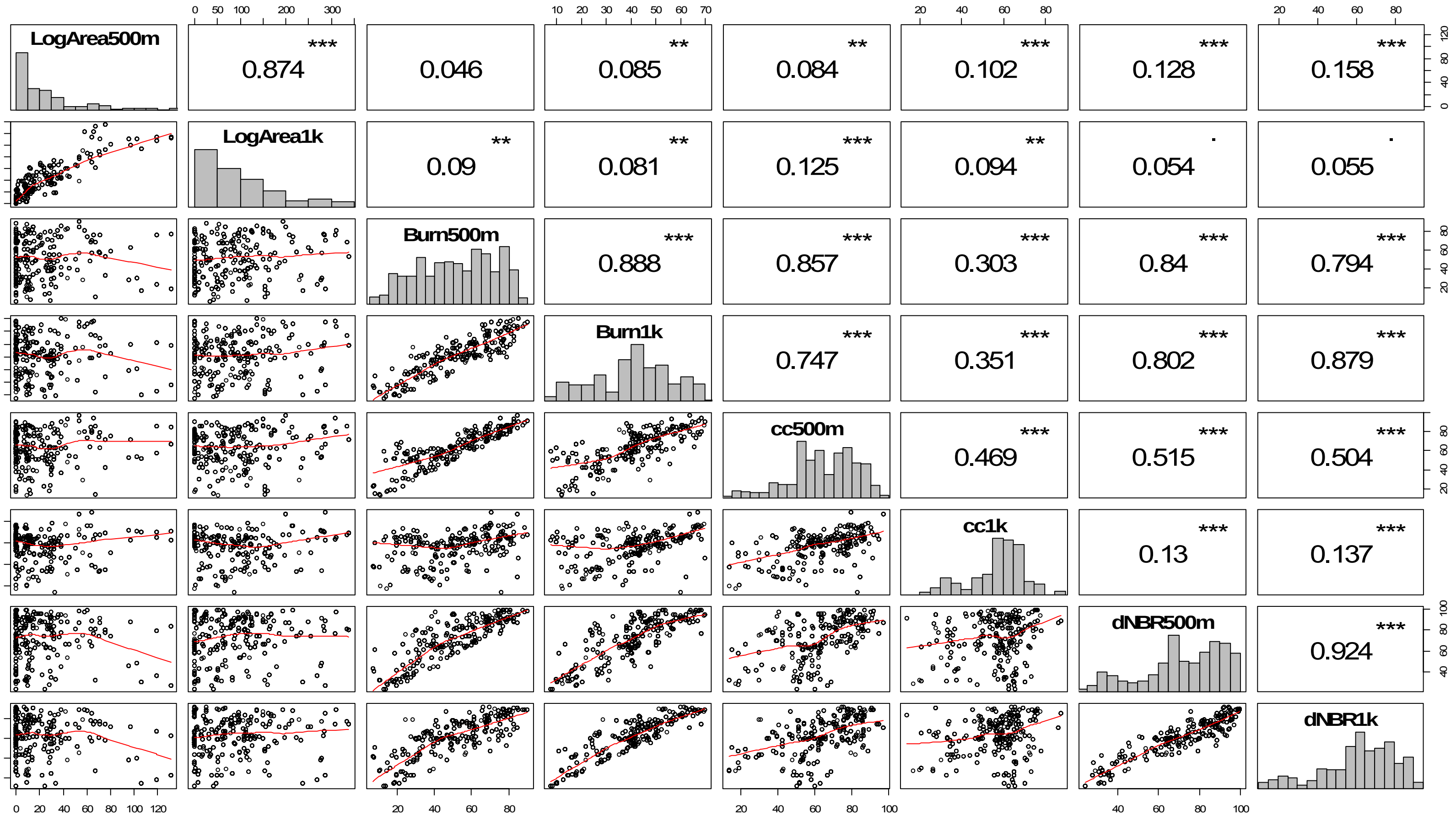
Appendix C (continued): Histograms, Pearson absolute correlation coefficients, and x-y scatter plots of landscape scale habitat variables used in nest-site selection models. Histograms and the variable name are situated on the diagonal. Pearson absolute correlation coefficients are found above the diagonal (*** = p<0.001, ** = p<0.01, * = p<0.05). X-y scatter plots are located below the diagonal and contain a smoothing line.



Appendix C (continued): Histograms, Pearson absolute correlation coefficients, and x-y scatter plots of nest/plot scale habitat variables used in nest survival models. Histograms and the variable name are situated on the diagonal. Pearson absolute correlation coefficients are found above the diagonal (*** = p<0.001, ** = p<0.01, * = p<0.05). X-y scatter plots are located below the diagonal and contain a smoothing line.



Appendix C (continued): Histograms, Pearson absolute correlation coefficients, and x-y scatter plots of landscape scale habitat variables used in nest survival models. Histograms and the variable name are situated on the diagonal. Pearson absolute correlation coefficients are found above the diagonal (*** = p<0.001, ** = p<0.01, * = p<0.05). X-y scatter plots are located below the diagonal and contain a smoothing line.



Appendix C (continued): Histograms, Pearson absolute correlation coefficients, and x-y scatter plots of abiotic habitat variables used in nest survival models. Histograms and the variable name are situated on the diagonal. Pearson absolute correlation coefficients are found above the diagonal (*** = p<0.001, ** = p<0.01, * = p<0.05). X-y scatter plots are located below the diagonal and contain a smoothing line.